Intra-Domain Routing: OSPF

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CS 3103: Compute Networks and Protocols

Recall: Limitation of RIP

- RIP uses an "infinity" of 16
  - cannot handle network with more than 15 hops
- no concept of network delays and link costs
  - routing decisions are based on hop counts
  - path with lowest hop count to the destination is always preferred even if the longer path has a better aggregate link bandwidth and less delays

Link State Routing

- distance vector approach: router knows only cost to each destination
  - hides information, causing problems
- if each node has the entire topology, it can use Dijkstra's algorithm to build forwarding table
- link state approach: router knows entire network topology
  - computes shortest path by itself
  - independent computation of routes

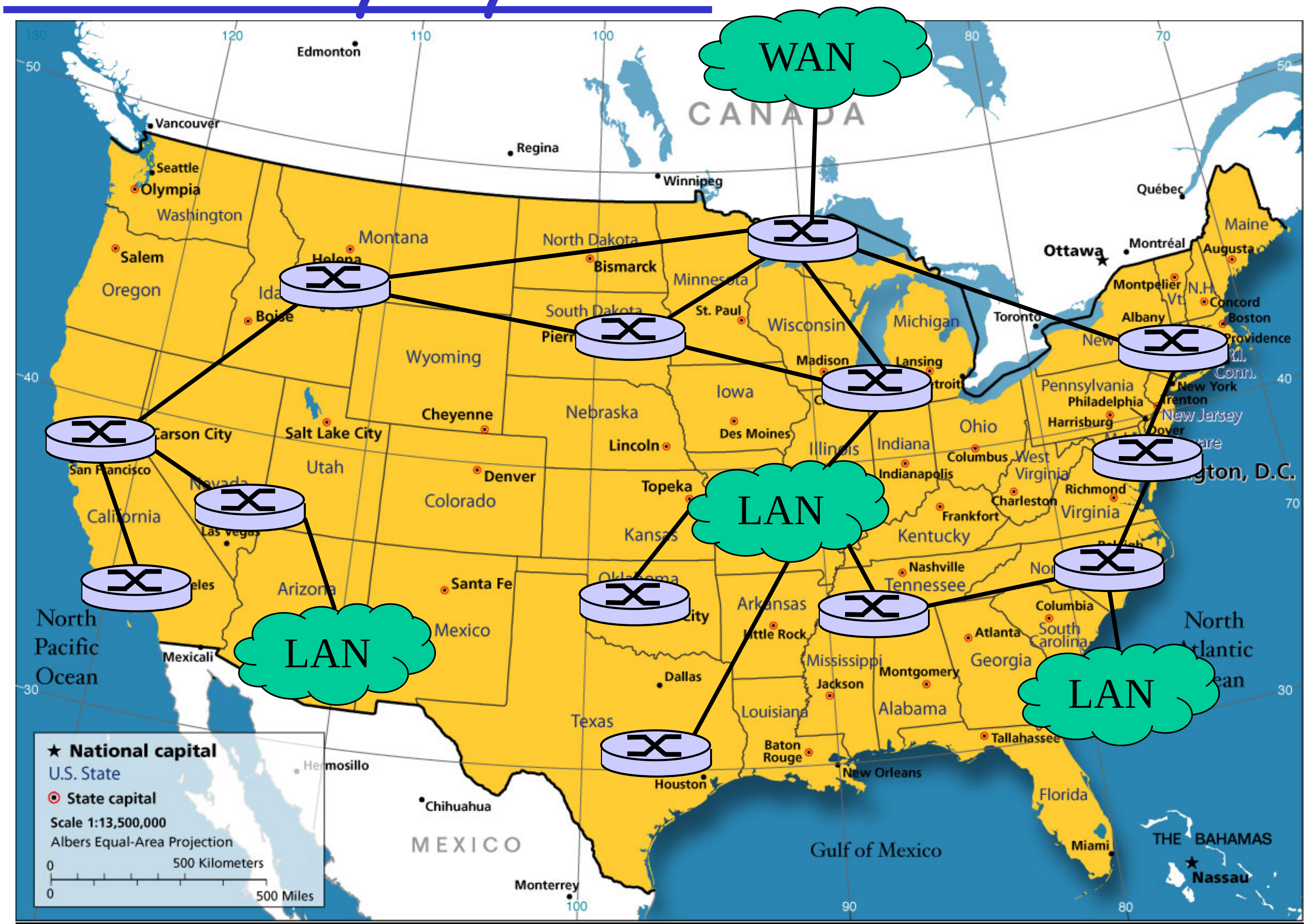
OSPF (Open Shortest Path First)

