


Computer Networks

CMSC 417 : Spring 2024

COMPUTER SCIENCE
UNIVERSITY OF MARYLAND

Topic: Link layer: WiFi, Mobility, BGP
(Textbook chapter 2, 4)

Nirupam Roy

Tu-Th 2:00-3:15pm
CSI 2117

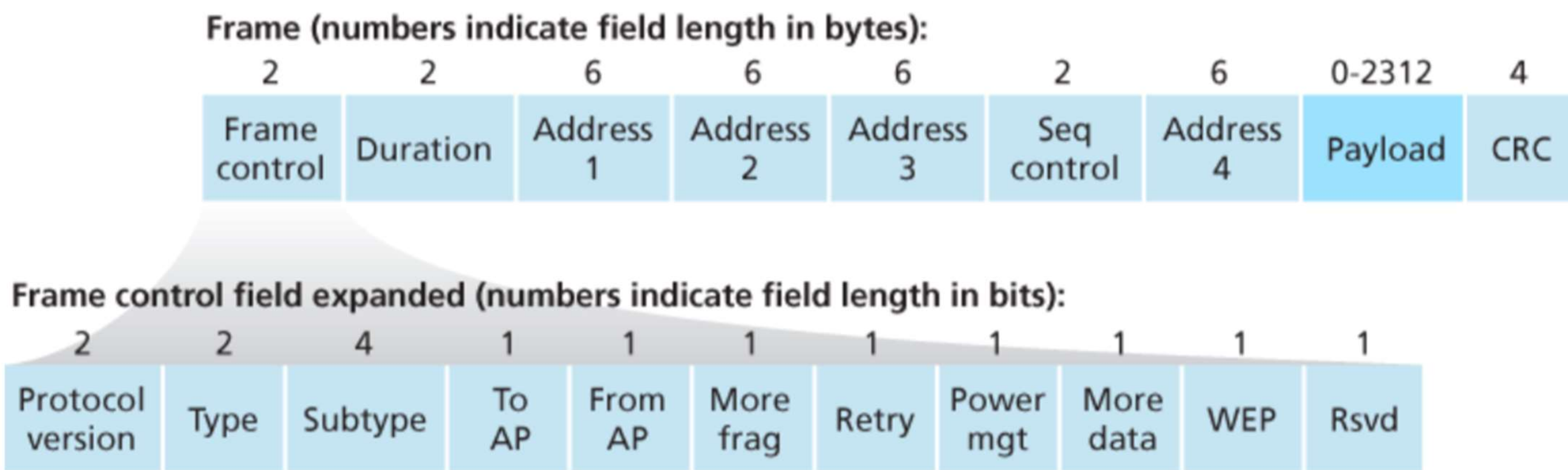
April 25th, 2024



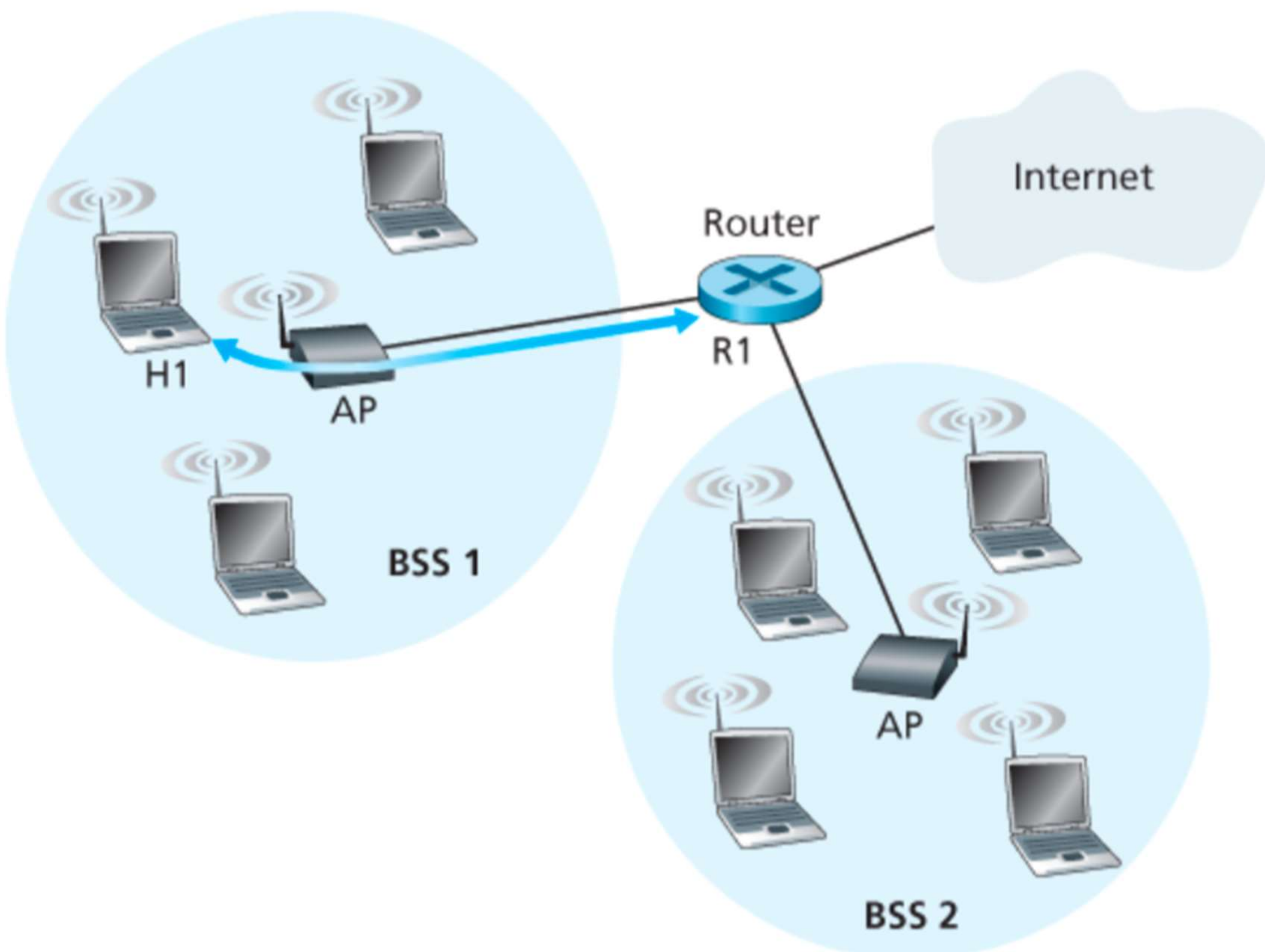

WiFi: IEEE 802.11 Wireless LANs

1. LAN Architecture
2. MAC protocol
3. Frame structure
4. Advanced features

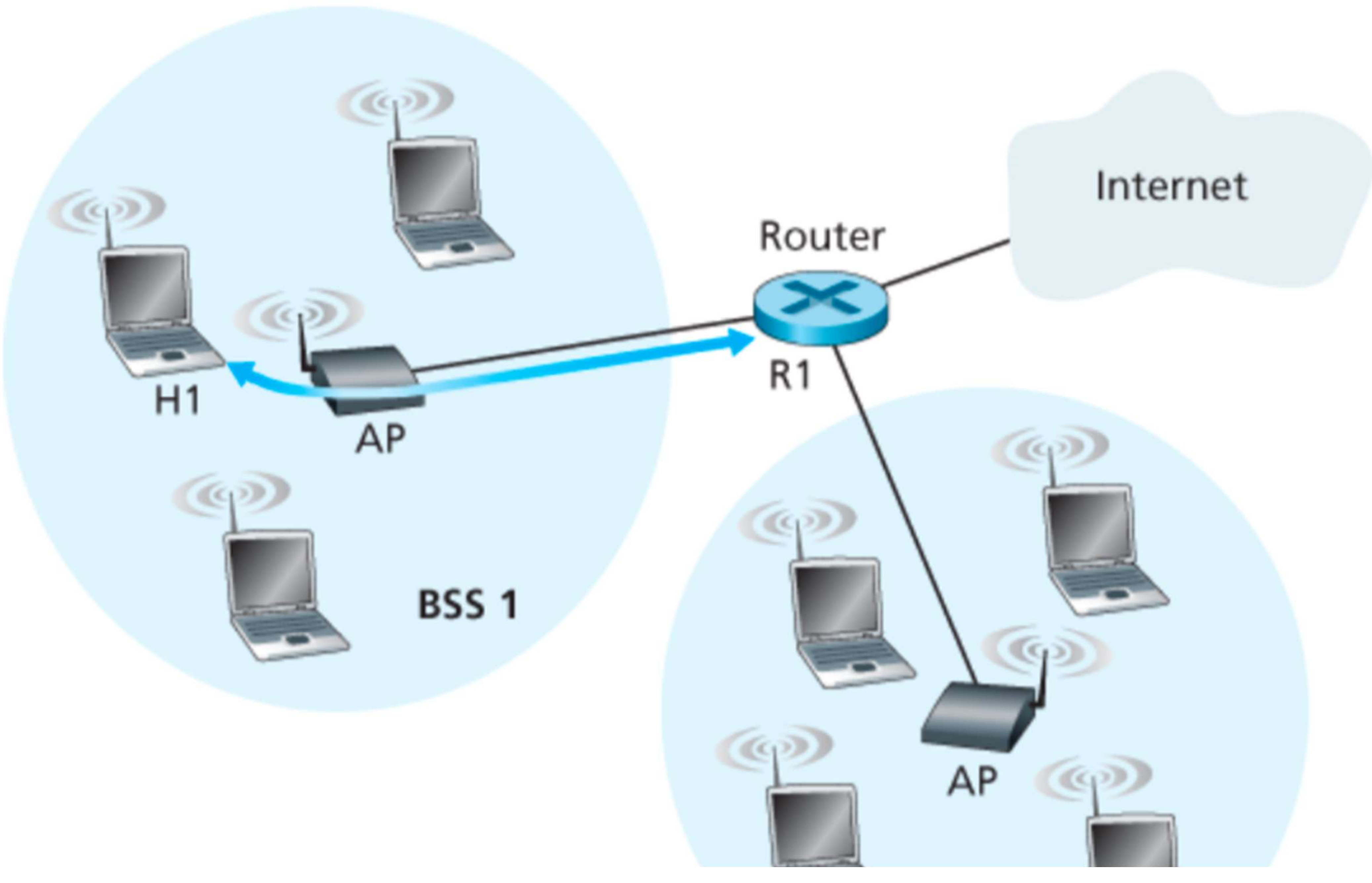
WiFi: IEEE 802.11 Frame



802.11 Frame: The secret of Address-3

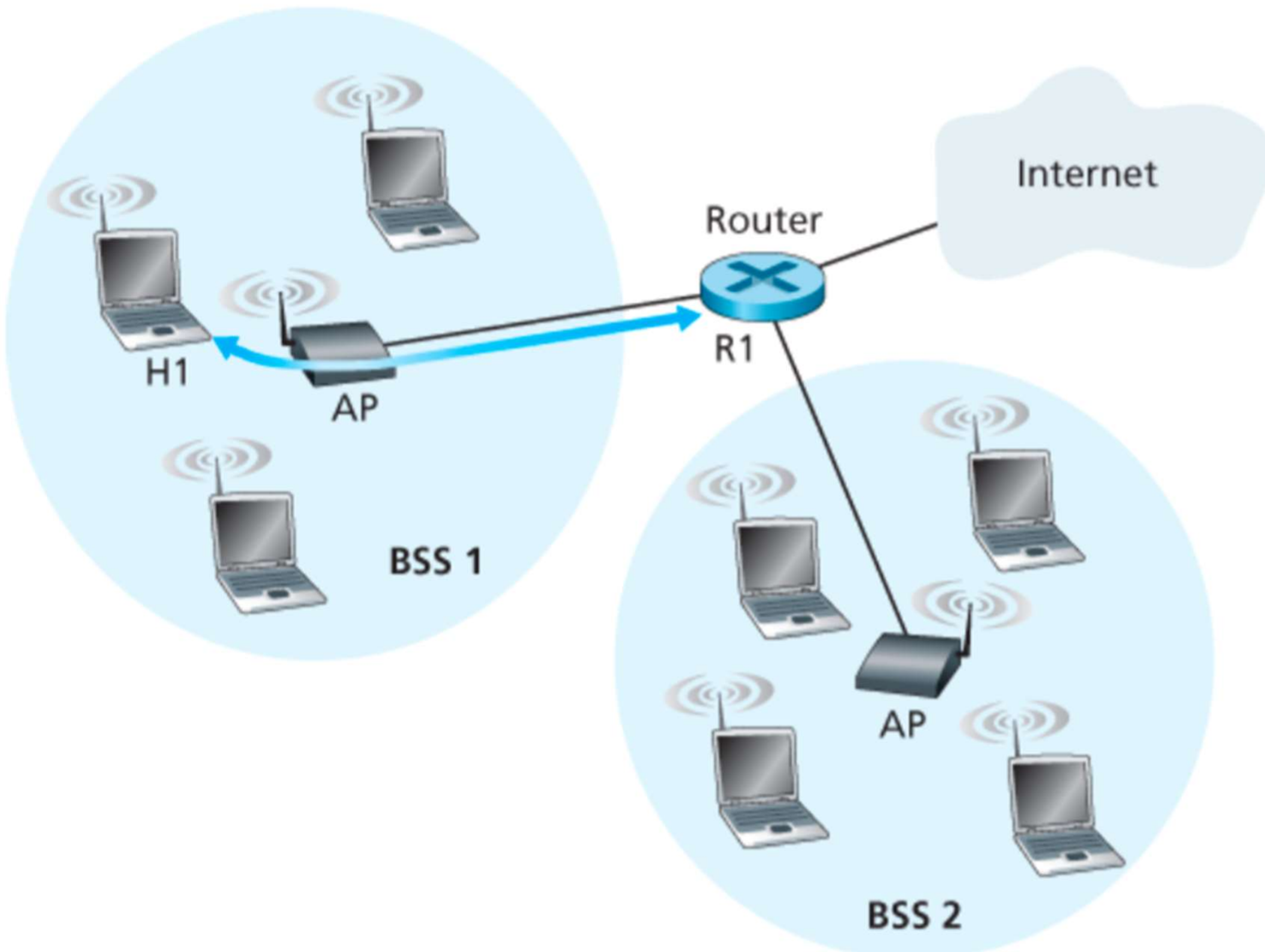


802.11 Frame: The secret of Address-3



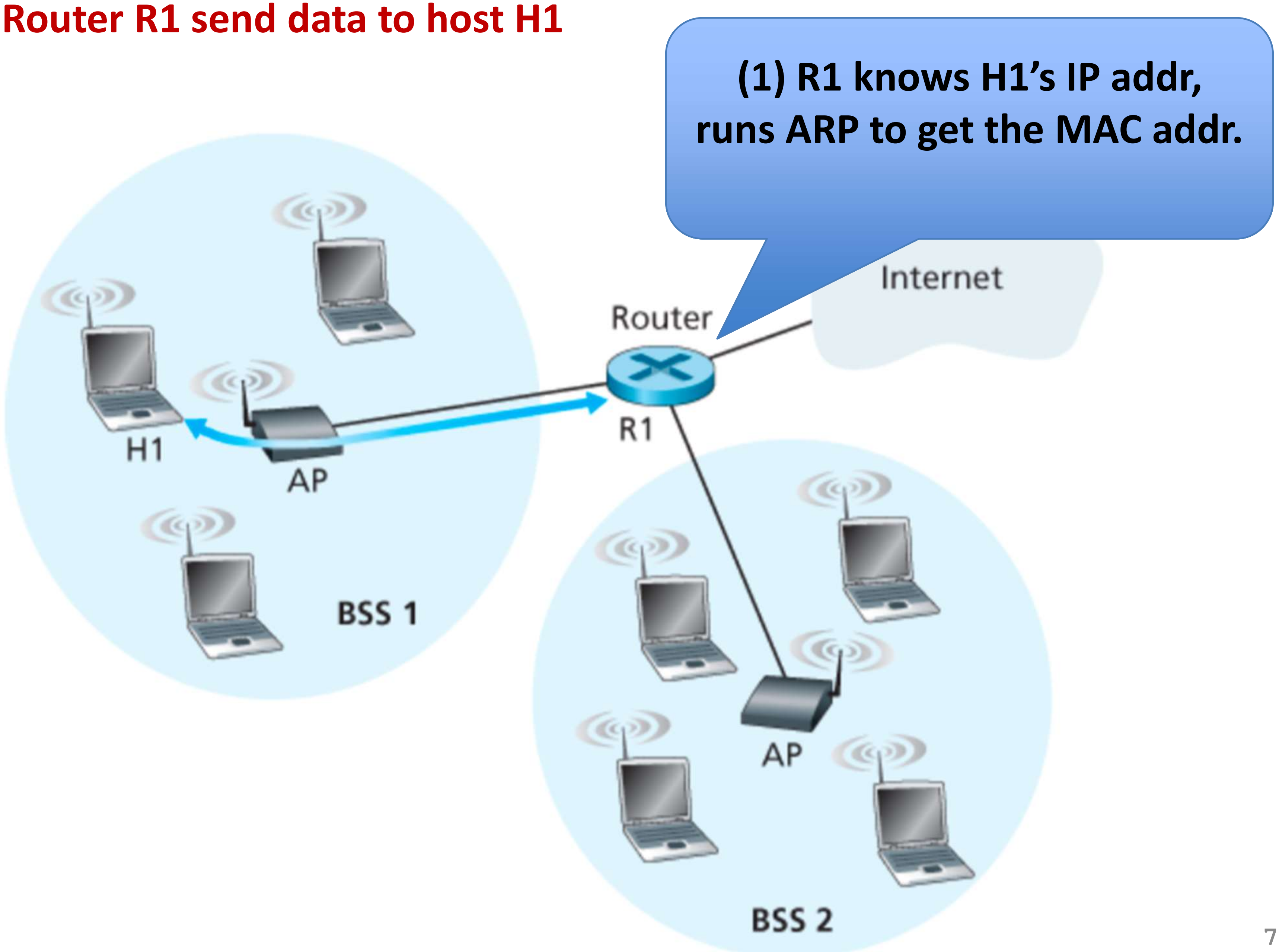
802.11 Frame: The secret of Address-3

Case 1: Router R1 send data to host H1



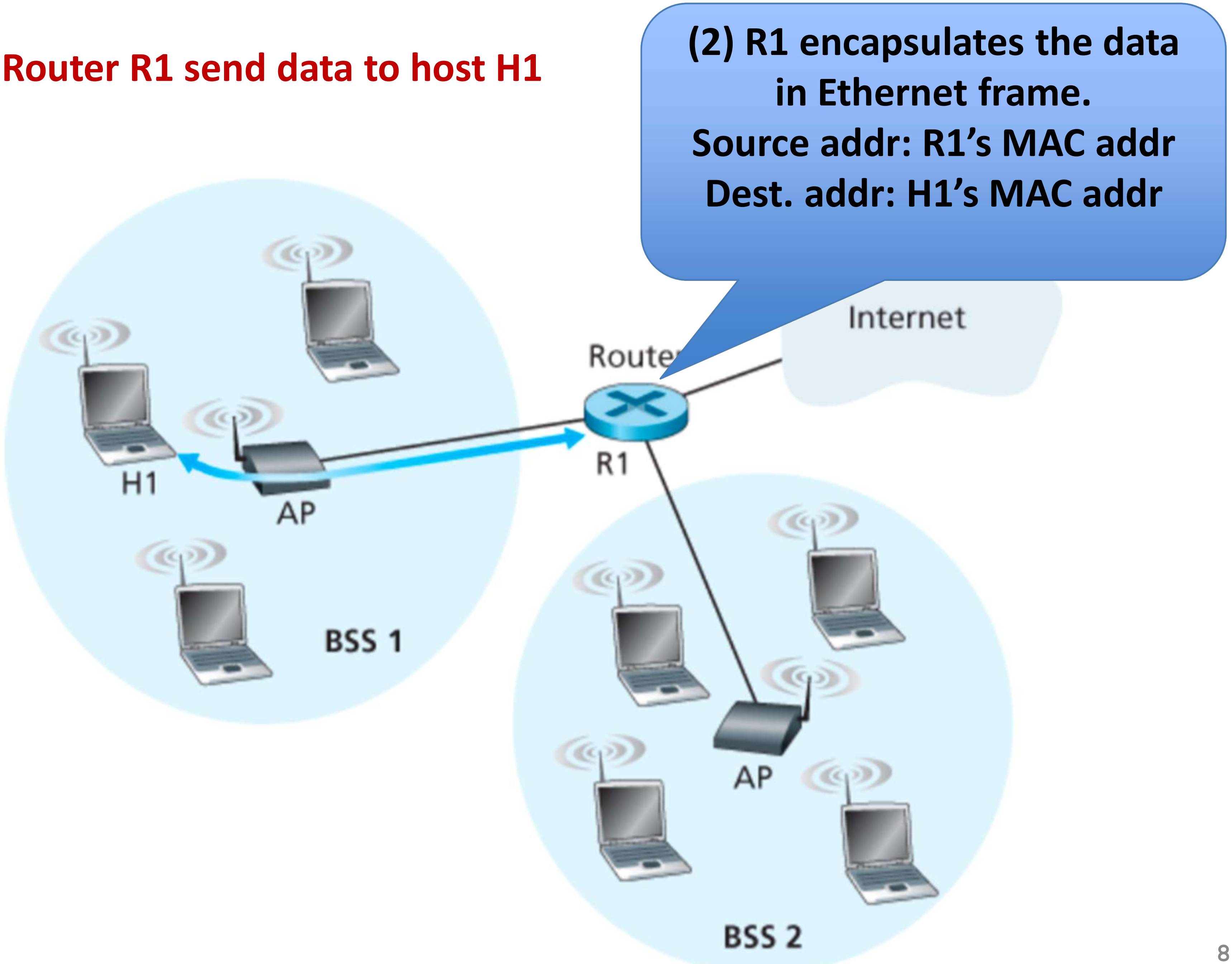
802.11 Frame: The secret of Address-3

Case 1: Router R1 send data to host H1



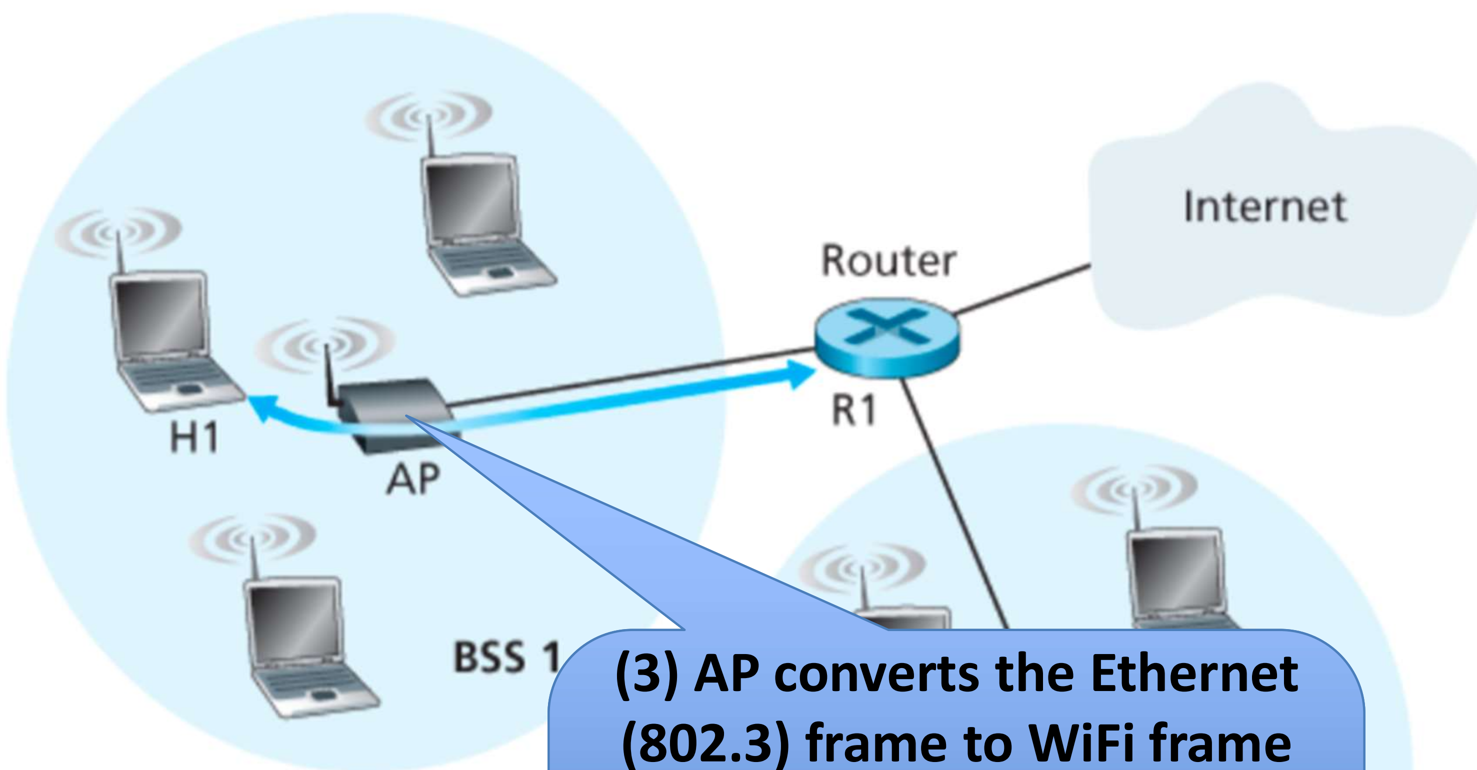
802.11 Frame: The secret of Address-3

Case 1: Router R1 send data to host H1



802.11 Frame: The secret of Address-3

Case 1: Router R1 send data to host H1