- “open”: publicly available
- uses link state algorithm
  - Link State Advertisement (LSA) dissemination
  - topology map at each node
  - route computation using Dijkstra’s algorithm
- each LSA carries link state info of one entry
- LSAs flooded throughout the *entire* AS
  - carried in OSPF messages directly over IP (rather than TCP or UDP)
- complicated protocol, RFC 2328 (244 pages)

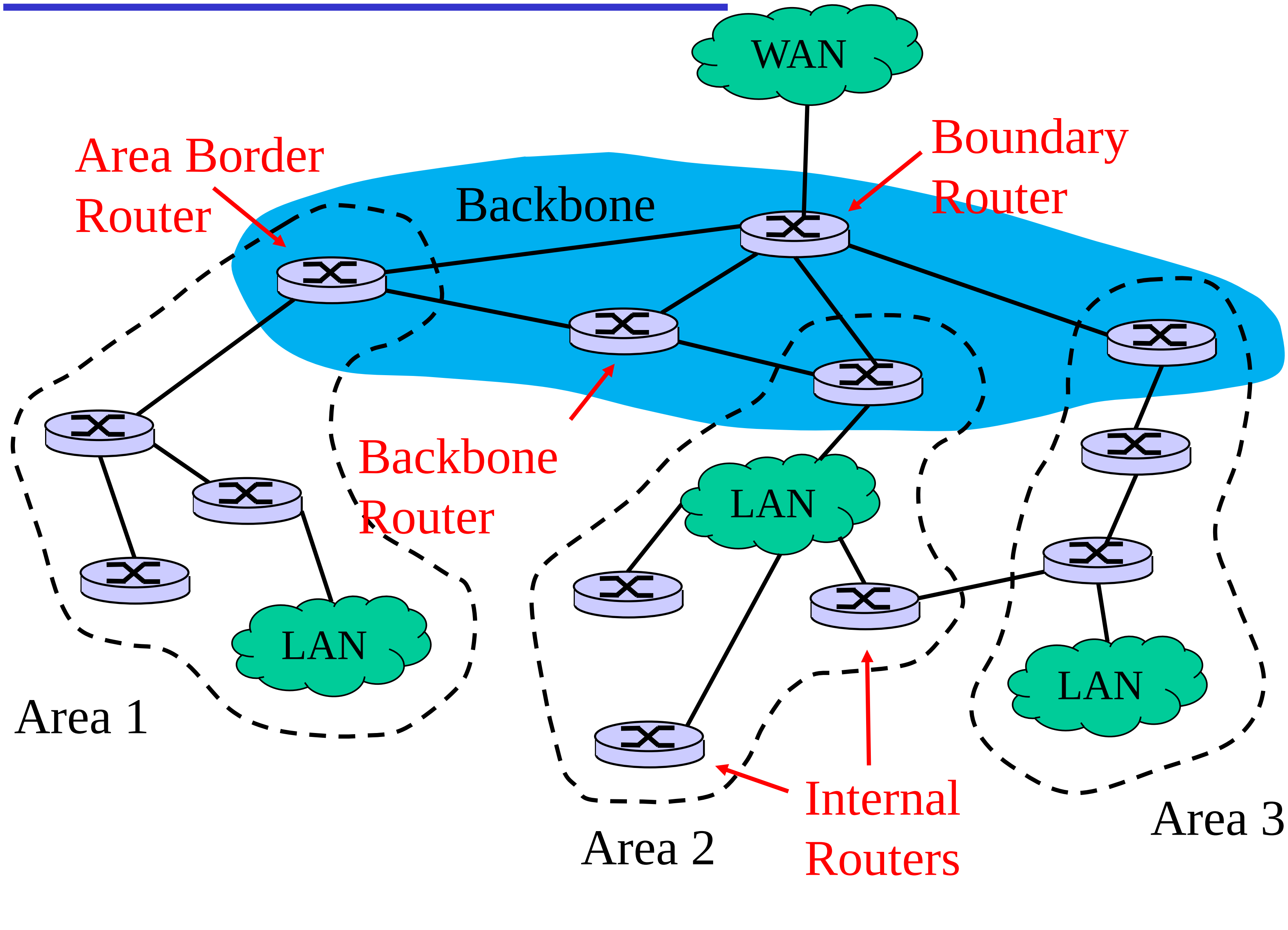
Advanced features of OSPF

- hierarchical OSPF: divide an AS into areas
  - an area is a collection of networks, host and routers contained within an AS
  - all networks inside an area must be connected
- variety of link cost
  - OSPF protocol assign a metric to each route
  - the metric can be based on a type of service
    - E.g. delay, throughput, etc.
- multiple same-cost paths allowed
- security and multicast support

Autonomy System



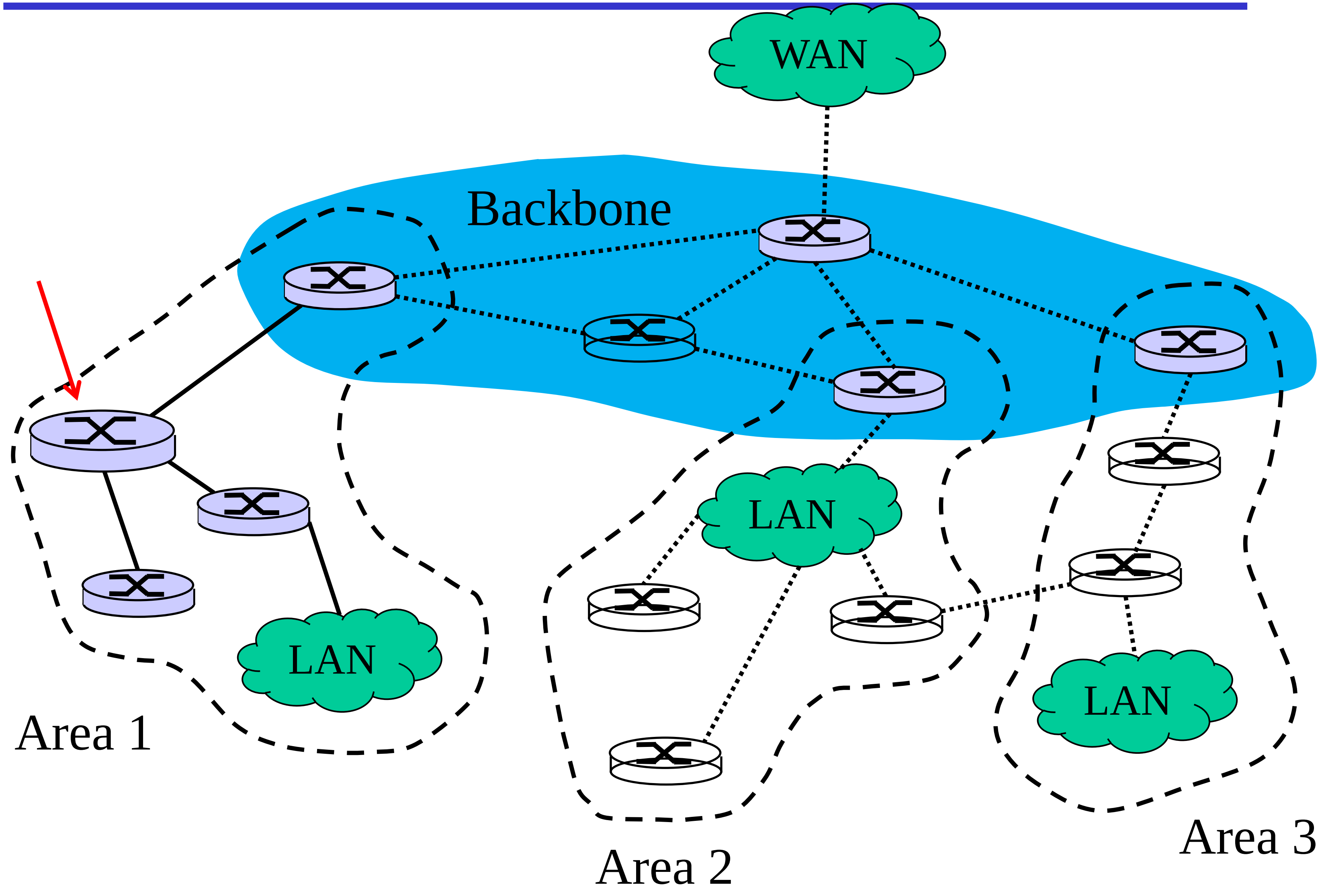
Hierarchical OSPF



Hierarchical OSPF

- *two-level hierarchy:* local areas and backbone
  - local LSAs flooded only in its own area
  - internal routers only know the shortest path to the area border router for subnets in other areas
- *area border routers (ABR):*
  - "summarize" distances to subnets in own area, advertise to other ABRs
- *backbone routers:*
  - run OSPF routing limited to backbone
- *boundary routers:*
  - connect to other AS's

From an Internal Router's View



From an Internal Router's View

- *internal routers* within an OSPF area
  - maintain the same topology, e.g., an identical link-state database;
  - have no knowledge of network topology outside the area;
  - know only of routers to destinations provided by Area Border Routers (ABRs) and AS Boundary Routers (ASBRs).