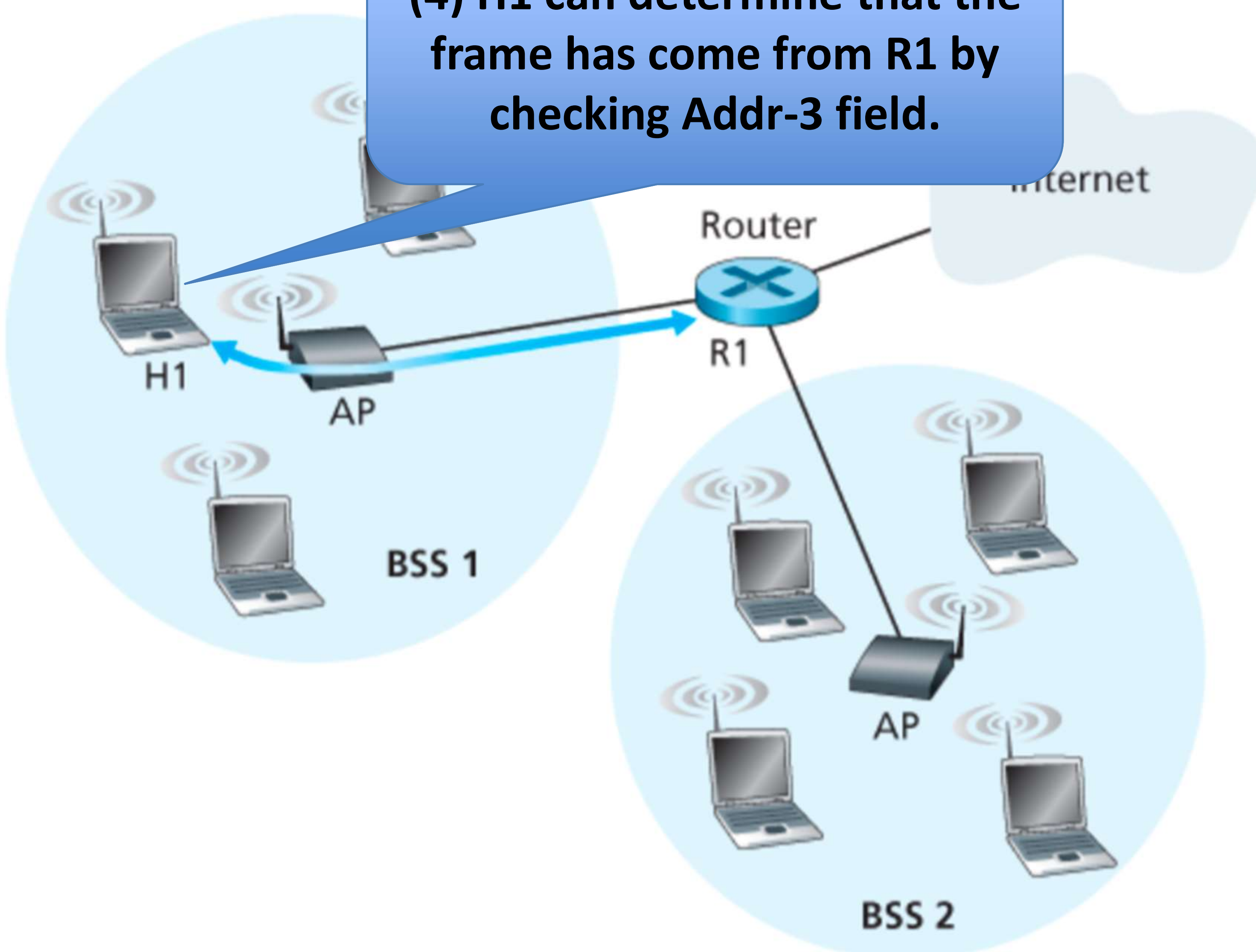


(3) AP converts the Ethernet (802.3) frame to WiFi frame (802.11).
Addr 1: H1's MAC addr
Addr 2: AP's MAC addr
Addr 3: R1's MAC addr

802.11 Frame: The secret of Address-3

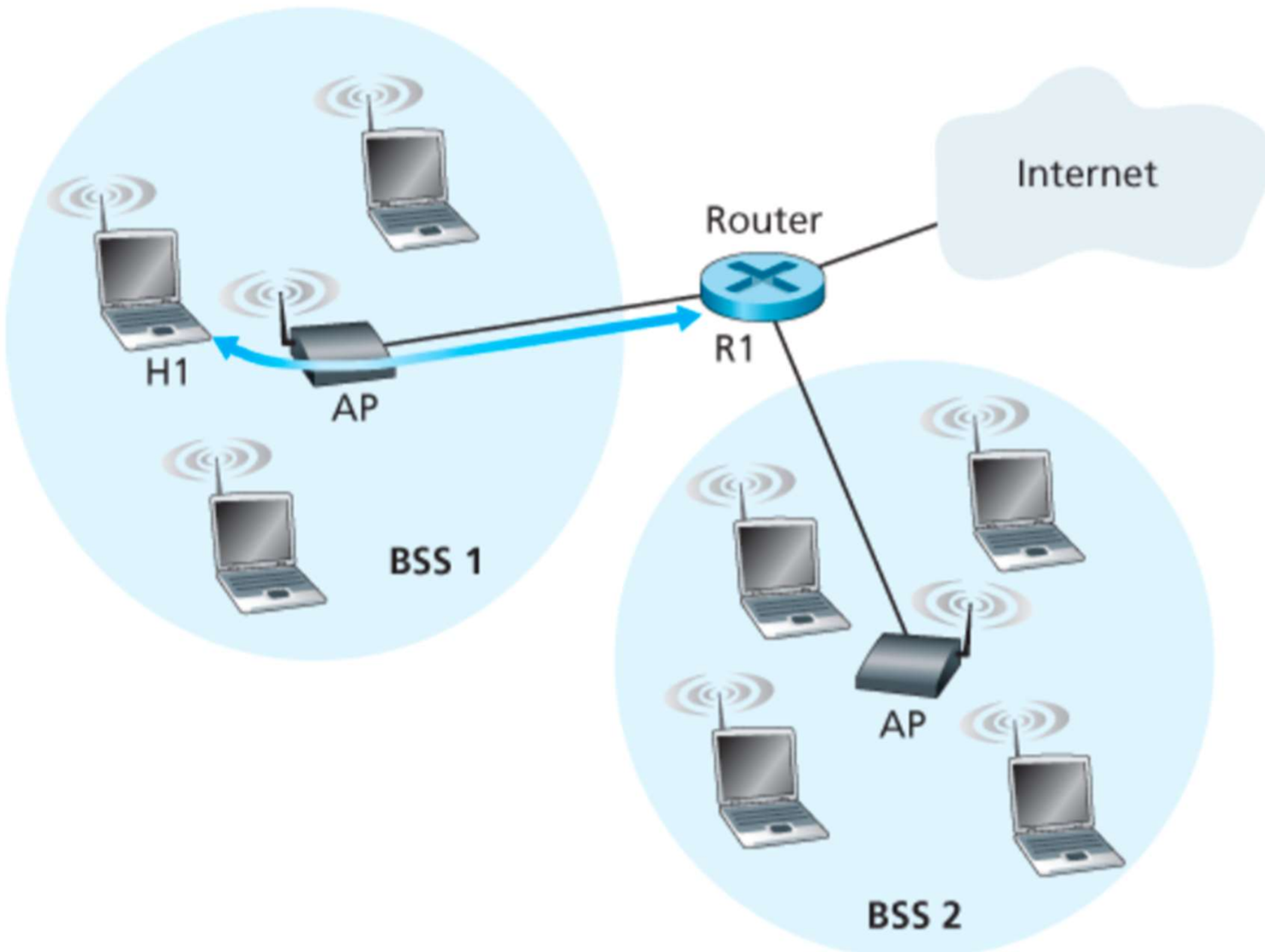
Case 1: Router R1 send data to host H1

(4) H1 can determine that the frame has come from R1 by checking Addr-3 field.



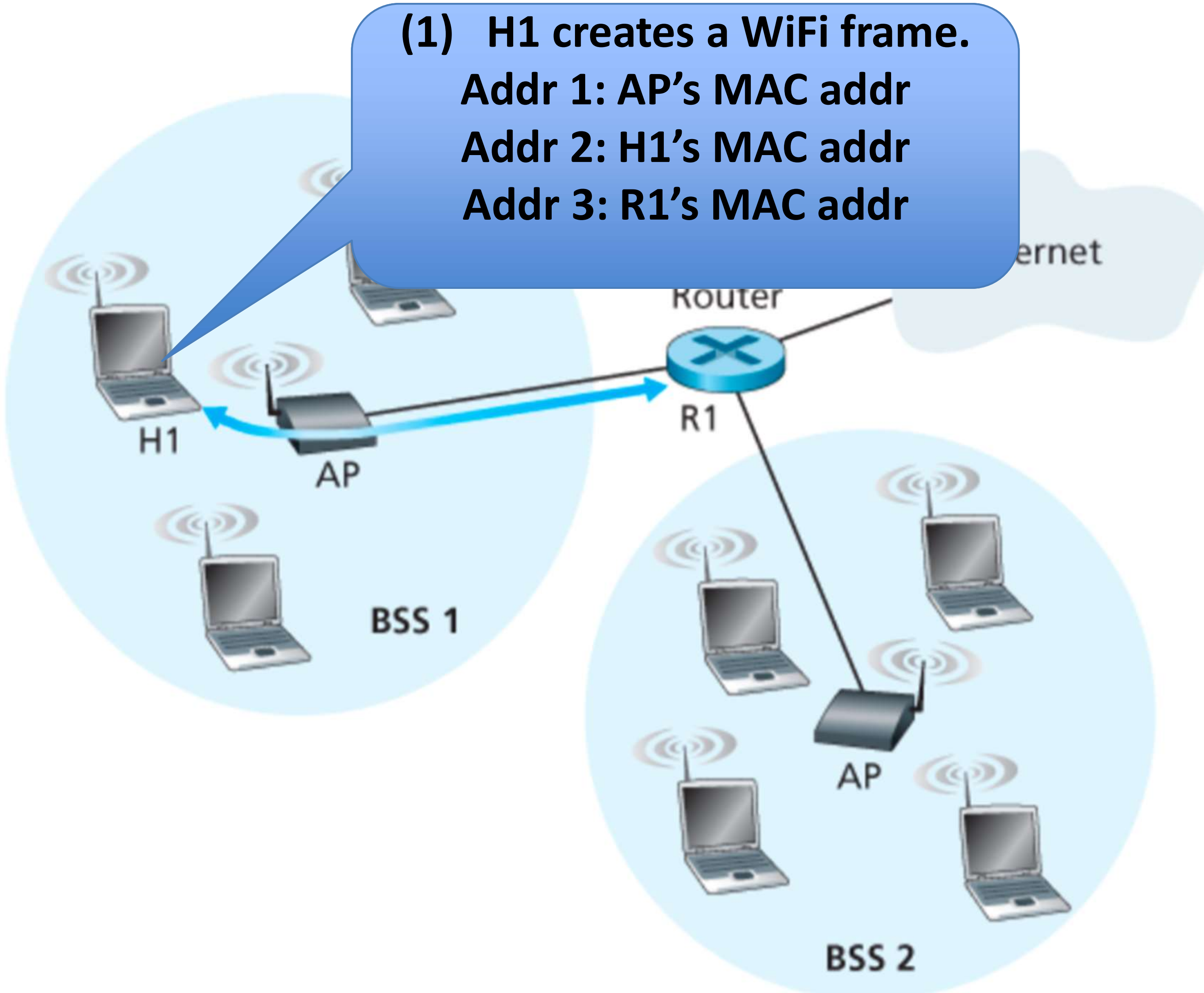
802.11 Frame: The secret of Address-3

Case 2: Host H1 responds by sending packet to Router R1



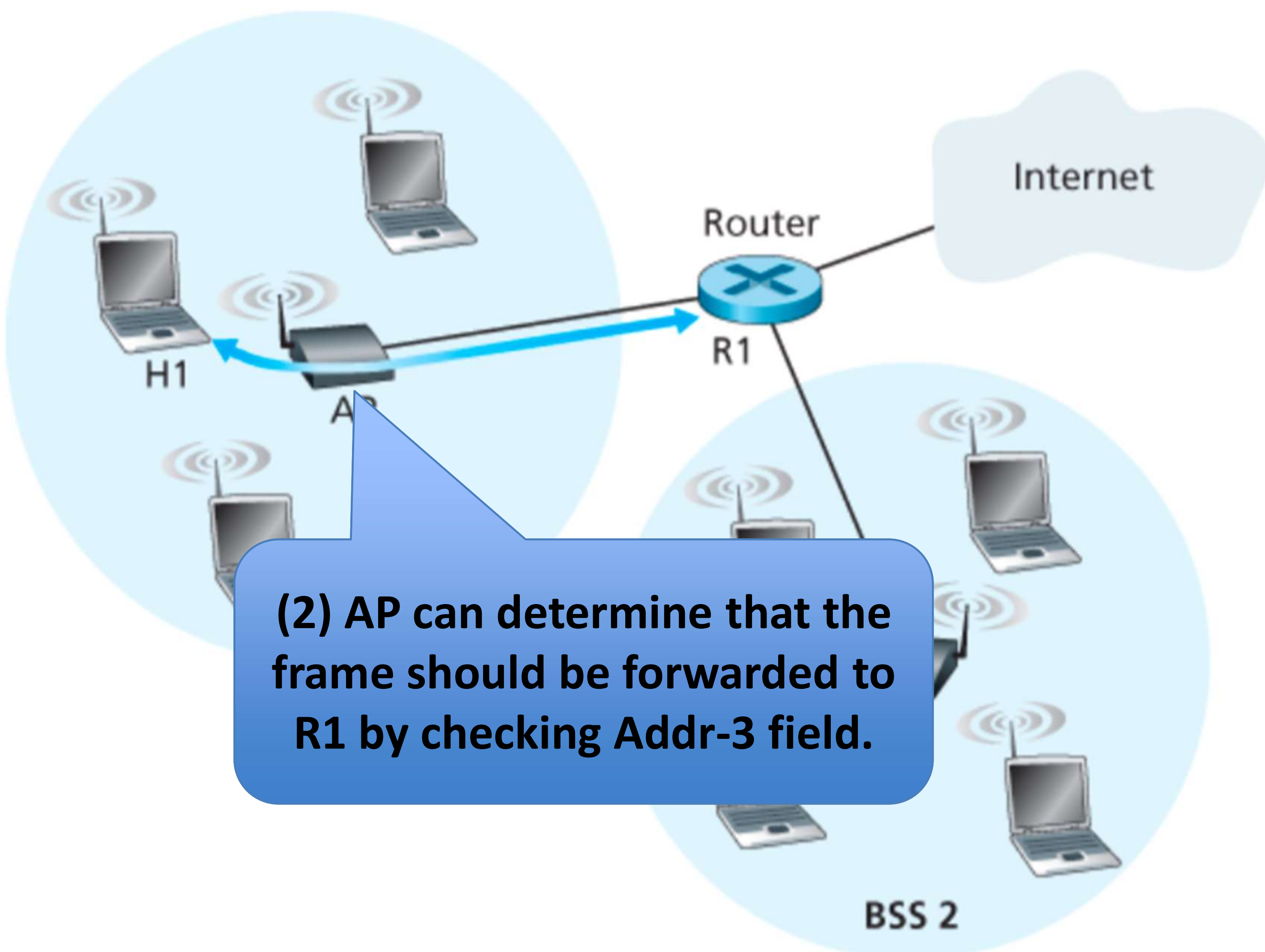
802.11 Frame: The secret of Address-3

Case 2: Host H1 responds by sending packet to Router R1



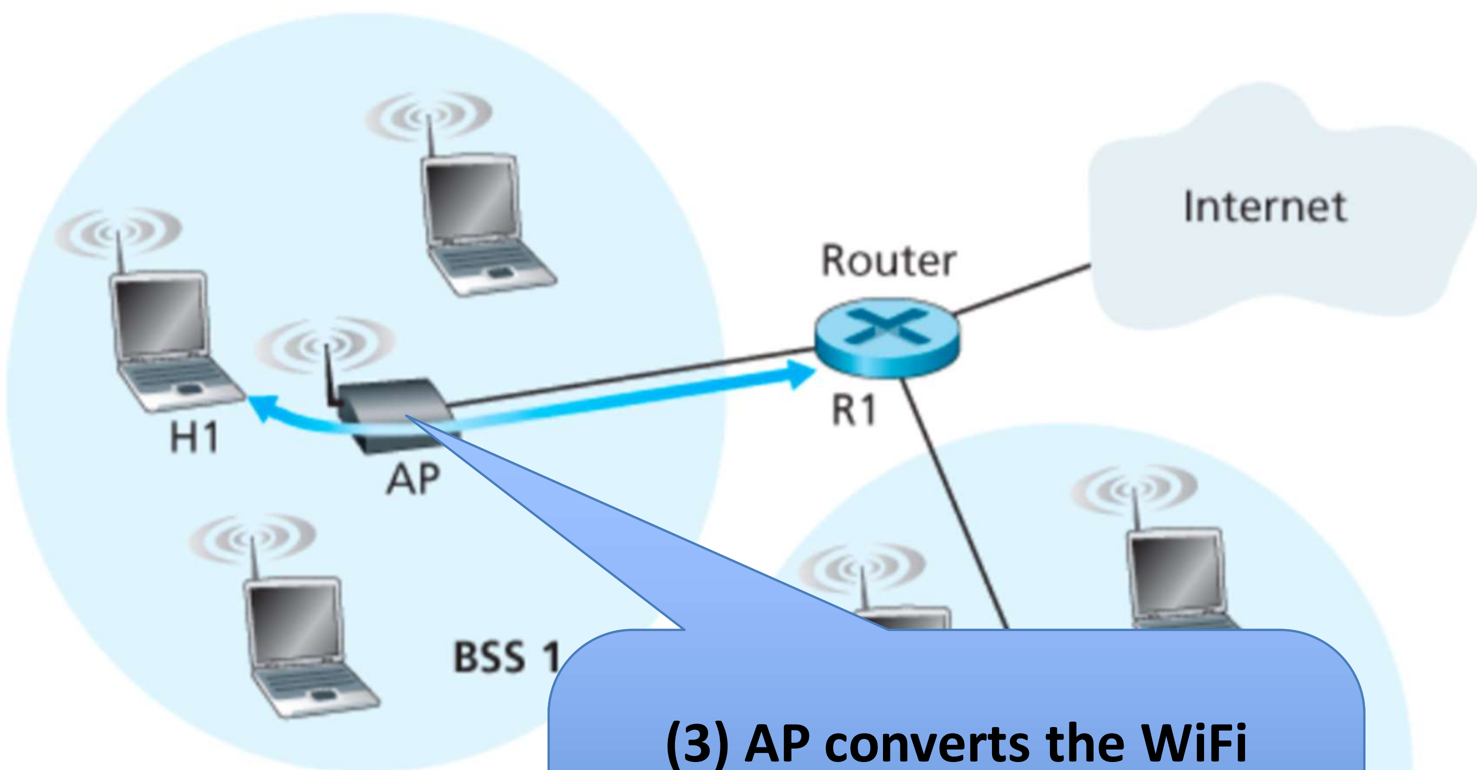
802.11 Frame: The secret of Address-3

Case 2: Host H1 responds by sending packet to Router R1



802.11 Frame: The secret of Address-3

Case 2: Host H1 responds by sending packet to Router R1



(3) AP converts the WiFi (802.11) frame to Ethernet frame (802.3).
Source addr : H1's MAC addr
Dest. addr : R1's MAC addr