OSPF Area Characteristics

- stops LSA flooding at the area boundary
- limits the amount of link-state info exchanged, size of routing table, and the amount of processing carried out by routers
- localizes impact of a topology change locally (within an area)
- requires the two-level hierarchical design

OSPF Common Header

- All OSPF packets have the same 24-byte common header:

<table>
<tr><td>Version</td><td>Type</td><td colspan="2">Message length</td></tr>
<tr><td colspan="4">Router Identification</td></tr>
<tr><td colspan="4">Area Identification</td></tr>
<tr><td colspan="2">Checksum</td><td colspan="2">Authentication type</td></tr>
<tr><td colspan="4">Authentication
(64 bits)</td></tr>
</table>

- Router ID could be any IP address of the router; however, when it changes, OSPF needs to restart.

OSPF Packets

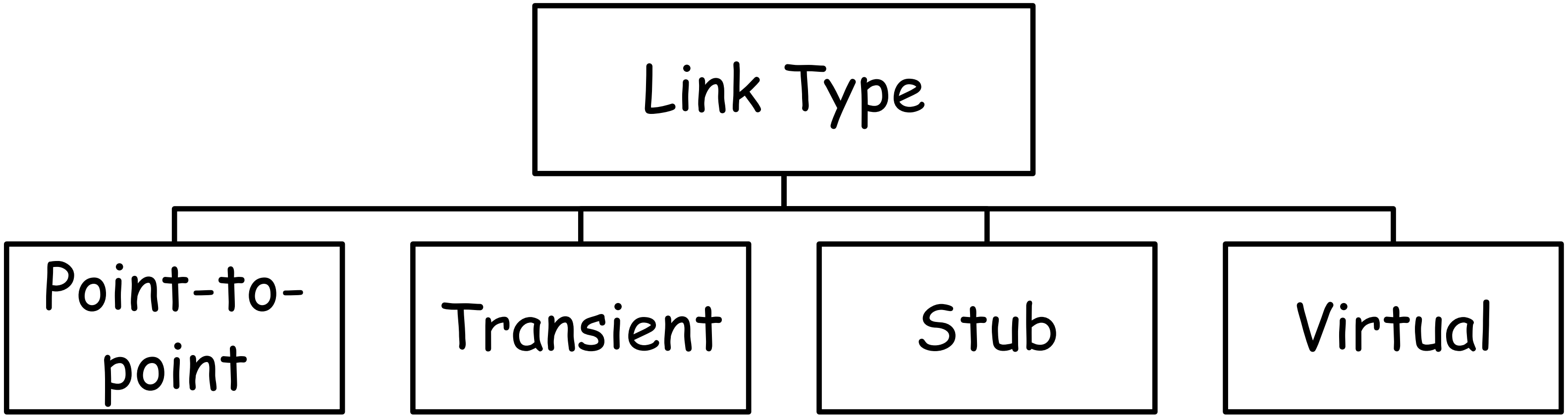
Version	Type	Message length
Router Identification		
Area Identification		
Checksum		Authentication type
Authentication		

- OSPF's five types of packets & functions:

Hello (Type 1)	Discover/maintain neighbors
Database description (Type 2)	Summarize database contents
Link state request (Type 3)	Database download
Link state update (Type 4)	Database update
Link state acknowledgment (Type 5)	Flooding acknowledgement