WiFi: IEEE 802.11 Wireless LANs

1. LAN Architecture
2. MAC protocol
3. Frame structure
4. Advanced features

WiFi: Advanced features

1) Rate adaptation

2) Power management

WiFi

Building Resilience through Internet and Digital Greenspace Exposure

Parks & Recreation M-NCPPC

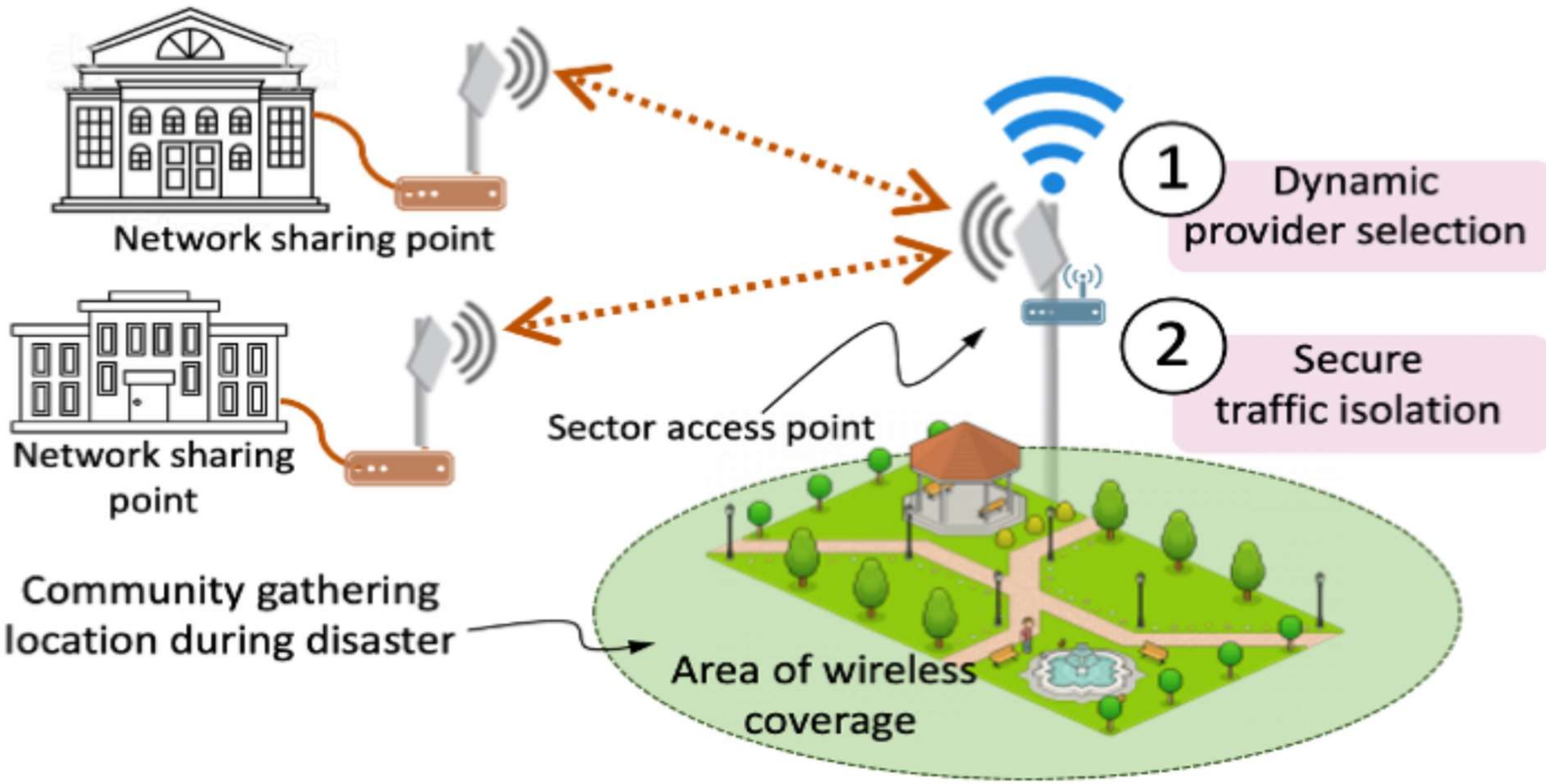
live more, play more

pgparks.com

NSF

Award # 2125526

UNIVERSITY OF MARYLAND


Network sharing point
Network sharing point
Sector access point
1
Dynamic provider selection
2
Secure traffic isolation
Community gathering location during disaster
Area of wireless coverage

Cellular Networks

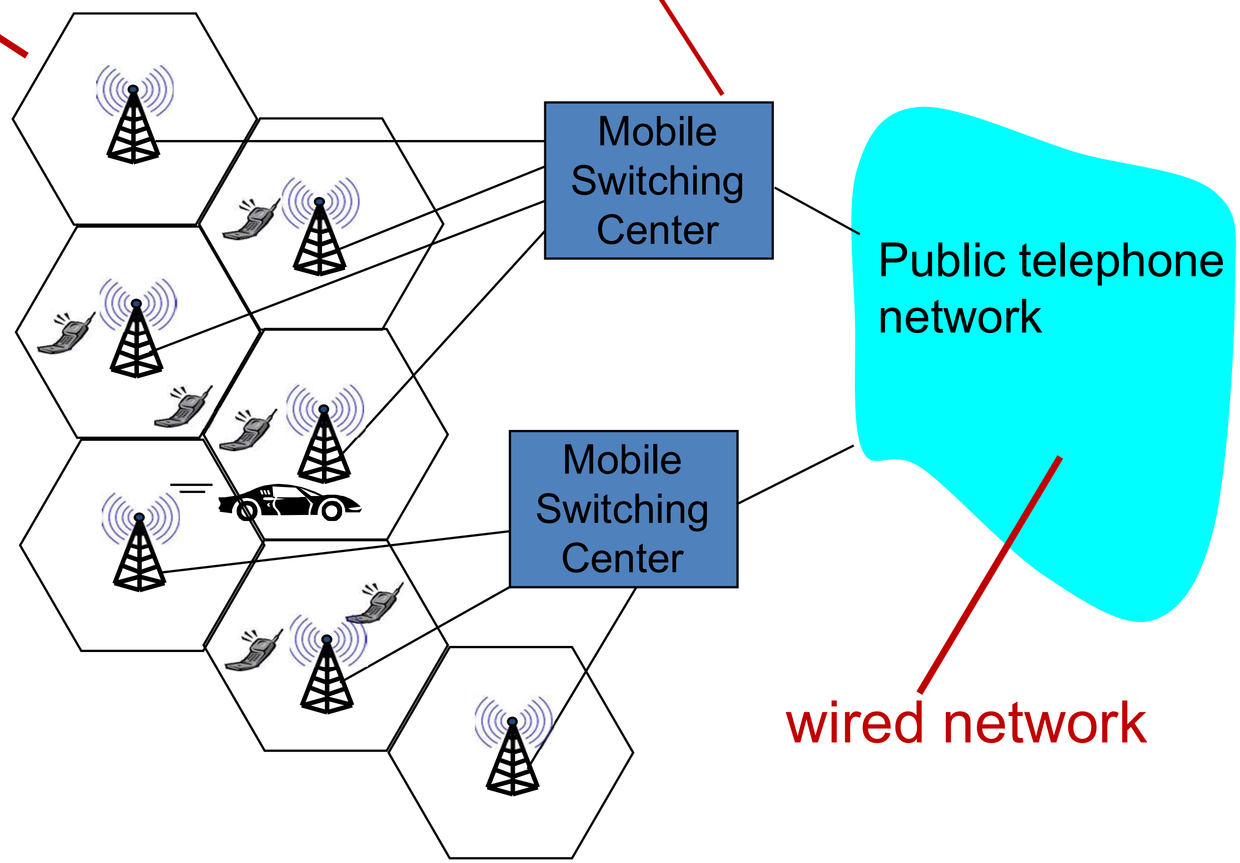
Components of cellular network architecture

cell

- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

MSC

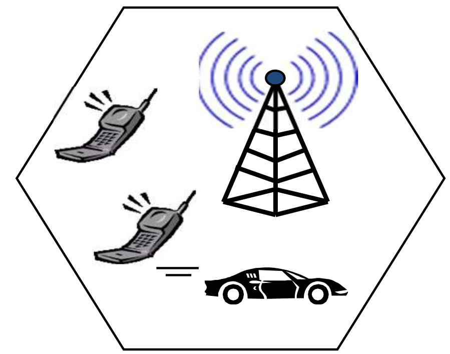
- connects cells to wired tel. net.
- manages call setup
- handles mobility

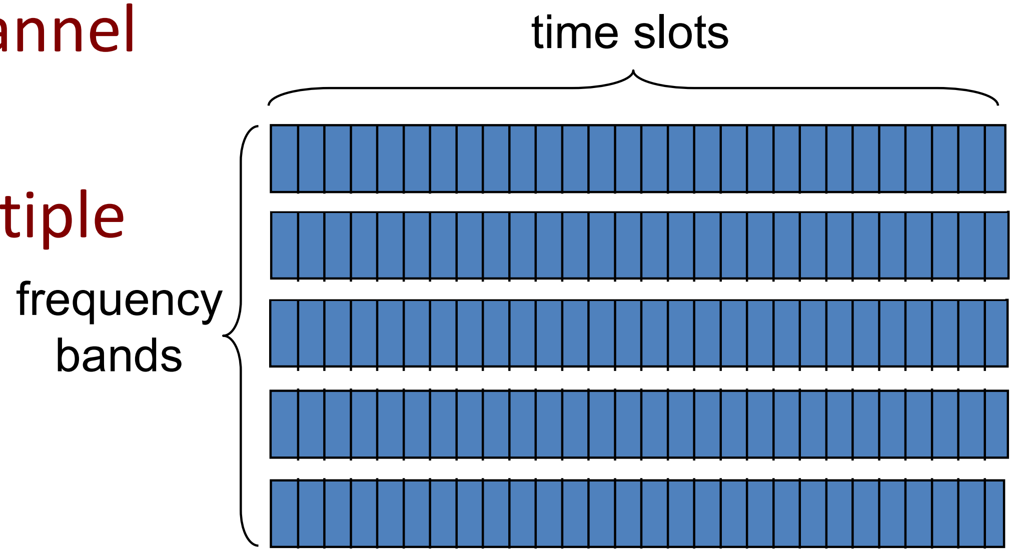


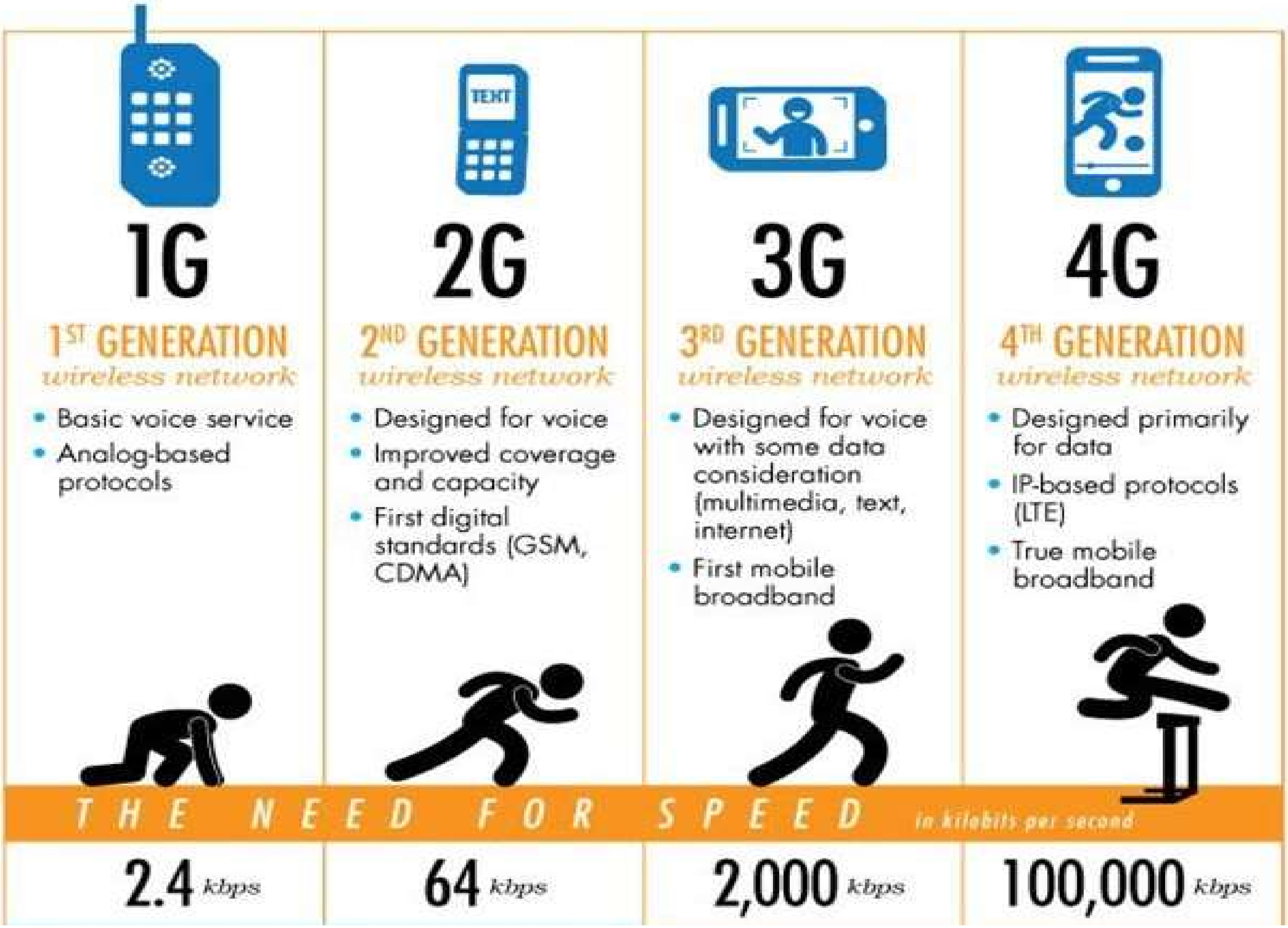
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

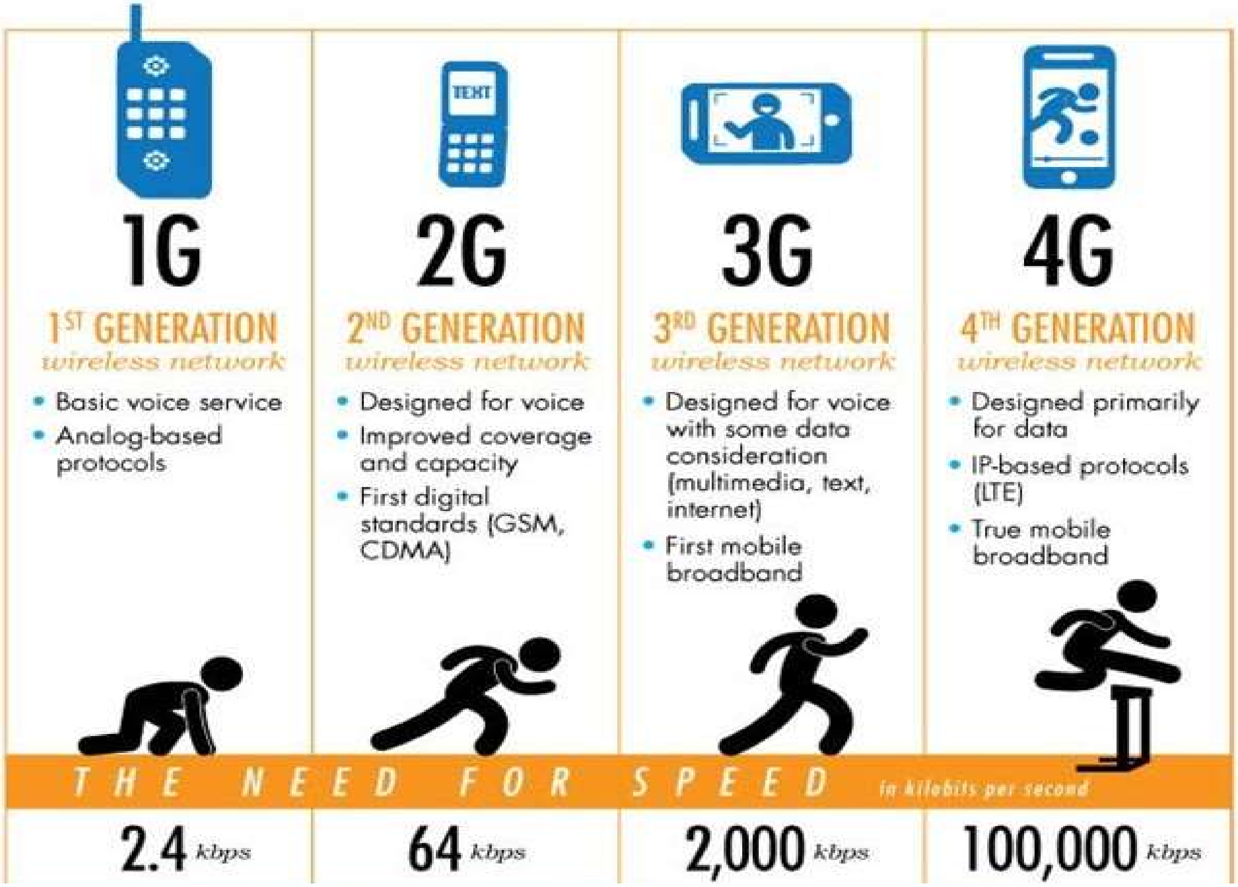
- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access







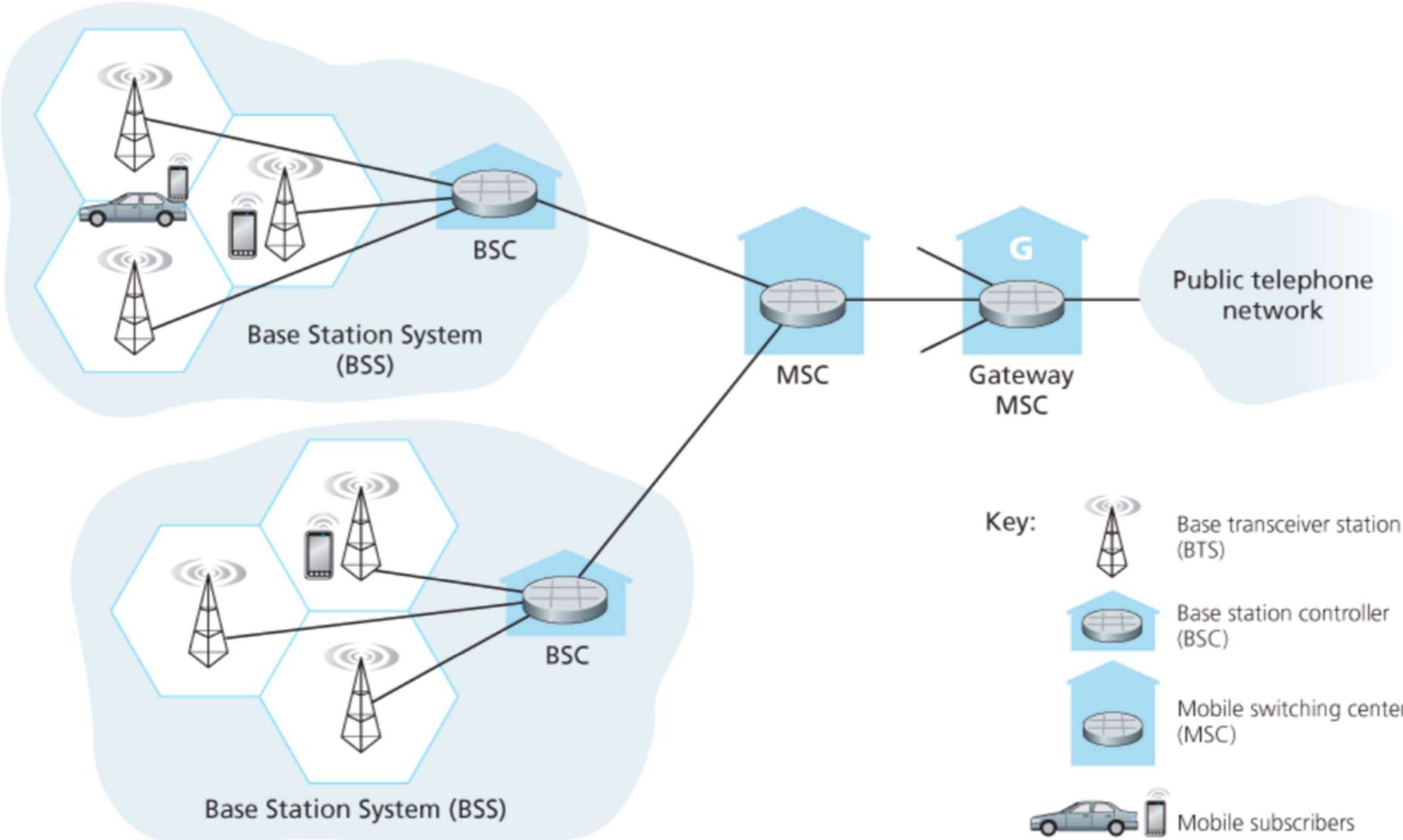
Picture1: https://www.brandsynario.com/the-evolution-of-gs-generation-networks/



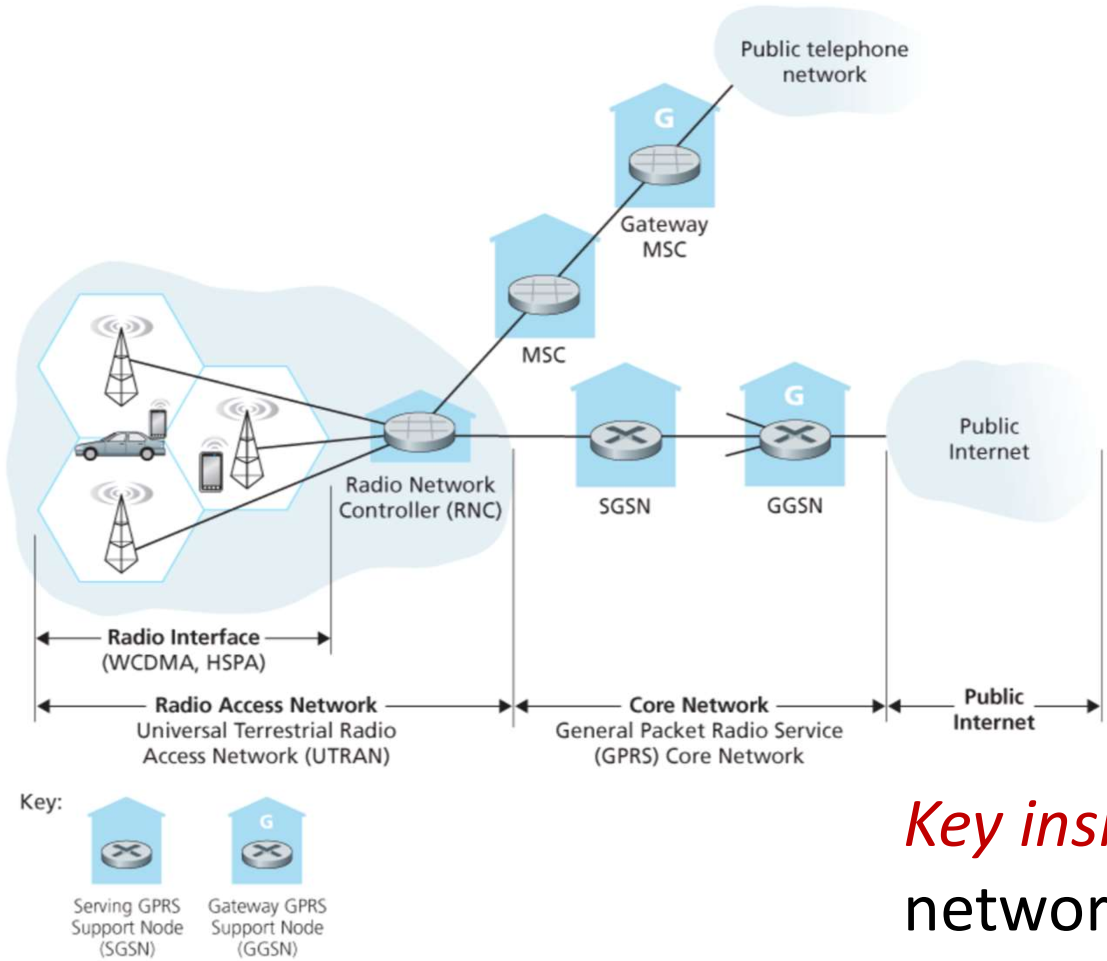
Tech. Generation	Year	Standard	Speed	Supports
1G (analog)	1980	AMPS, TACS, C-450	2 kbps	Voice only
2G	1990	GSM, CDMA	64 kbps	SMS
2.5G	2000	GPRS	110 kbps	MMS
2.75G	2003	EDGE	135 kbps	WAP
3G	2002	UMTS, WCDMA	144 kbps - 2 Mbps	Video call
3.5G	2010	HSPA	5.76 Mbps - 56 Mbps	Multimedia
3.75G	2010	HSPA+, HSPAP	28 Mbps - 168 Mbps	Multimedia
4G	2010	LTE	100 Mbps - 300 Mbps	Streaming video
4.5G	2015	LTE+	100 Mbps - 1 Gbps	VoIP
5G	2020	???	1 Gbps - 20 Gbps	WWWW, IoT

Picture1: https://www.brandsynario.com/the-evolution-of-gs-generation-networks/
Picture2: http://kaaale.blogspot.com/2019/02/the-evolution-of-cellular-mobile.html

2G (voice) network architecture



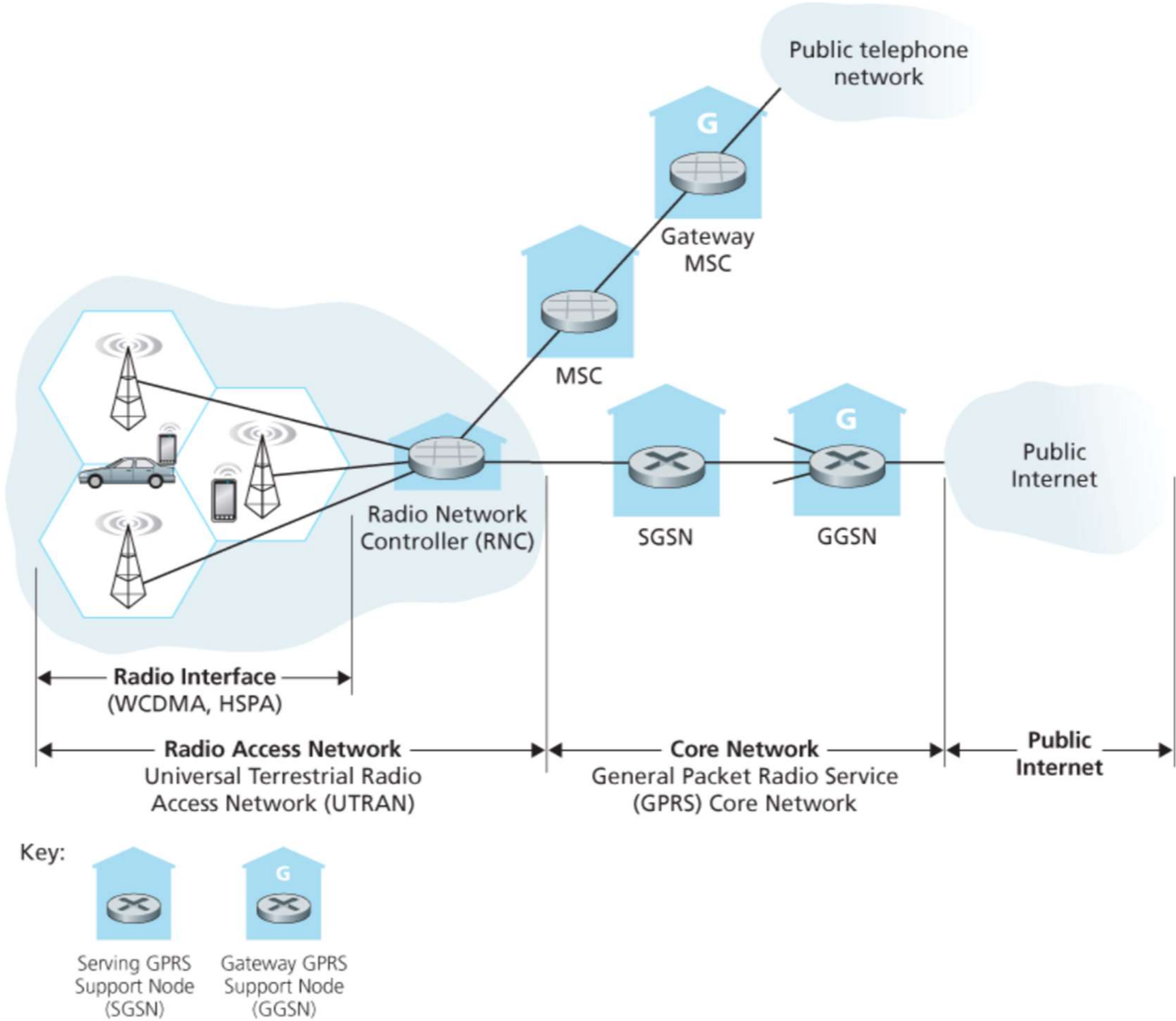
3G (voice+data) network architecture



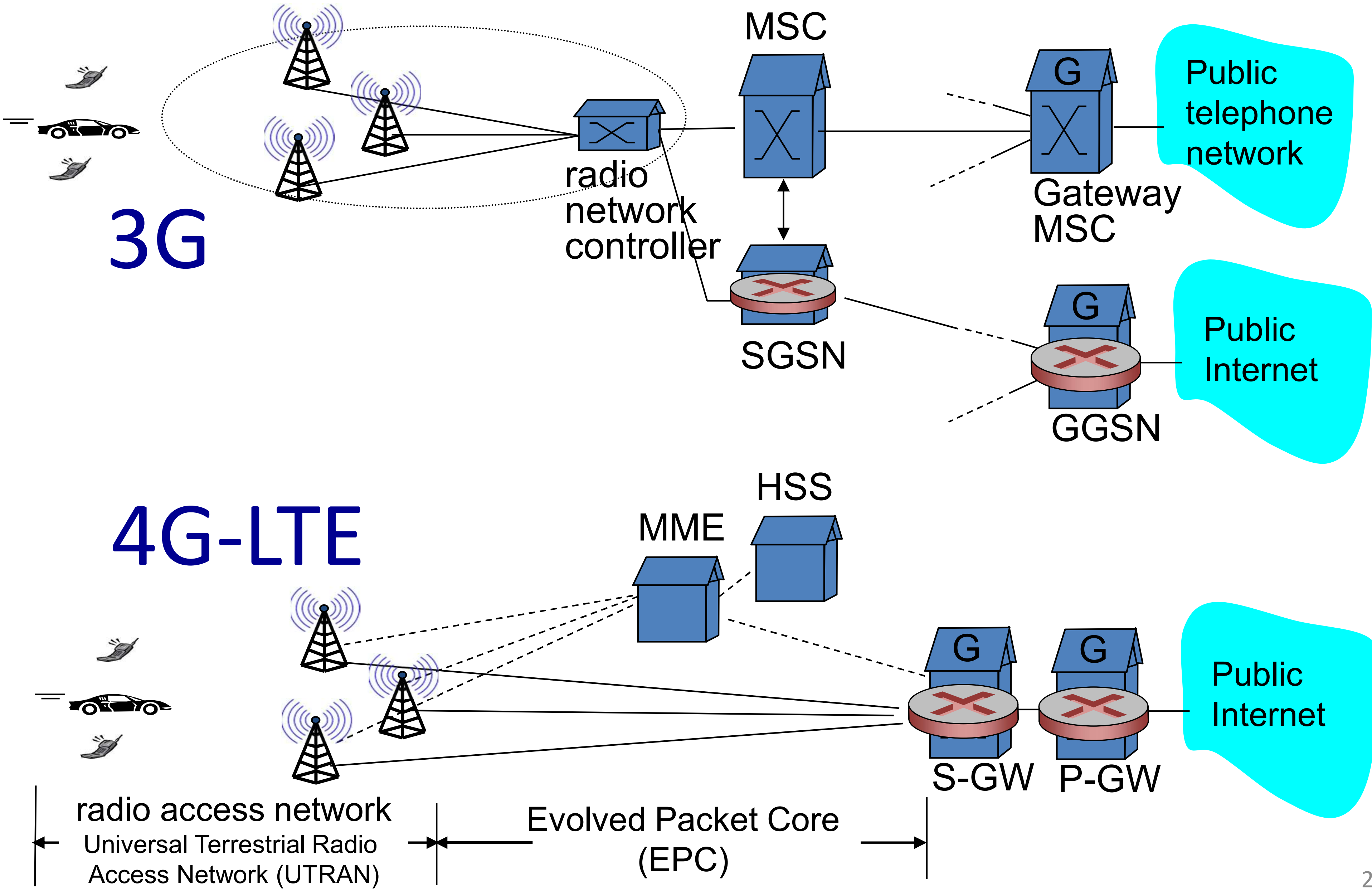
Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

- voice network *unchanged* in core
- data network operates in parallel

3G (voice+data) network architecture

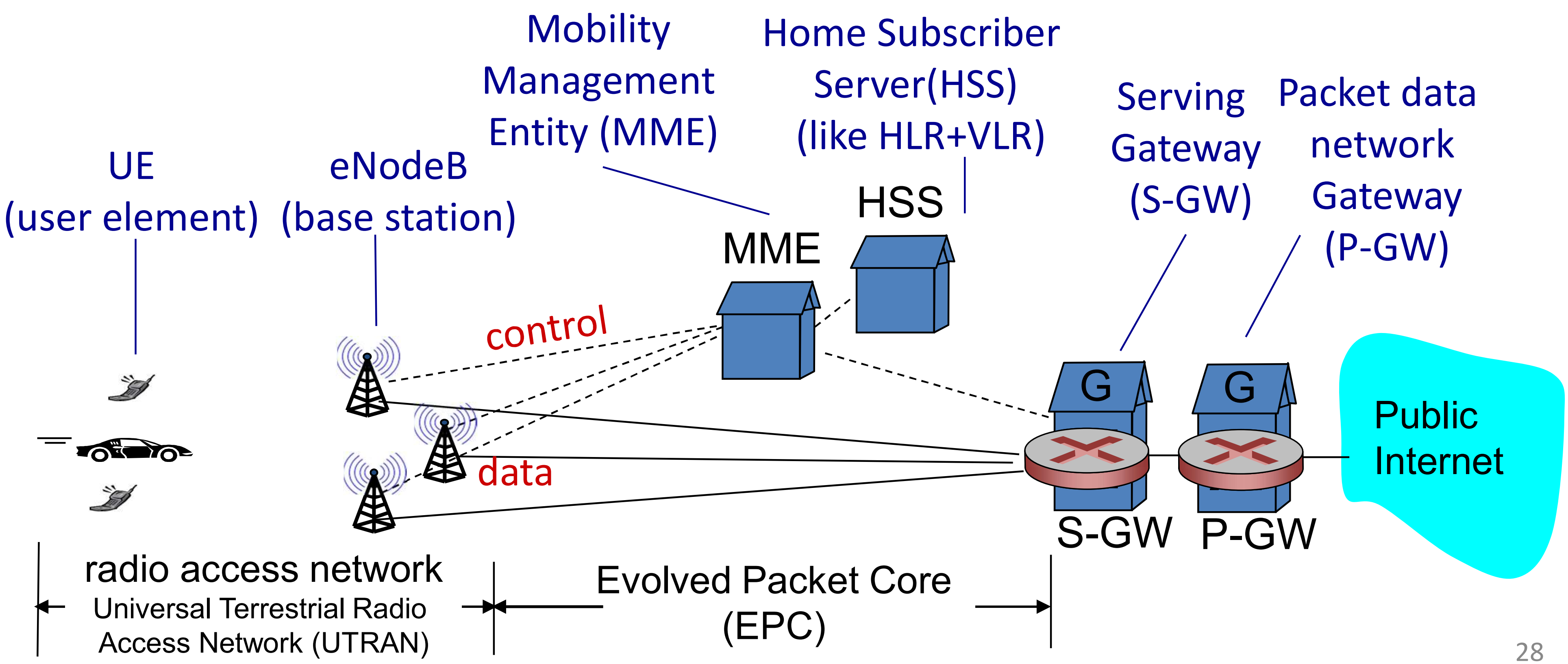


3G versus 4G LTE network architecture

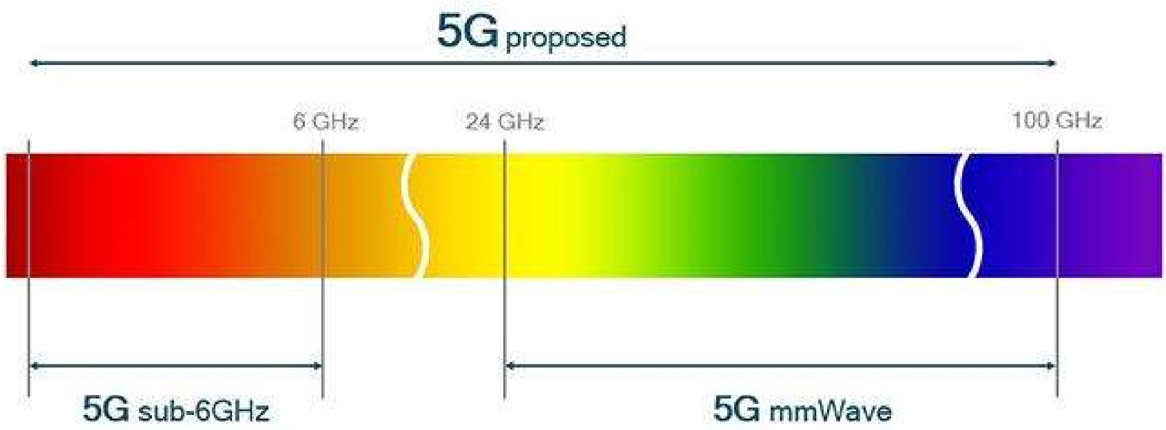


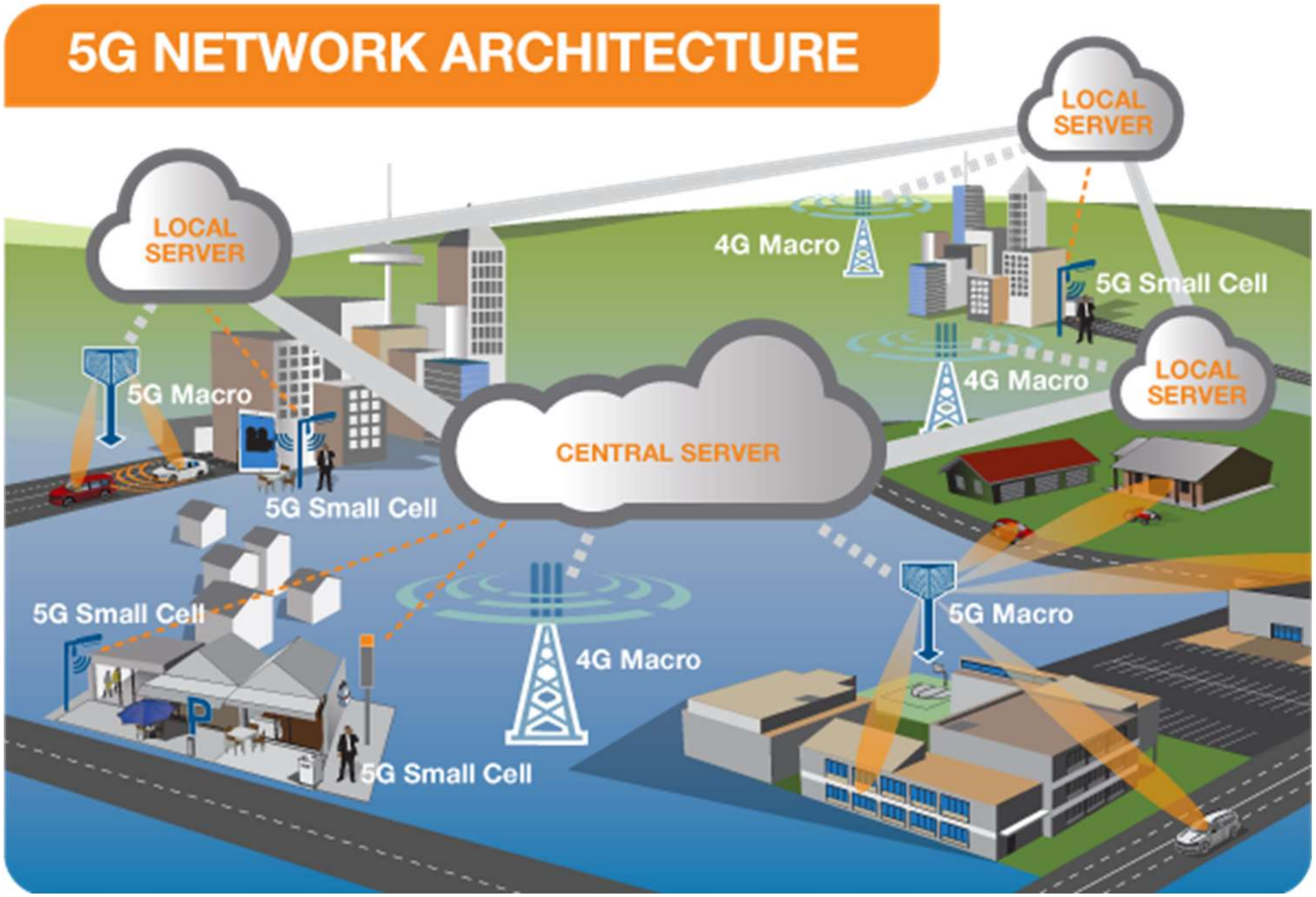
4G: differences from 3G

- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway



5G cellular networks

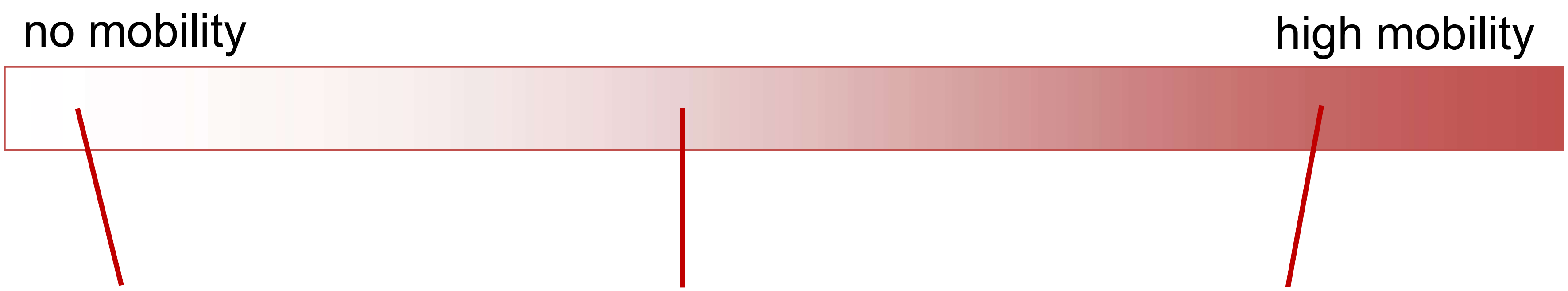




Mobility in Wireless Networks

What is mobility?

- spectrum of mobility, from the *network* perspective:



mobile wireless user, using same access point

mobile user, connecting/ disconnecting from network using DHCP.

mobile user, passing through multiple access point while maintaining ongoing connections (like cell phone)

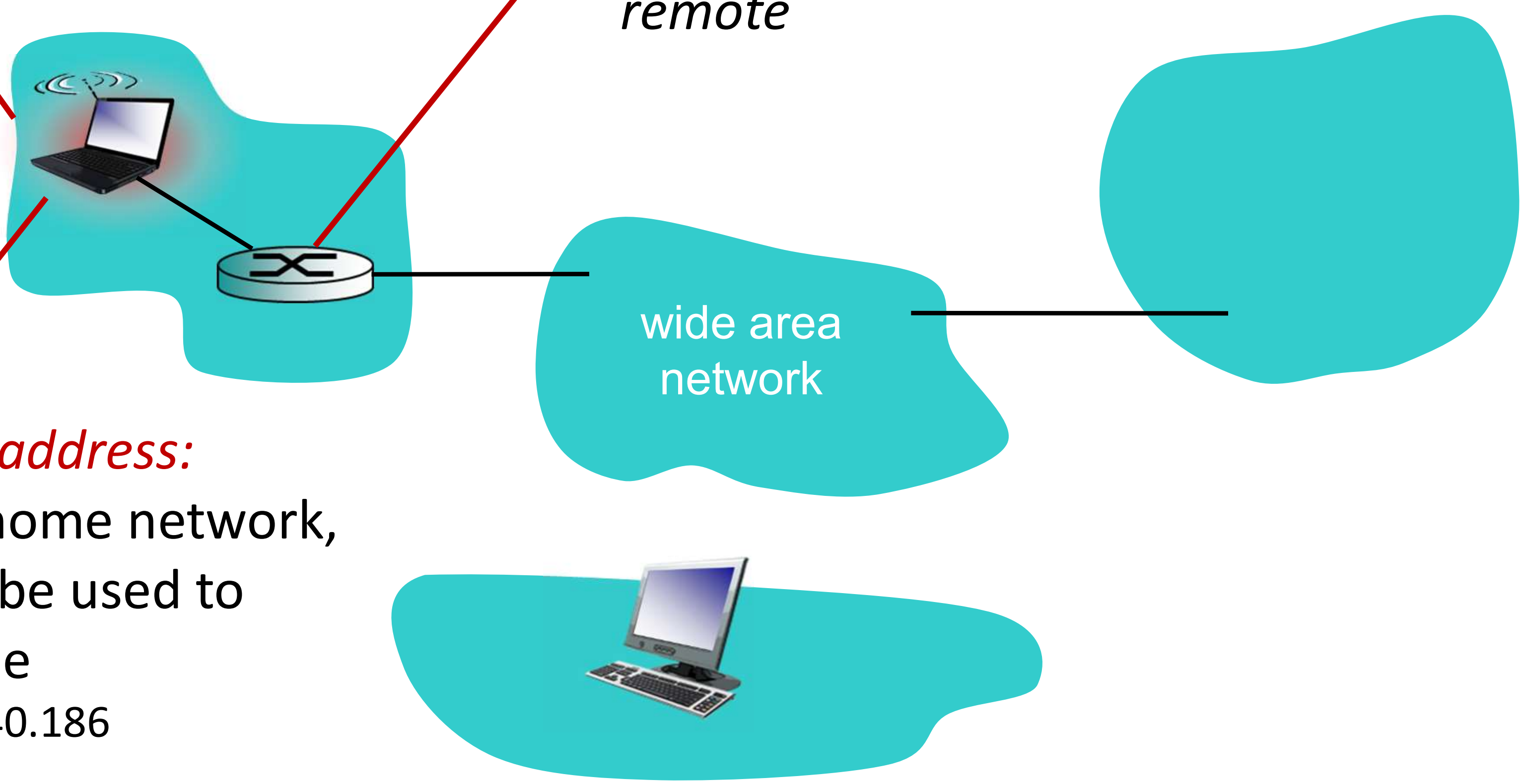
Mobility: approaches

- *let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - routing tables indicate where each mobile located
  - no changes to end-systems
- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

Mobility: vocabulary

home network: "home" of mobile
(e.g., 128.119.40/24)

home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote



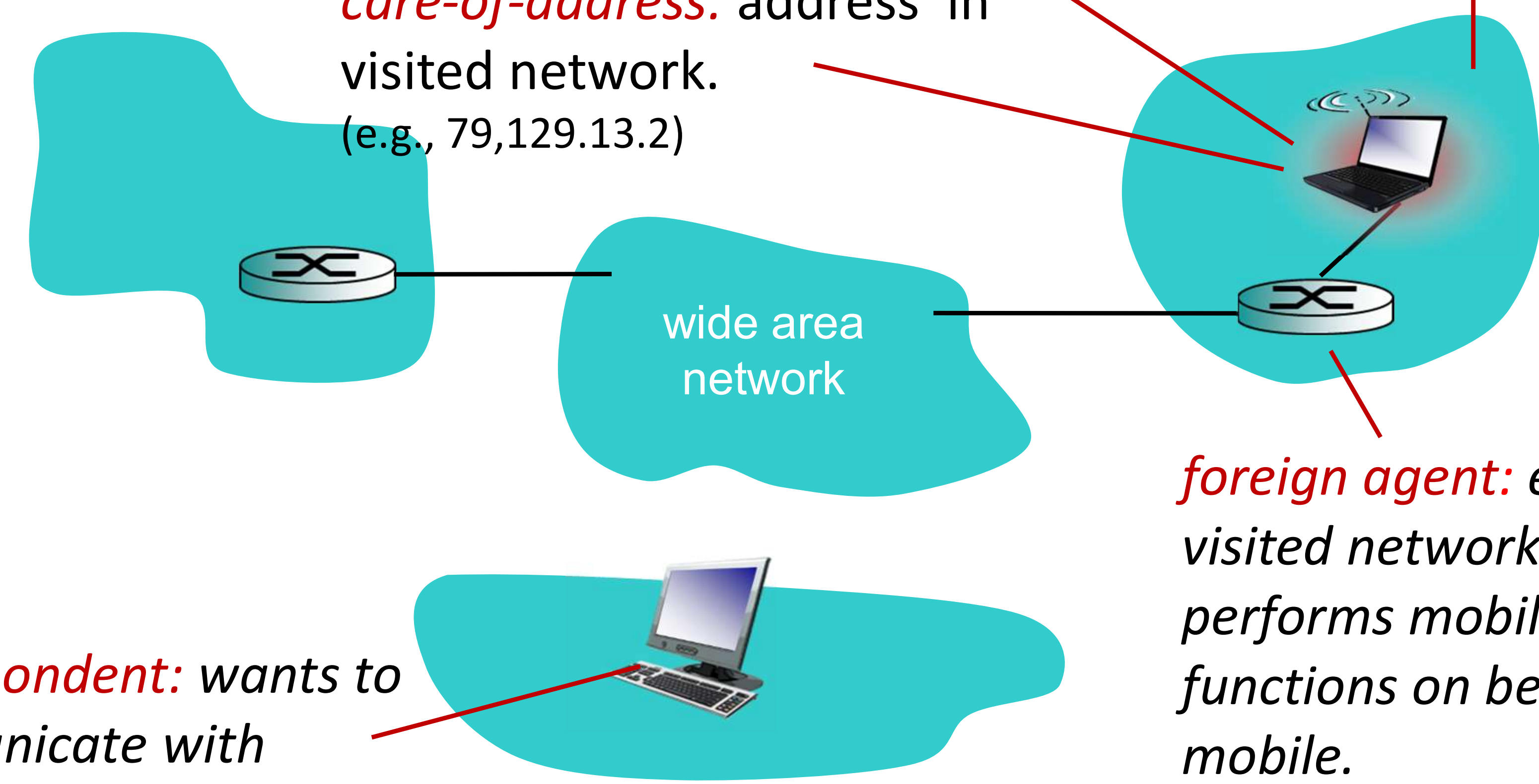
permanent address:
address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

Mobility: more vocabulary

permanent address: remains constant (e.g., 128.119.40.186)

visited network: network in which mobile currently resides (e.g., 79.129.13/24)

care-of-address: address in visited network. (e.g., 79,129.13.2)



foreign agent: entity in visited network that performs mobility functions on behalf of mobile.

correspondent: wants to communicate with mobile

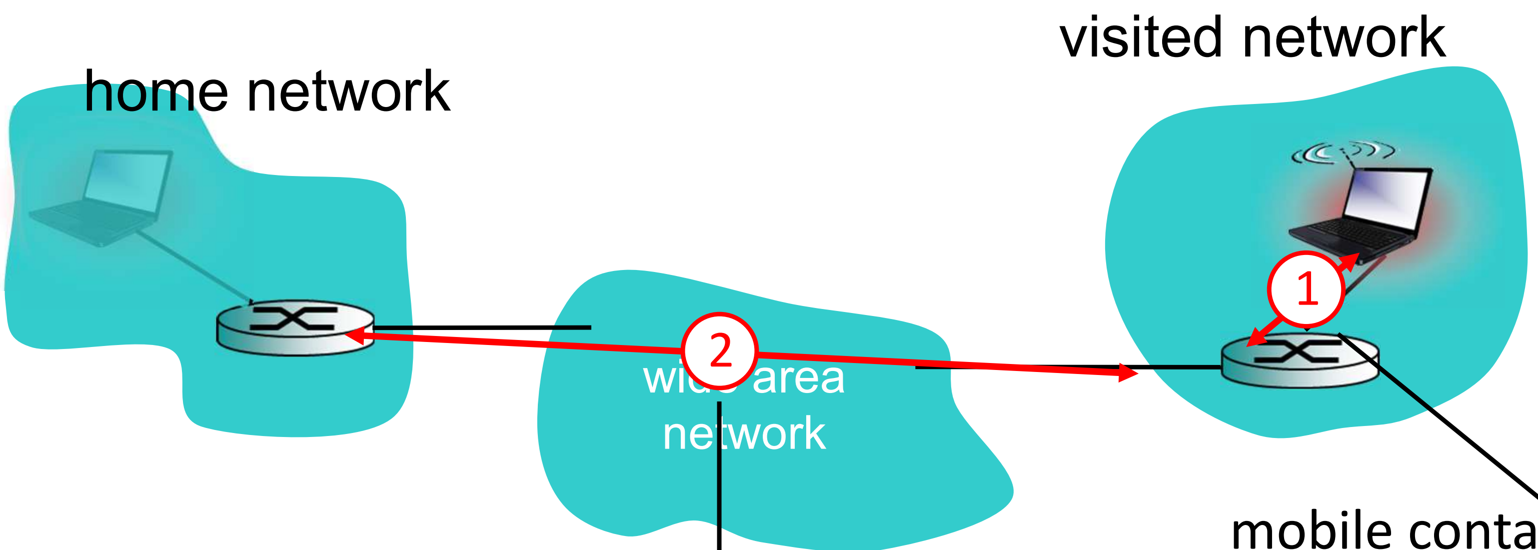
Mobility: approaches

- *let routing handle it:* routers advertise permanent addr… …bile-nodes-in-residence via u… …table exchange.
  - routing tables… …e each mobile located
  - no changes to e… …s

not scalable to millions of mobiles

- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

Mobility: registration



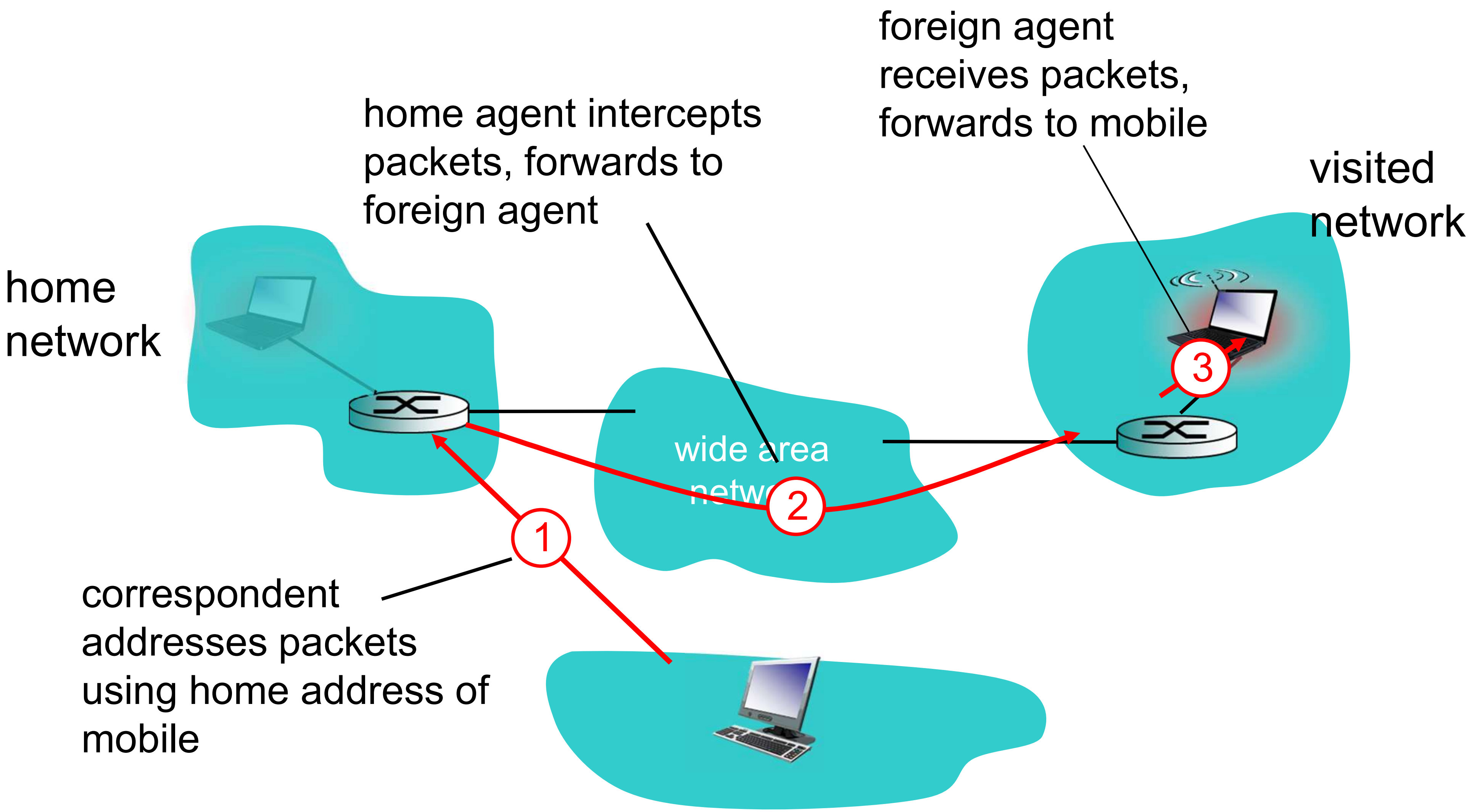
foreign agent contacts home agent home: “this mobile is resident in my network”

mobile contacts foreign agent on entering visited network

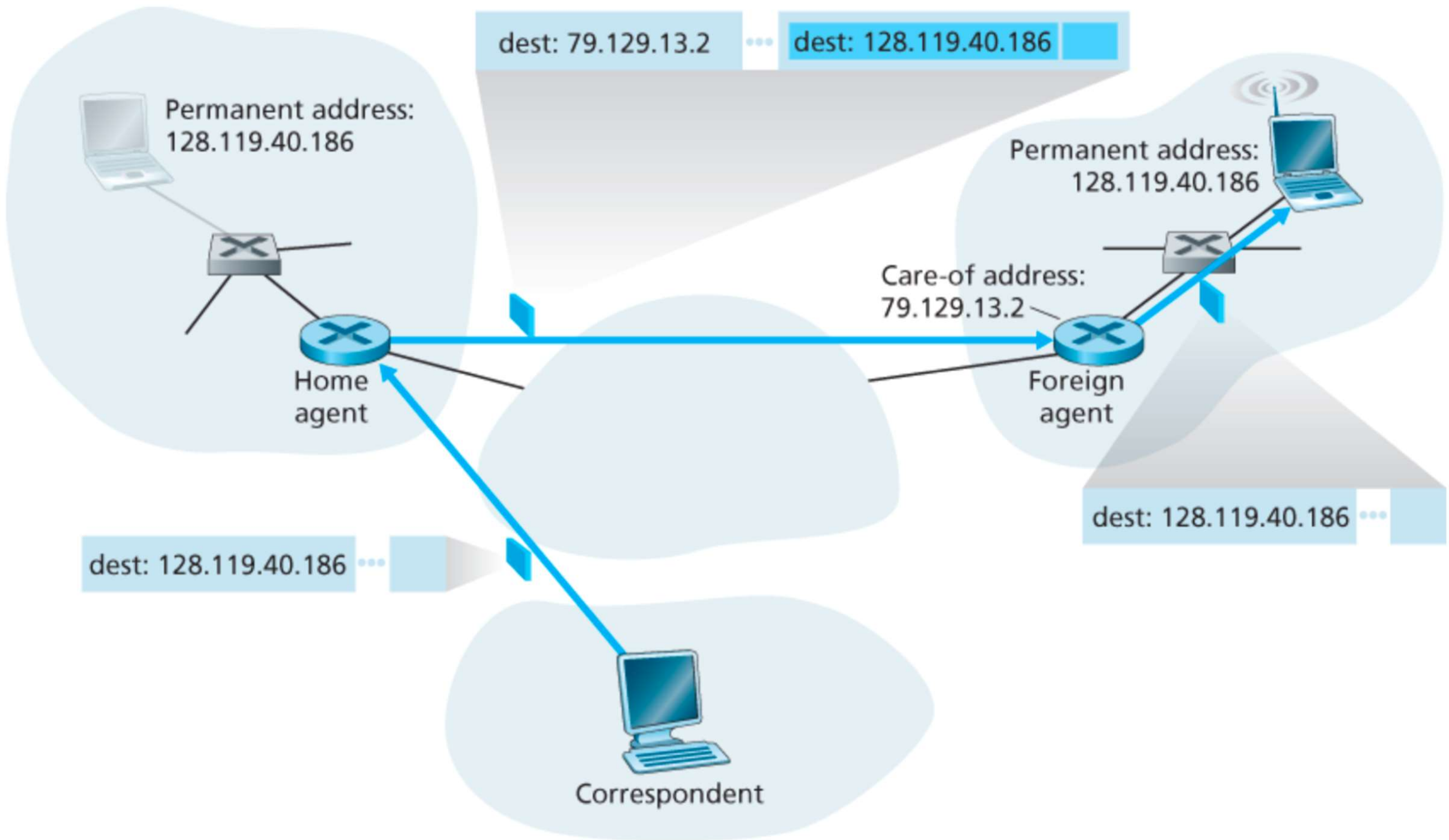
end result:

- foreign agent knows about mobile
- home agent knows location of mobile

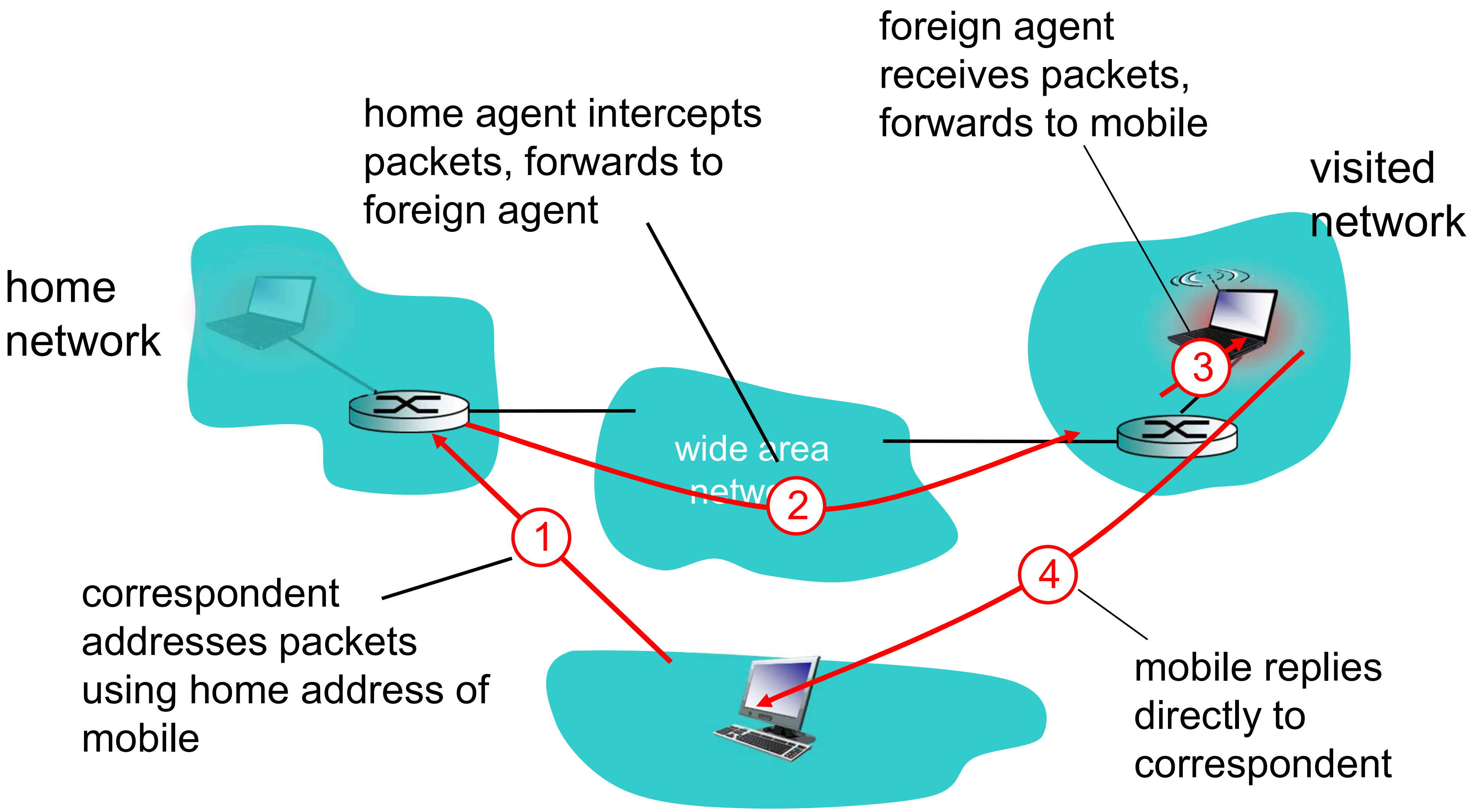
Mobility via indirect routing



Packet encapsulation

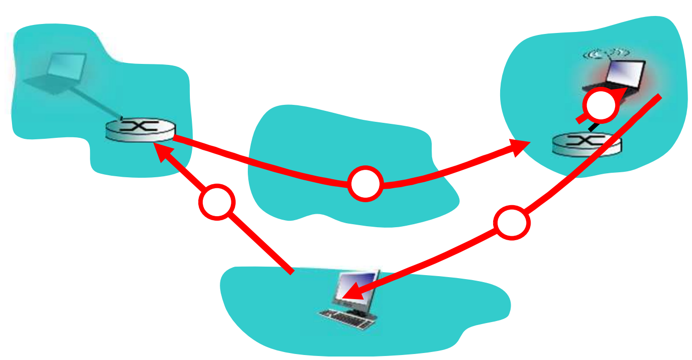


Mobility via indirect routing

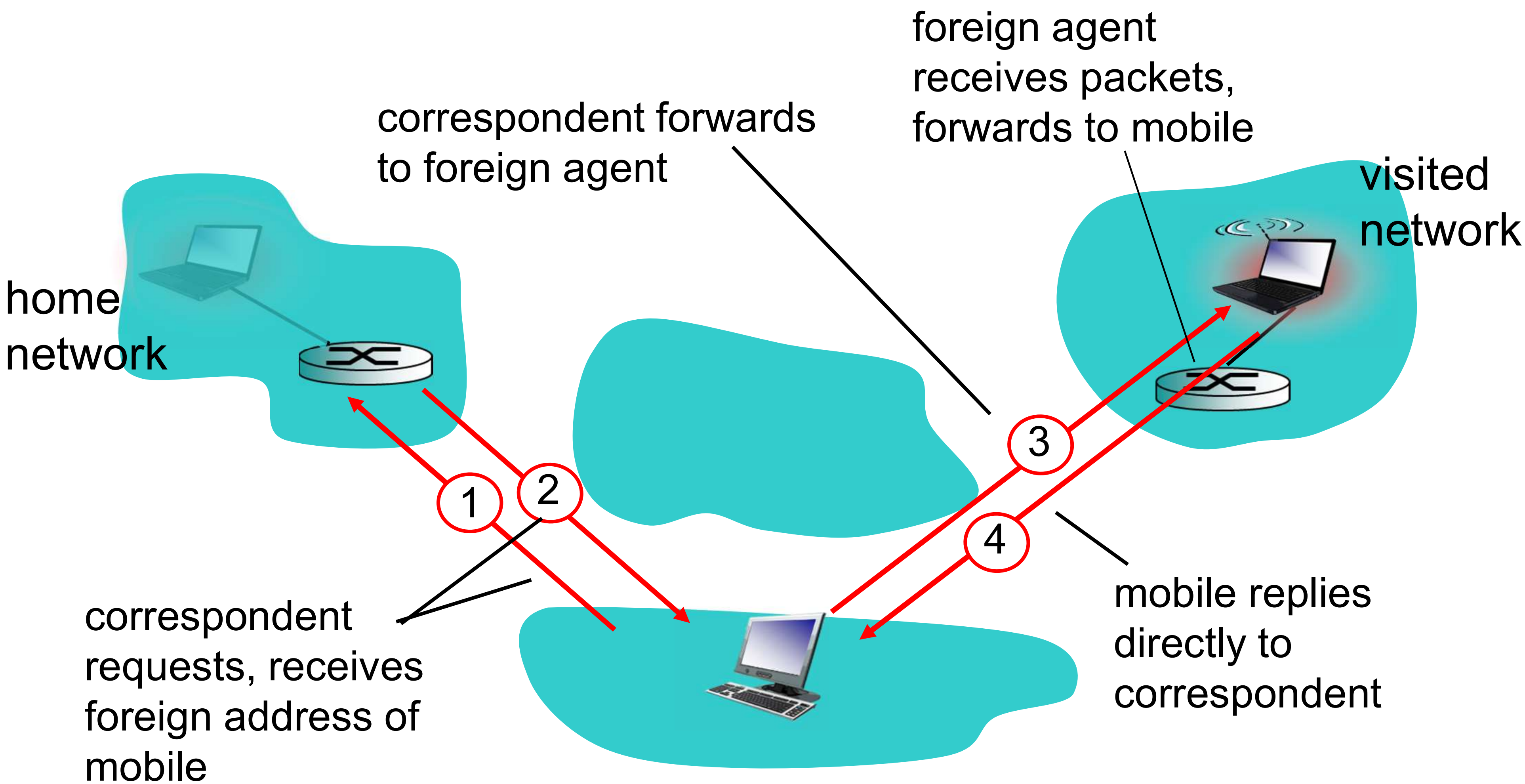


Indirect Routing: comments

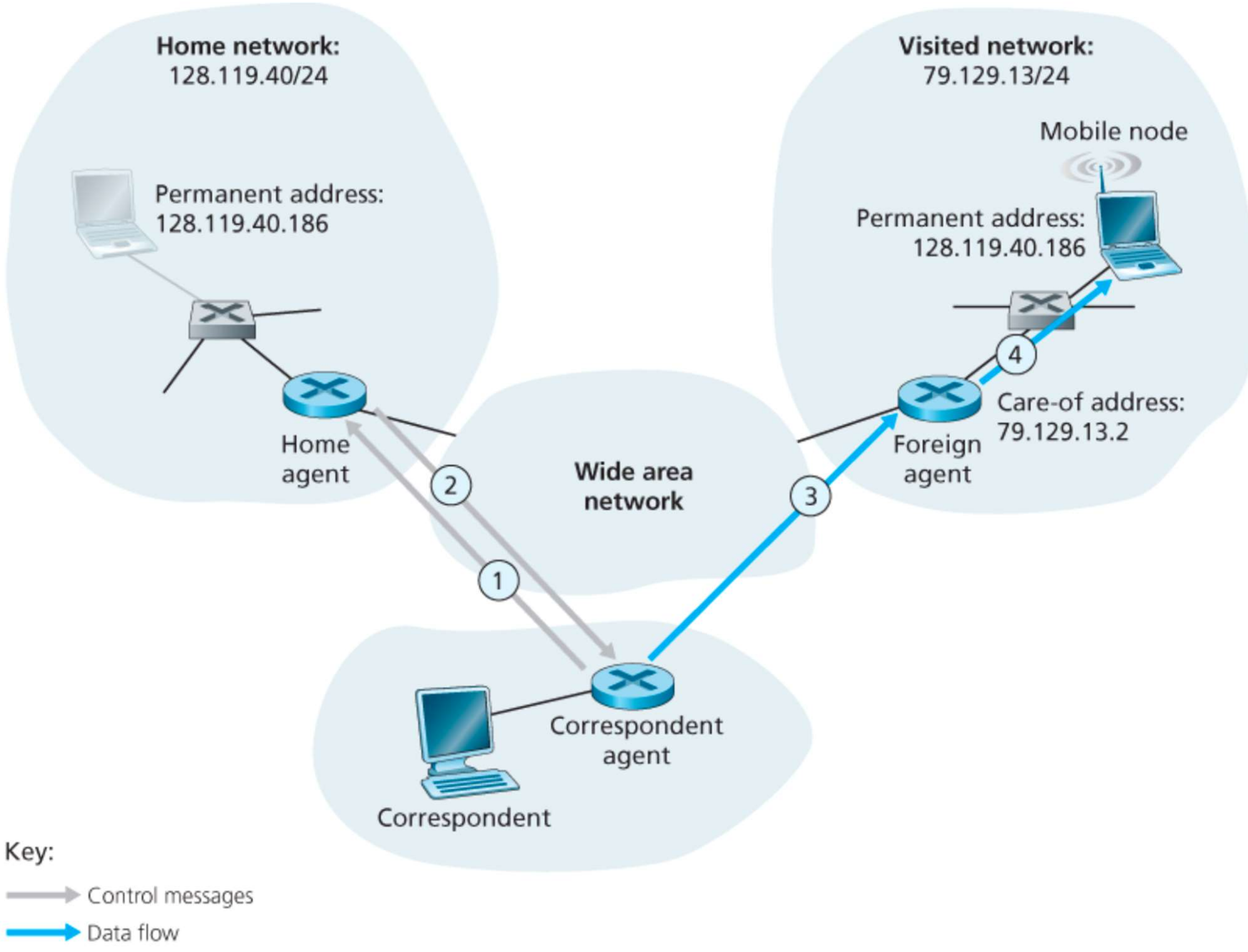
- mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile
  - inefficient when correspondent, mobile are in same network



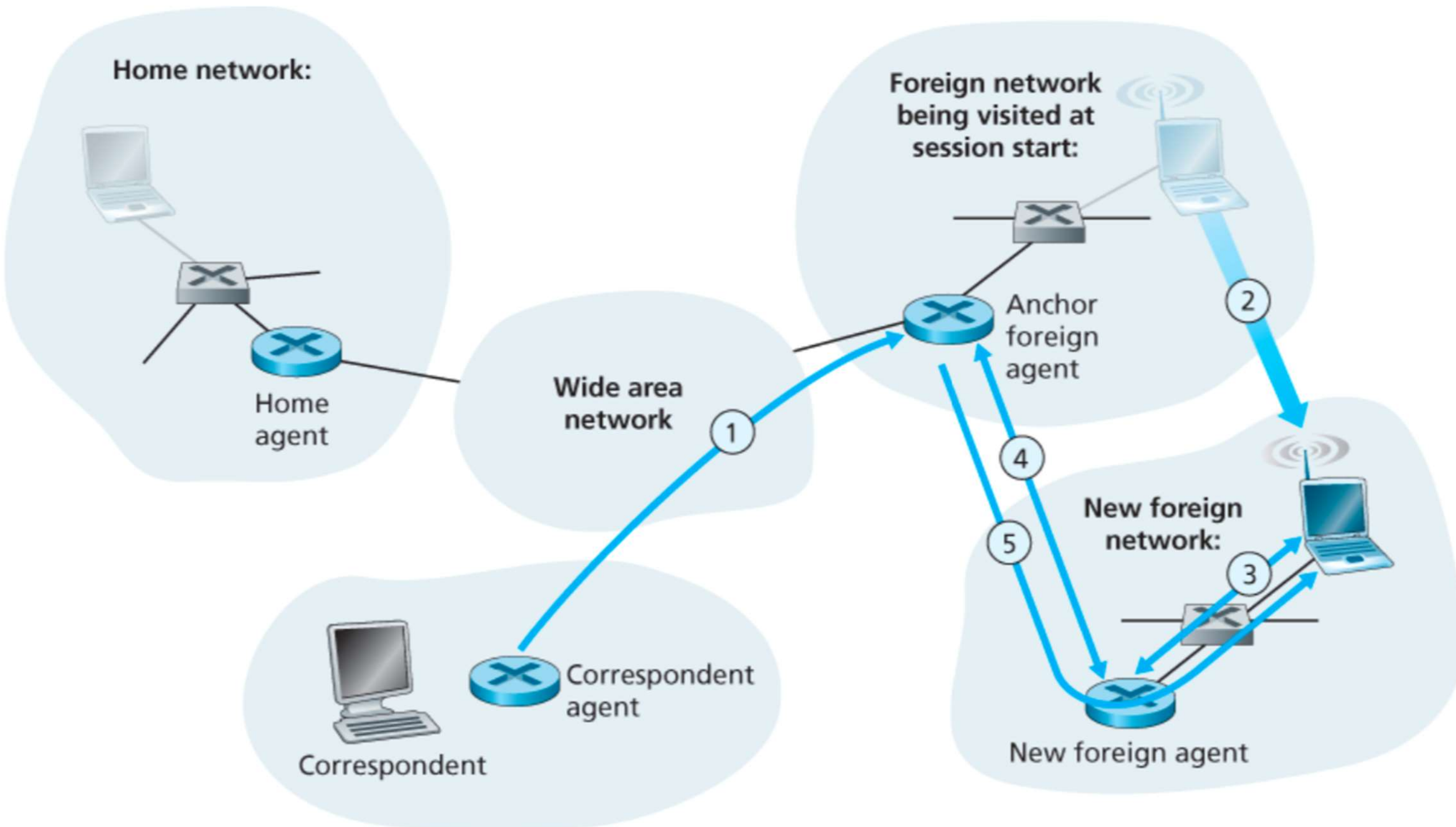
Mobility via direct routing



Mobility via direct routing

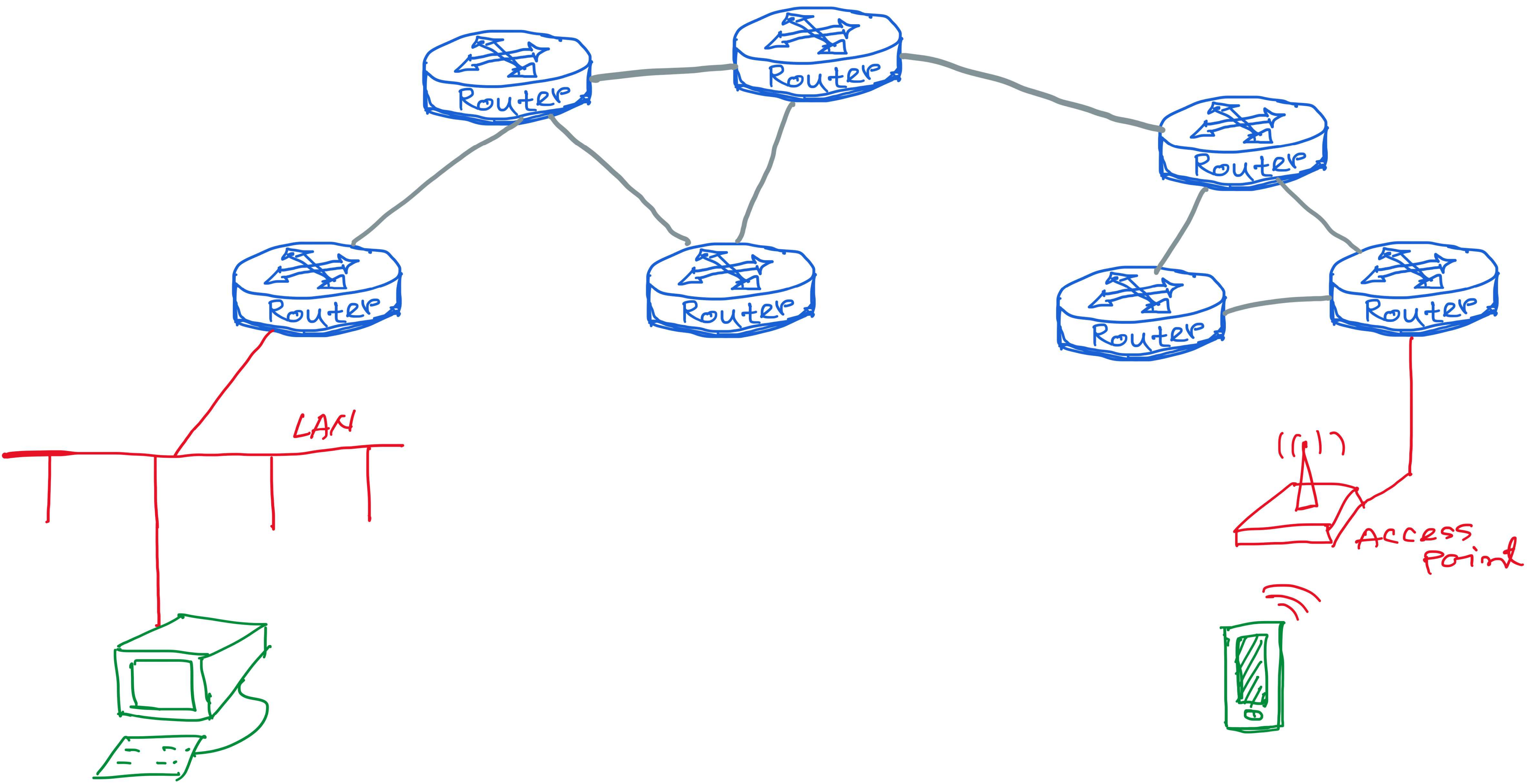


Mobility through multiple foreign networks



Inter-domain routing

Our (improved) view of the Internet



Making routing scalable

our routing study thus far - idealized

- **all routers identical**
- **network "flat"**

… ***not* true in practice**

scale: with billions of destinations:

- Can't store all destinations in routing tables!
- routing table exchange would swamp links!

administrative autonomy

- internet = network of networks
- each network admin may want to control routing in its own network

Autonomous Routing Domains

A collection of physical networks glued together using IP, that have a unified administrative routing policy.

- **Campus networks**
- **Corporate networks**
- **ISP Internal networks**
- **…**

Autonomous Systems (ASes)

An autonomous system is an autonomous routing domain that has been assigned an Autonomous System Number (ASN).

… the administration of an AS appears to other ASes to have a single coherent interior routing plan and presents a consistent picture of what networks are reachable through it.

RFC 1930: Guidelines for creation, selection, and registration of an Autonomous System

AS Numbers (ASNs)

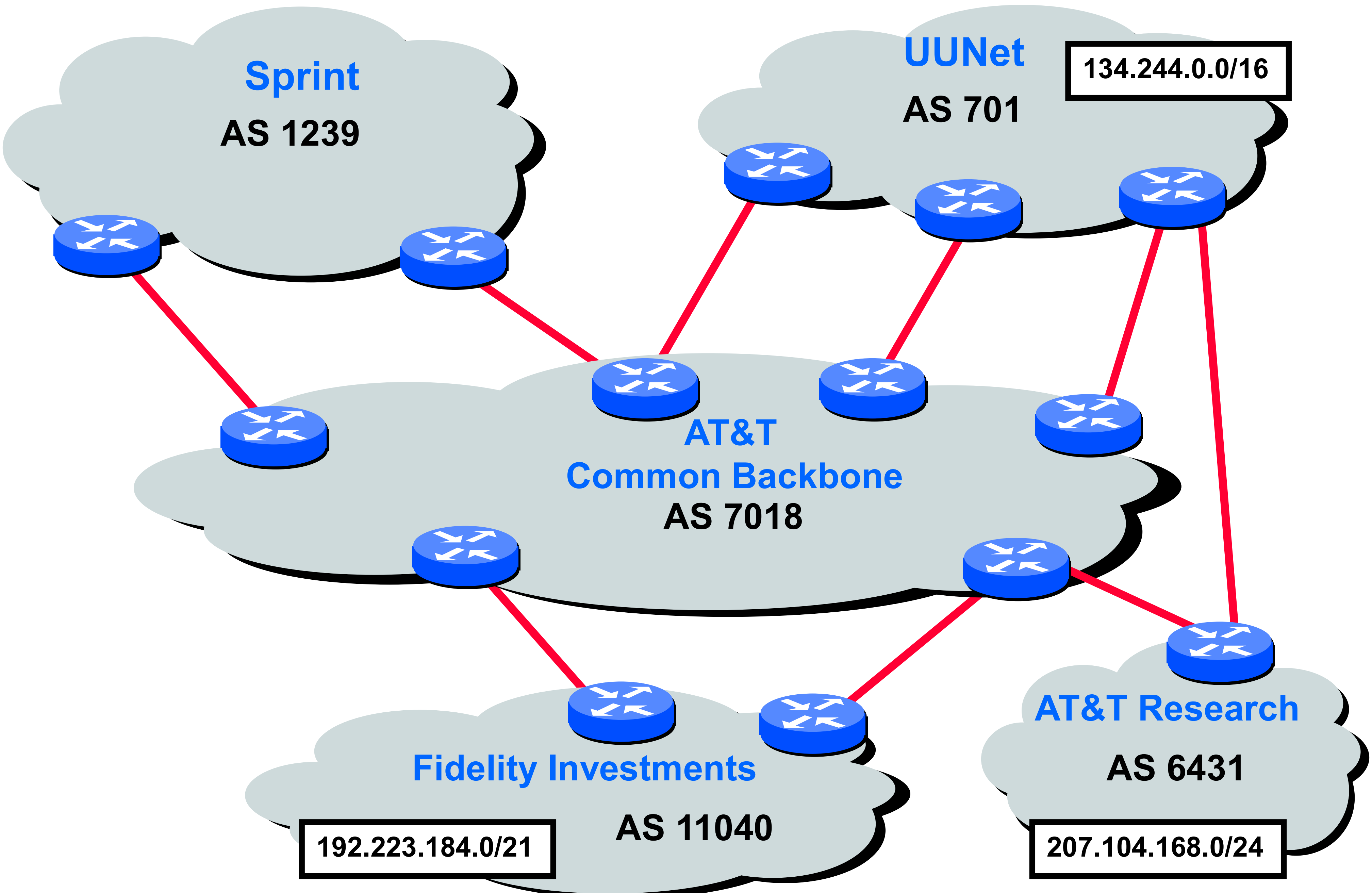
ASNs are 16 and 32 bit values.
64512 through 65535 are "private"

Currently over 11,000 in use.

- **Genuity: 1**
- **MIT: 3**
- **Harvard: 11**
- **UC San Diego: 7377**
- **AT&T: 7018, 6341, 5074, ...**
- **UUNET: 701, 702, 284, 12199, ...**
- **Sprint: 1239, 1240, 6211, 6242, ...**
- **...**

ASNs represent units of routing policy

Interdomain routing = routing between autonomous systems



Internet approach to scalable routing

aggregate routers into regions known as "autonomous systems" (AS) (a.k.a. "domains")

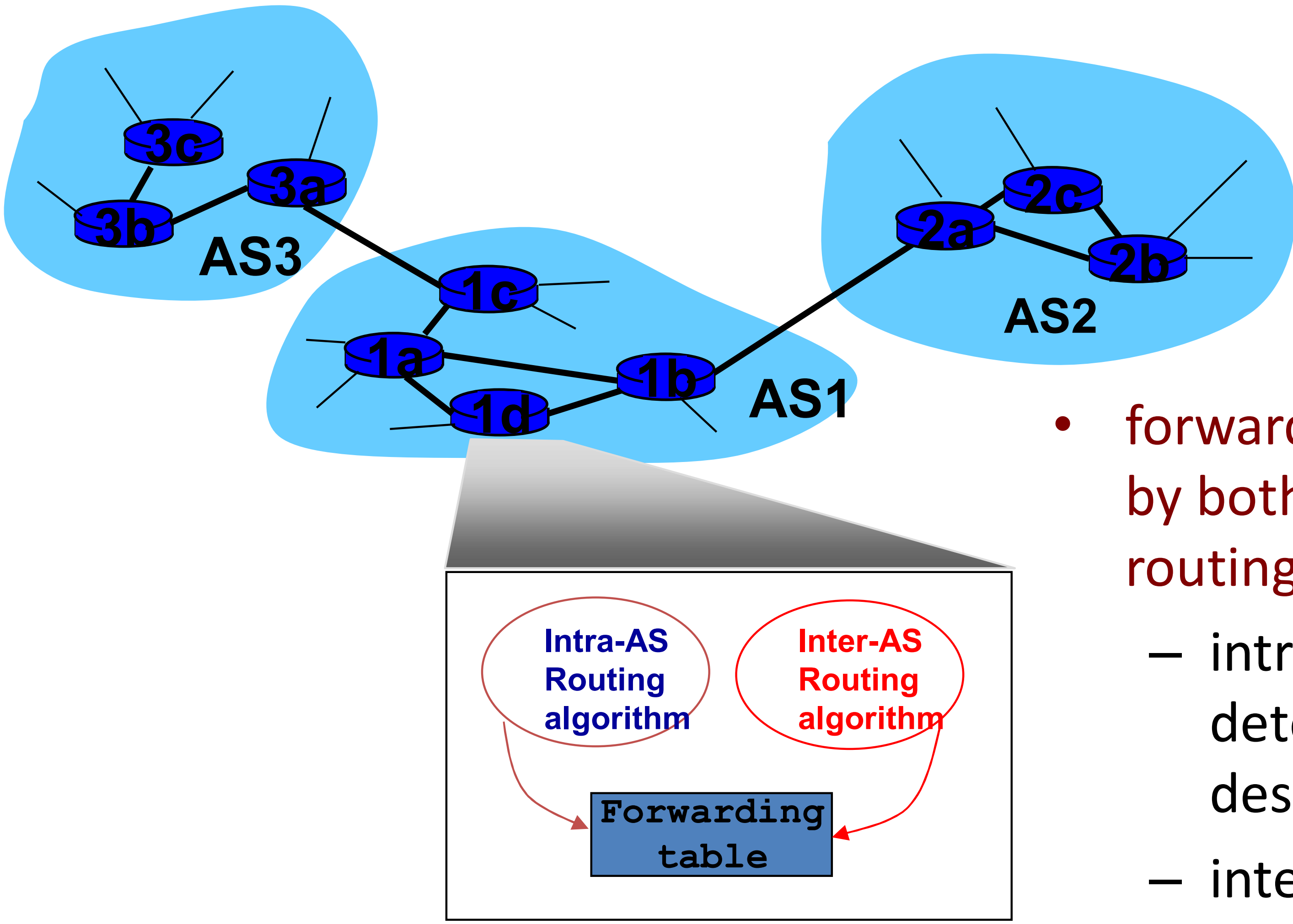
intra-AS routing

- routing among hosts, routers in same AS ("network")
- all routers in AS must run *same* intra-domain protocol
- routers in *different* AS can run *different* intra-domain routing protocol
- gateway router: at "edge" of its own AS, has link(s) to router(s) in other AS'es

inter-AS routing

- routing among AS'es
- gateways perform inter-domain routing (as well as intra-domain routing)

Interconnected ASes



- forwarding table configured by both intra- and inter-AS routing algorithm
  - intra-AS routing determine entries for destinations within AS
  - inter-AS & intra-AS determine entries for external destinations

Intra-AS Routing

Intra-AS Routing

- also known as *interior gateway protocols (IGP)*
- most common intra-AS routing protocols:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco proprietary for decades, until 2016)

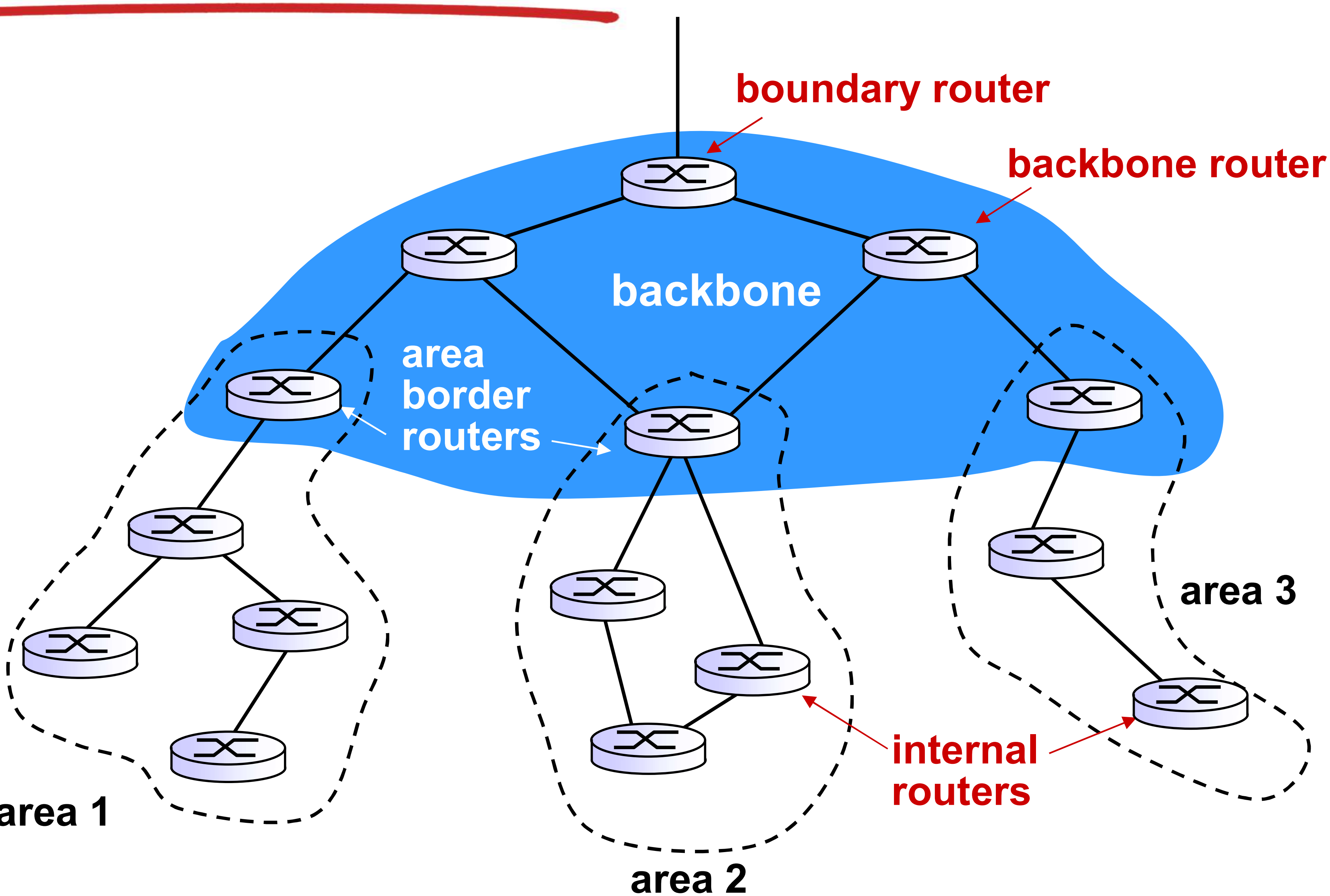
OSPF (Open Shortest Path First)

- "open": publicly available
- uses link-state algorithm
  - link state packet dissemination
  - topology map at each node
  - route computation using Dijkstra's algorithm
- router floods OSPF link-state advertisements to all other routers in *entire* AS
  - carried in OSPF messages directly over IP (rather than TCP or UDP
  - link state: for each attached link

OSPF "advanced" features

- *security:* all OSPF messages authenticated (to prevent malicious intrusion)
- multiple same-cost paths allowed (only one path in RIP)
- for each link, multiple cost metrics for different ToS (e.g., satellite link cost set low for best effort ToS; high for real-time ToS)
- integrated uni- and multi-cast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- hierarchical OSPF in large domains.

Hierarchical OSPF



Hierarchical OSPF

- *two-level hierarchy:* local area, backbone.
  - link-state advertisements only in area
  - each nodes has detailed area topology; only know direction (shortest path) to nets in other areas.
- *area border routers:* "summarize" distances to nets in own area, advertise to other Area Border routers.
- *backbone routers:* run OSPF routing limited to backbone.
- *boundary routers:* connect to other AS'es.

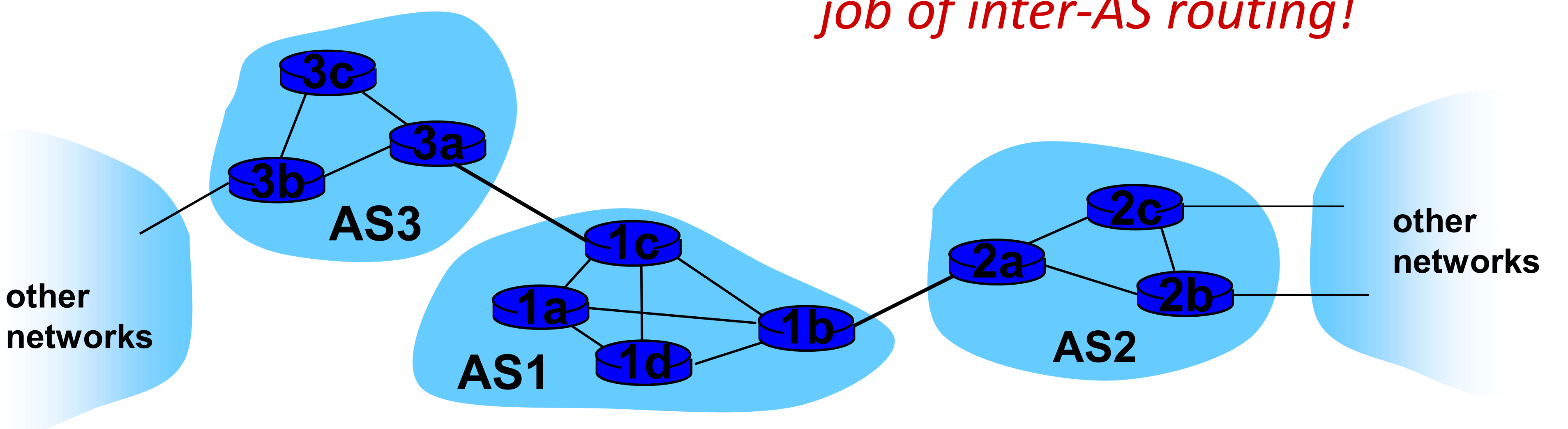
Inter-AS tasks

- suppose router in AS1 receives datagram destined outside of AS1:
  - router should forward packet to gateway router, but which one?

AS1 must:

1. learn which dests are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1

job of inter-AS routing!

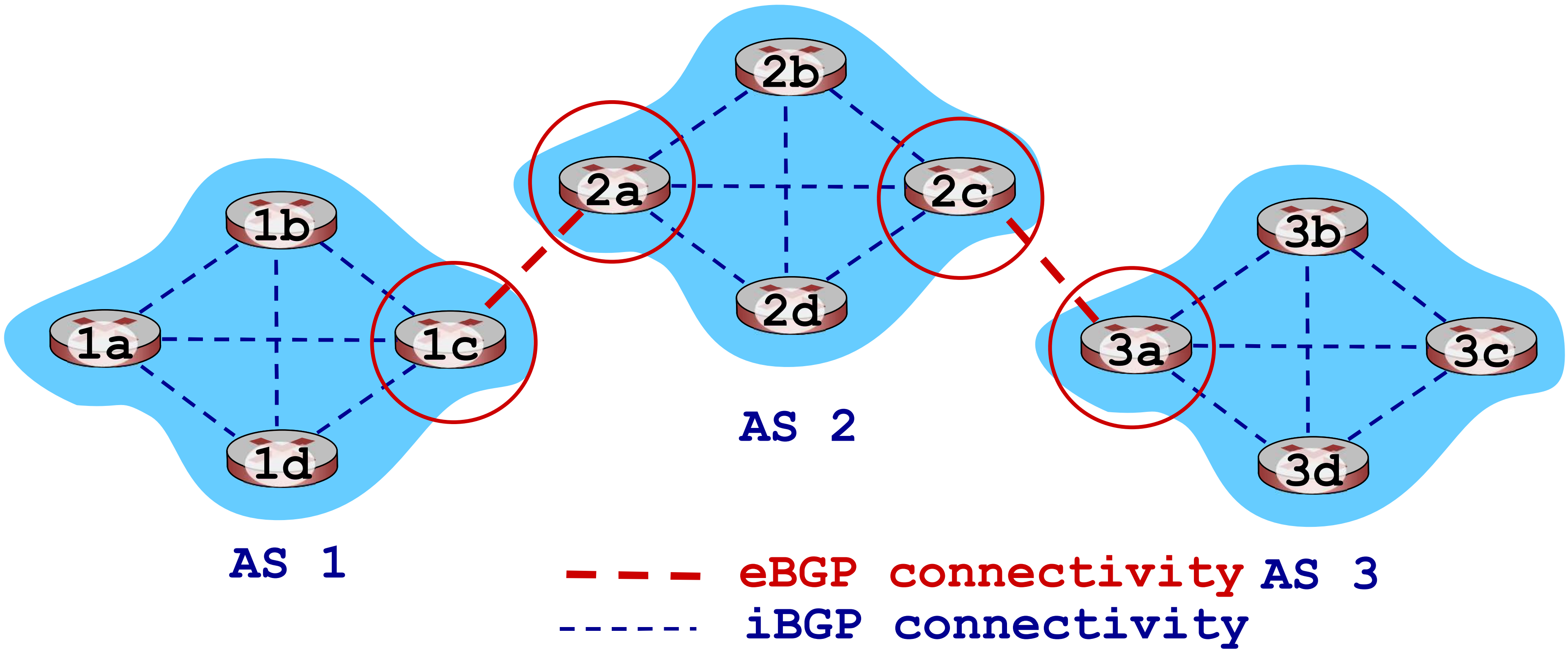


Inter-AS Routing

Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto inter-domain routing protocol
  - "glue that holds the Internet together"
- BGP provides each AS a means to:
  - eBGP: obtain subnet reachability information from neighboring ASes
  - iBGP: propagate reachability information to all AS-internal routers.
  - determine "good" routes to other networks based on reachability information and *policy*
- allows subnet to advertise its existence to rest of Internet: *"I am here"*

eBGP, iBGP connections

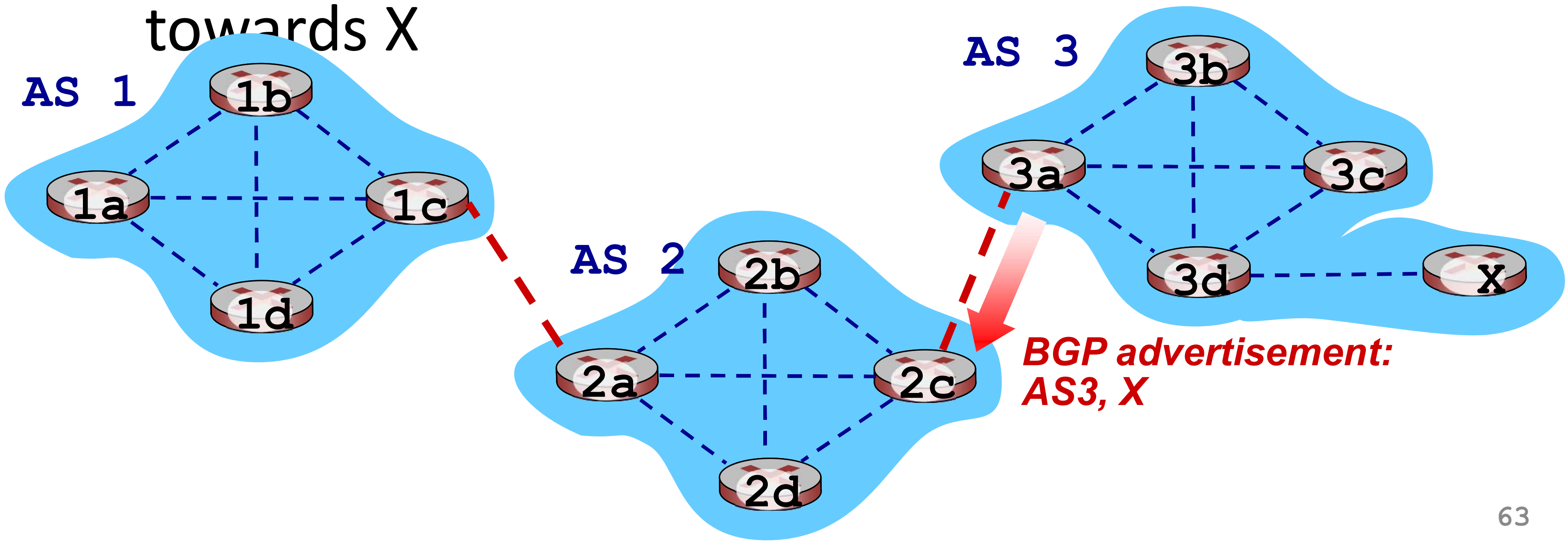


gateway routers run both eBGP and iBGP protoco

BGP basics

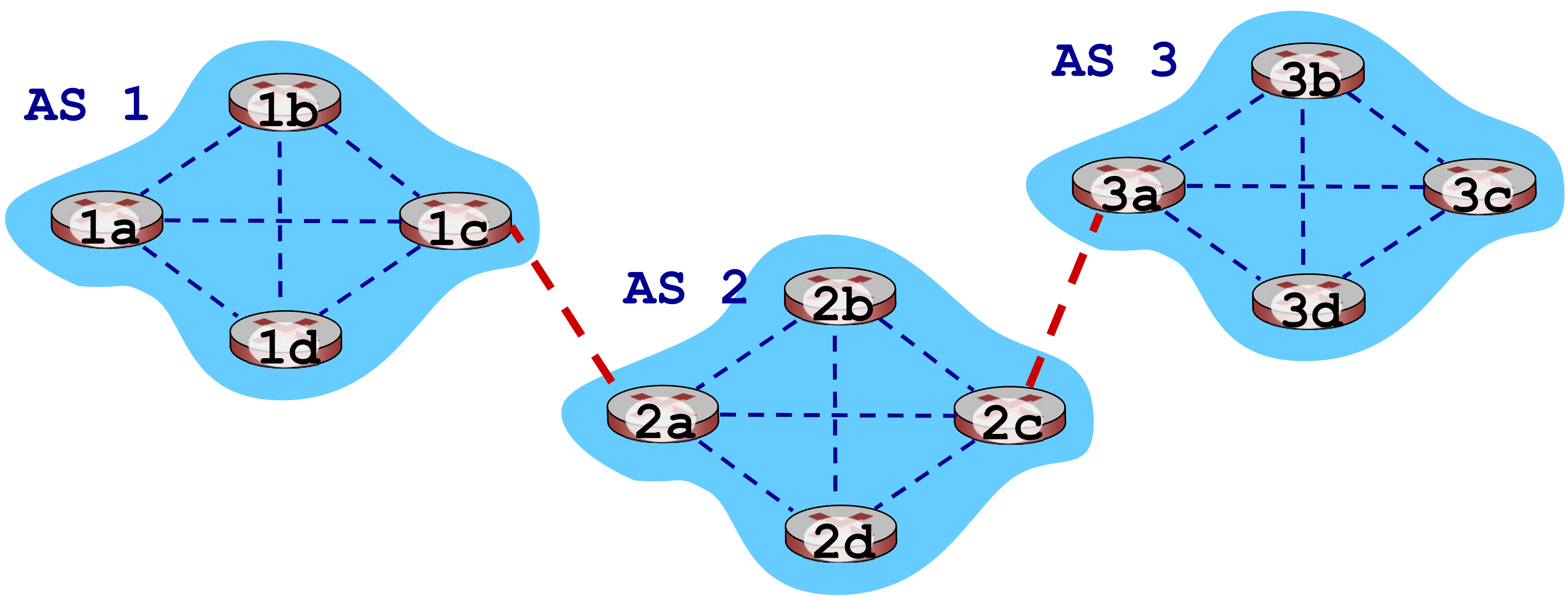
- **BGP session:** two BGP routers ("peers") exchange BGP messages over semi-permanent TCP connection:
  - advertising *paths* to different destination network prefixes (BGP is a "path vector" protocol)

- when AS3 gateway router 3a advertises path AS3,X to AS2 gateway router 2c:
  - AS3 *promises* to AS2 it will forward datagrams towards X



BGP basics

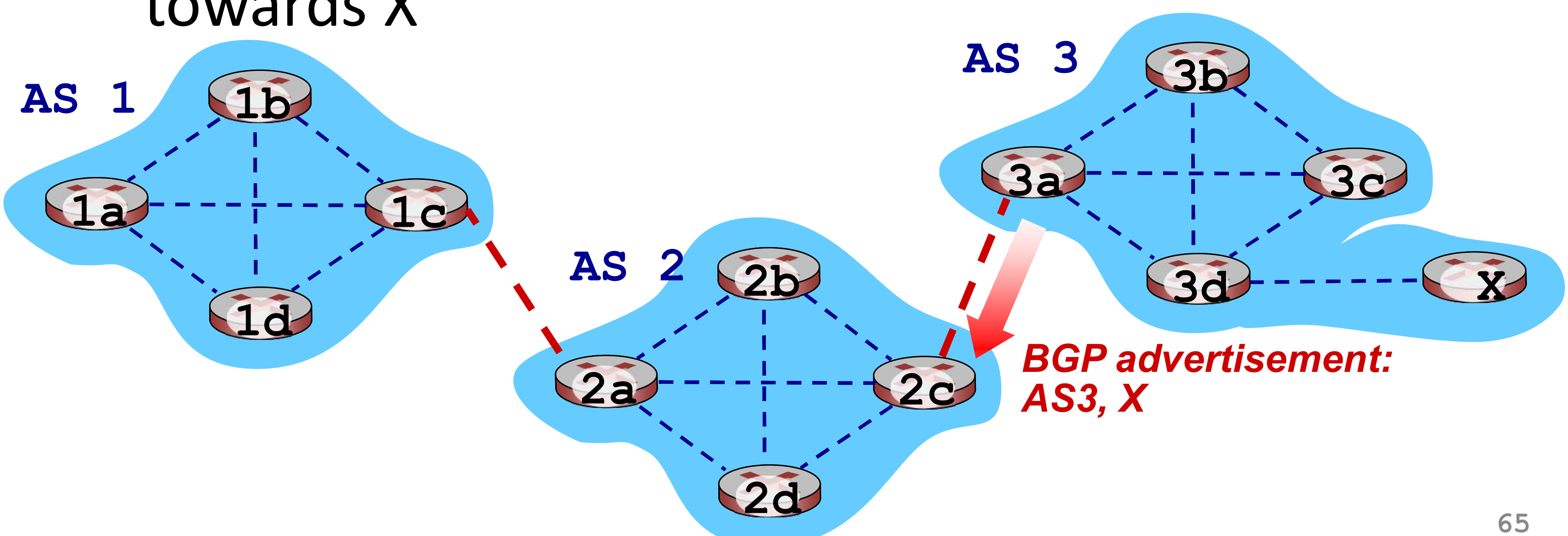
- **BGP session:** two BGP routers ("peers") exchange BGP messages over semi-permanent TCP connection:
  - advertising *paths* to different destination network prefixes (BGP is a "path vector" protocol)



BGP basics

- **BGP session:** two BGP routers ("peers") exchange BGP messages over semi-permanent TCP connection.

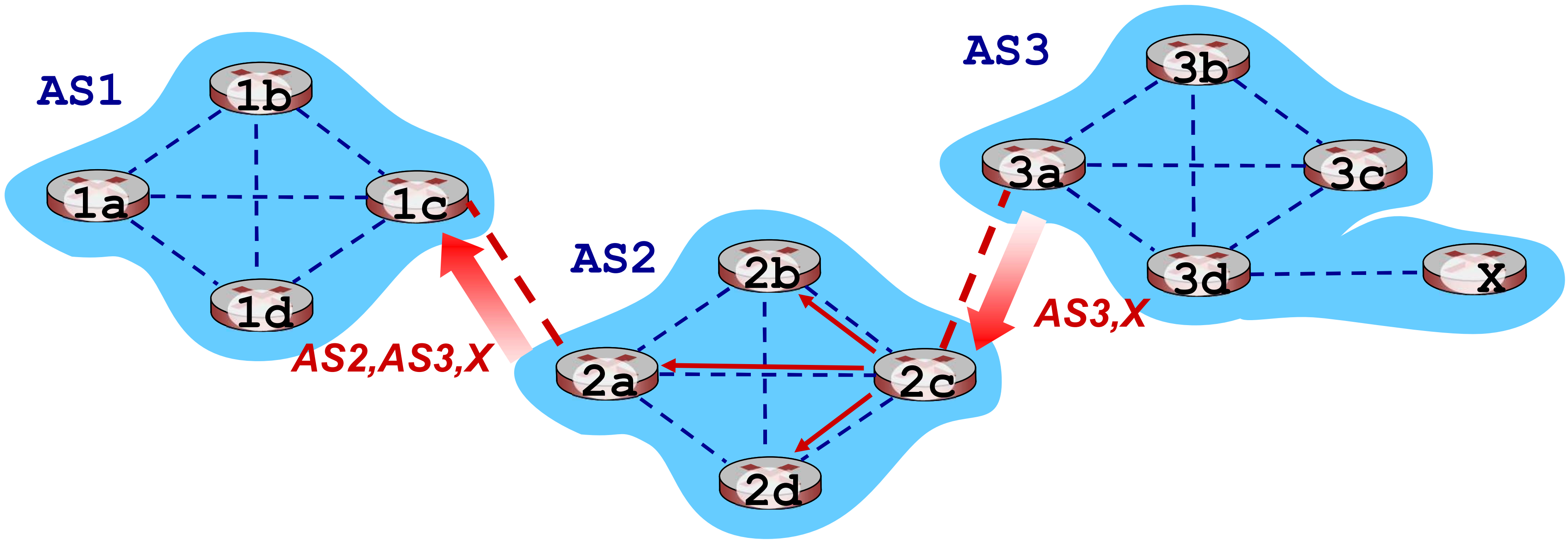
- when AS3 gateway router 3a advertises path AS3,X to AS2 gateway router 2c:
  - AS3 *promises* to AS2 it will forward datagrams towards X



Path attributes and BGP routes

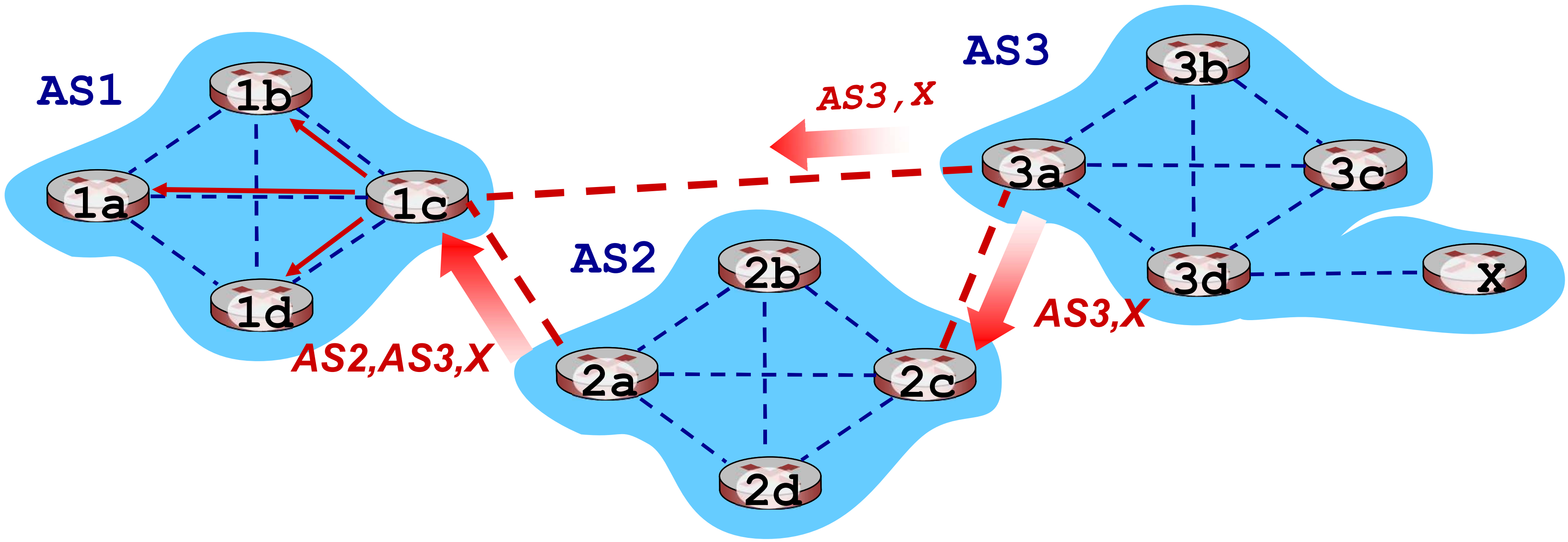
- advertised prefix includes BGP attributes
  - prefix + attributes = "route"
- two important attributes:
  - AS-PATH: list of ASes through which prefix advertisement has passed
  - NEXT-HOP: indicates specific internal-AS router to next-hop AS
- *Policy-based routing:*
  - gateway receiving route advertisement uses *import policy* to accept/decline path (e.g., never route through AS Y).
  - AS policy also determines whether to *advertise* path to other other neighboring ASes

BGP path advertisement



- **AS2 router 2c receives path advertisement AS3,X (via eBGP) from AS3 router 3a**
- Based on AS2 policy, AS2 router 2c accepts path AS3,X, propagates (via iBGP) to all AS2 routers
- **Based on AS2 policy, AS2 router 2a advertises (via eBGP) path AS2, AS3, X to AS1 router 1c**

BGP path advertisement



gateway router may learn about multiple paths to destination:

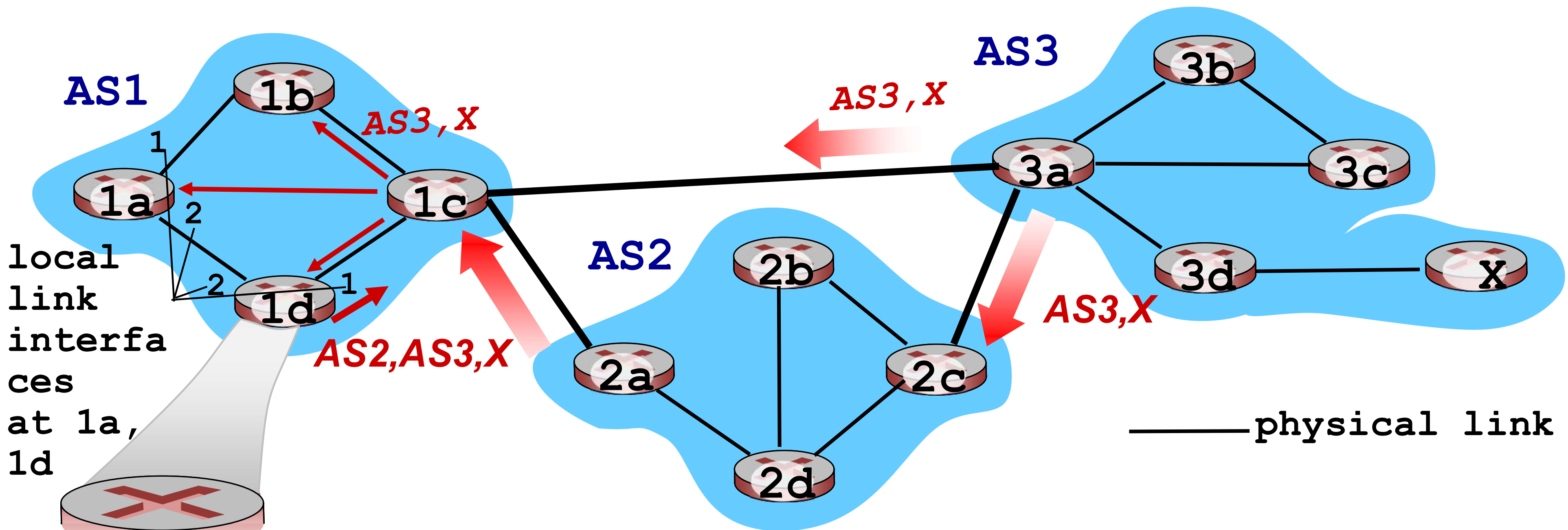
- AS1 gateway router 1c learns path *AS2,AS3,X* from 2a
- **AS1 gateway router 1c learns path *AS3,X* from 3a**
- **Based on policy, AS1 gateway router 1c chooses path *AS3,X, and advertises path within AS1 via iBGP***

BGP messages

- BGP messages exchanged between peers over TCP connection
- BGP messages:
  - OPEN: opens TCP connection to remote BGP peer and authenticates sending BGP peer
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE: keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection

BGP, OSPF, forwarding table entries

Q: how does router set forwarding table entry to distant

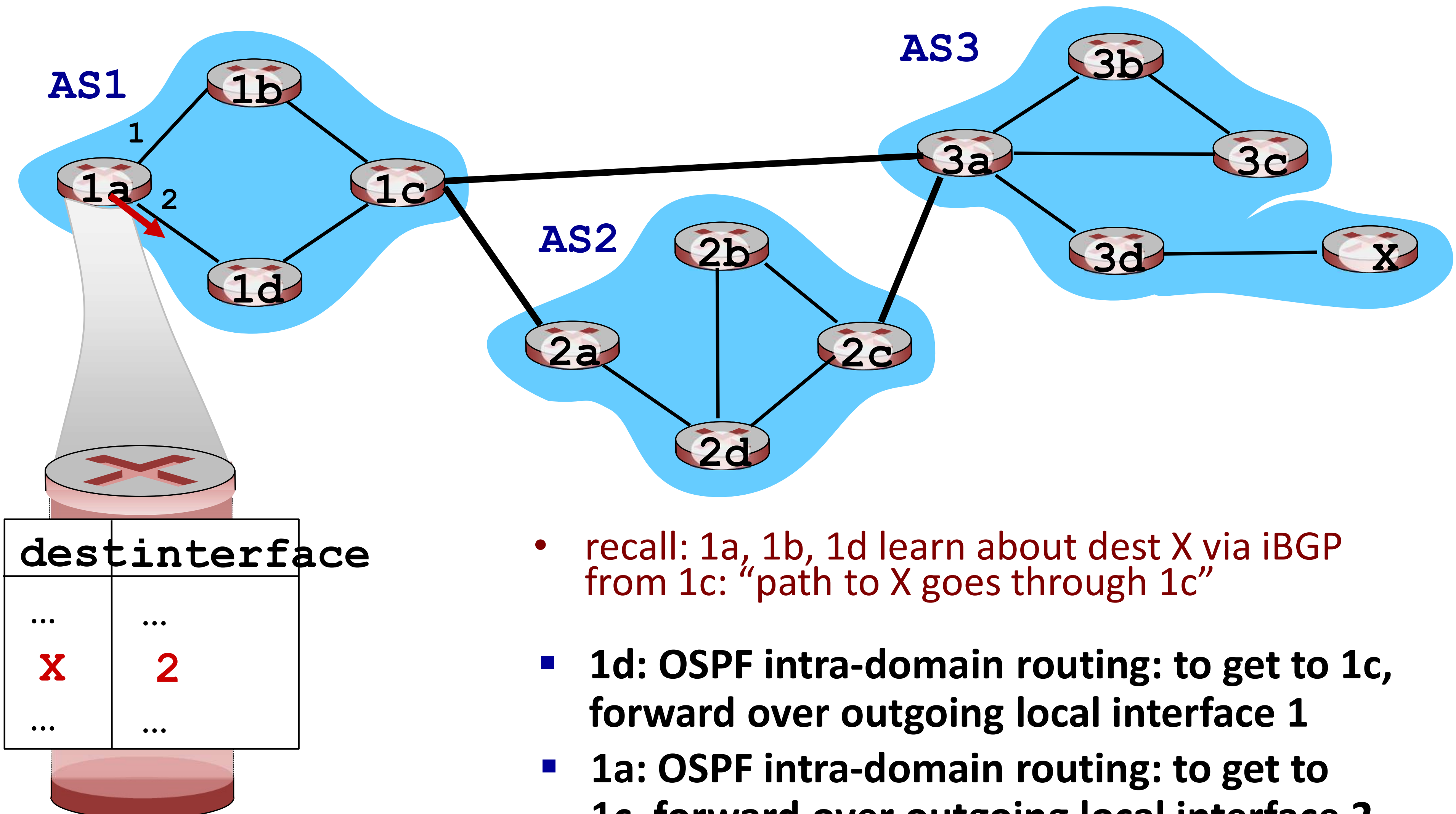


dest	interface
…	…
X	1
…	…

- recall: 1a, 1b, 1d learn about dest X via iBGP from 1c: "path to X goes through 1c"
- **1d: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 1**

BGP, OSPF, forwarding table entries

Q: how does router set forwarding table entry to distant



dest	interface
…	…
X	2
…	…

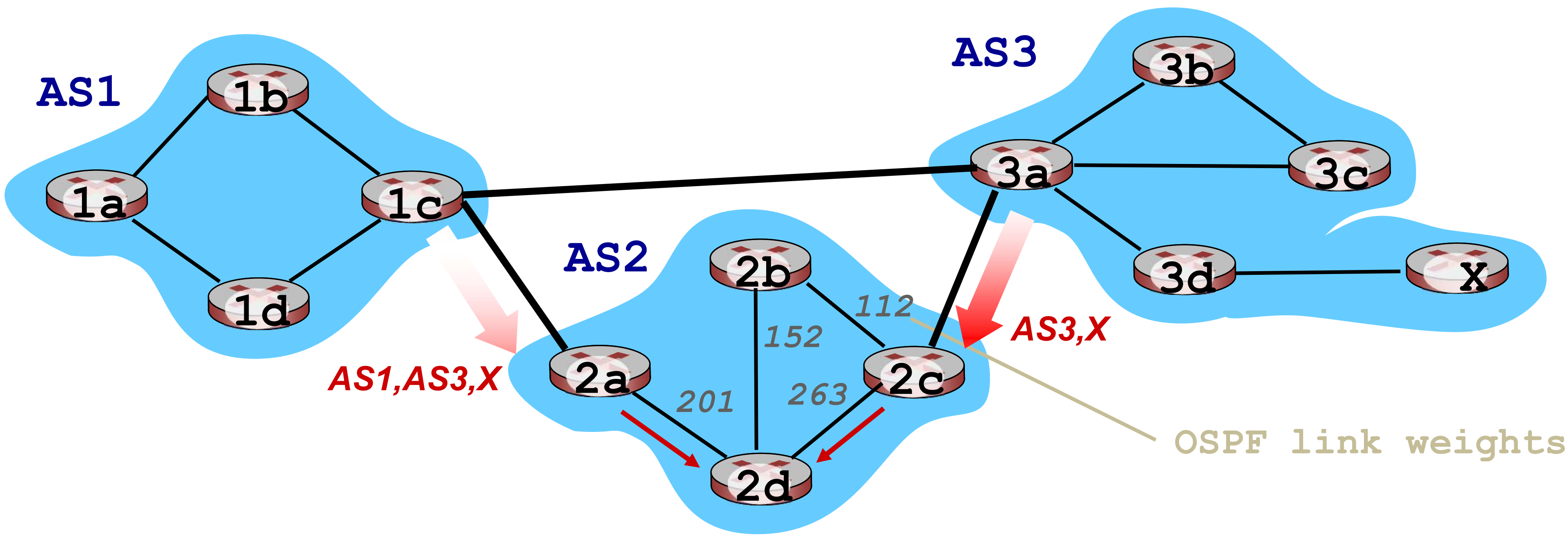
- recall: 1a, 1b, 1d learn about dest X via iBGP from 1c: "path to X goes through 1c"

- **1d: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 1**
- **1a: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 2**

BGP route selection

- router may learn about more than one route to destination AS, selects route based on:
  1. local preference value attribute: policy decision
  2. shortest AS-PATH
  3. closest NEXT-HOP router: hot potato routing
  4. additional criteria

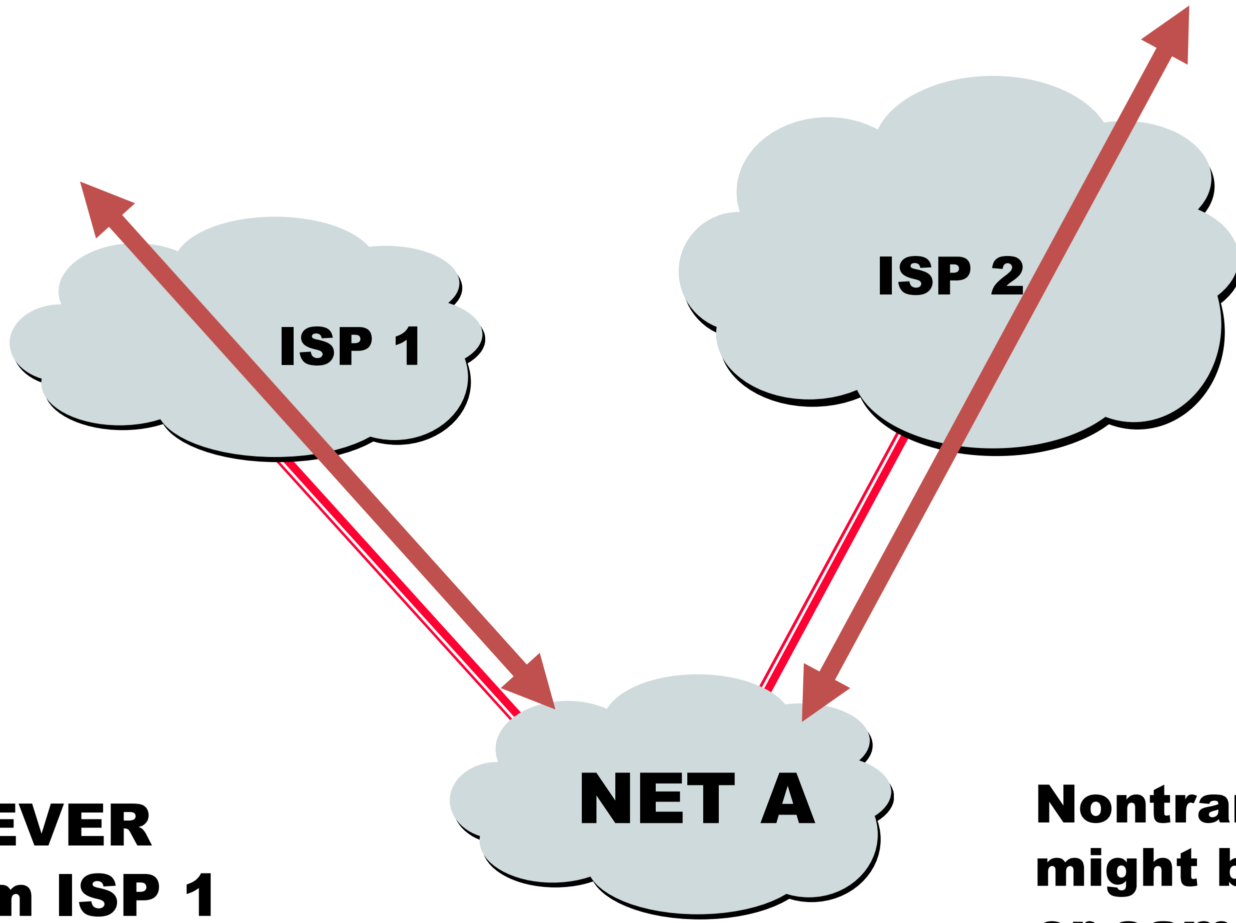
Hot Potato Routing



- 2d learns (via iBGP) it can route to X via 2a or 2c
- *hot potato routing:* choose local gateway that has least intra-domain cost (e.g., 2d chooses 2a, even though more AS hops to *X*): don't worry about inter-domain cost!

A dive into the BGP policies

Nontransit vs. Transit ASes



Internet Service providers (often) have transit networks

Traffic NEVER flows from ISP 1 through NET A to ISP 2 (At least not intentionally!)

Nontransit AS might be a corporate or campus network. Could be a "content provider"