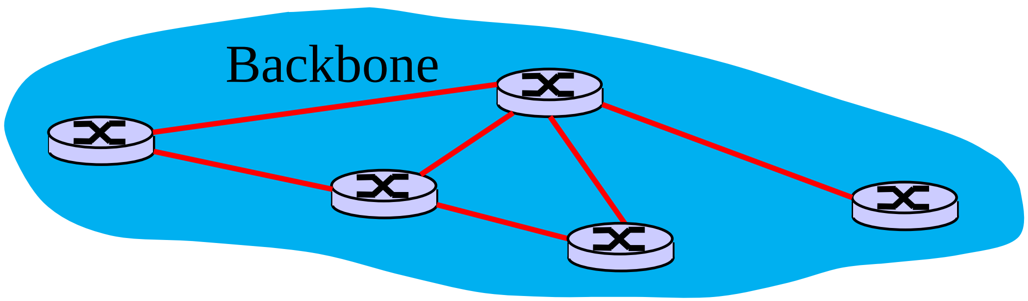
Map real networks to Dijkstra

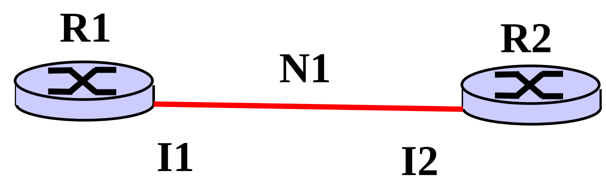
- in Dijkstra's algorithm, links are simple abstractions of router connections
- in OSPF, different types of links are used to capture various real network scenarios
- link info forms the link state database



Point-to-Point Link

- Connects routers directly
  - i.e. no other host or router in between





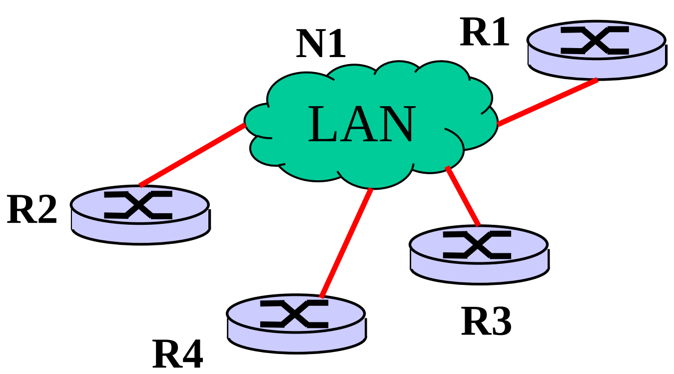
	From			
To		R1	R2	N1
	R1			X
	R2			X
	N1	X	X	

or

	From		
To		R1	R2
	R1		X
	R2	X	
	I1		X
	I2	X	

Transient Link

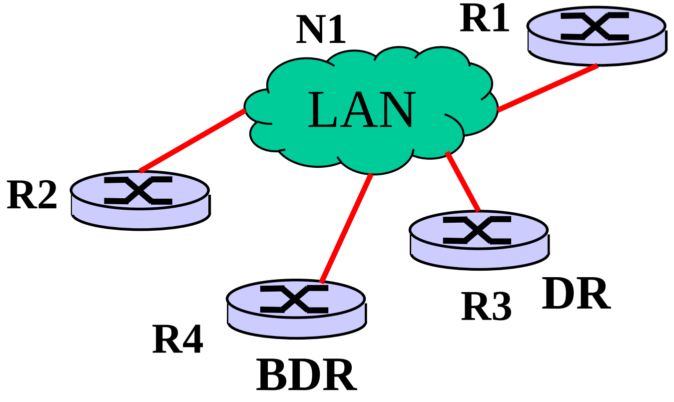
- network with several routers attached to it
- packets enter and leave through any router
  - E.g., different LAN technologies
- link info to subnet N1



	From					
To		R1	R2	R3	R4	N1
	R1					X
	R2					X
	R3					X
	R4					X
	N1	X	X	X	X	

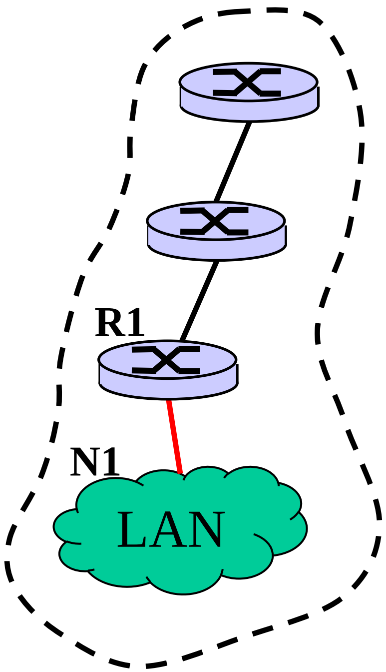
Designated Router (DR)

- but subnet cannot speak for itself
- for a broadcast domain with N routers, its LSA message complexity could be $O(N^2)$
- solution: designated router (DR) and backup (BDR) are elected (via Hello protocol) to represent the subnet and broadcast subnet info



Stub Link

- network connected to only one router
- packets enter and leave through the same router
- R1 becomes the DR for N1

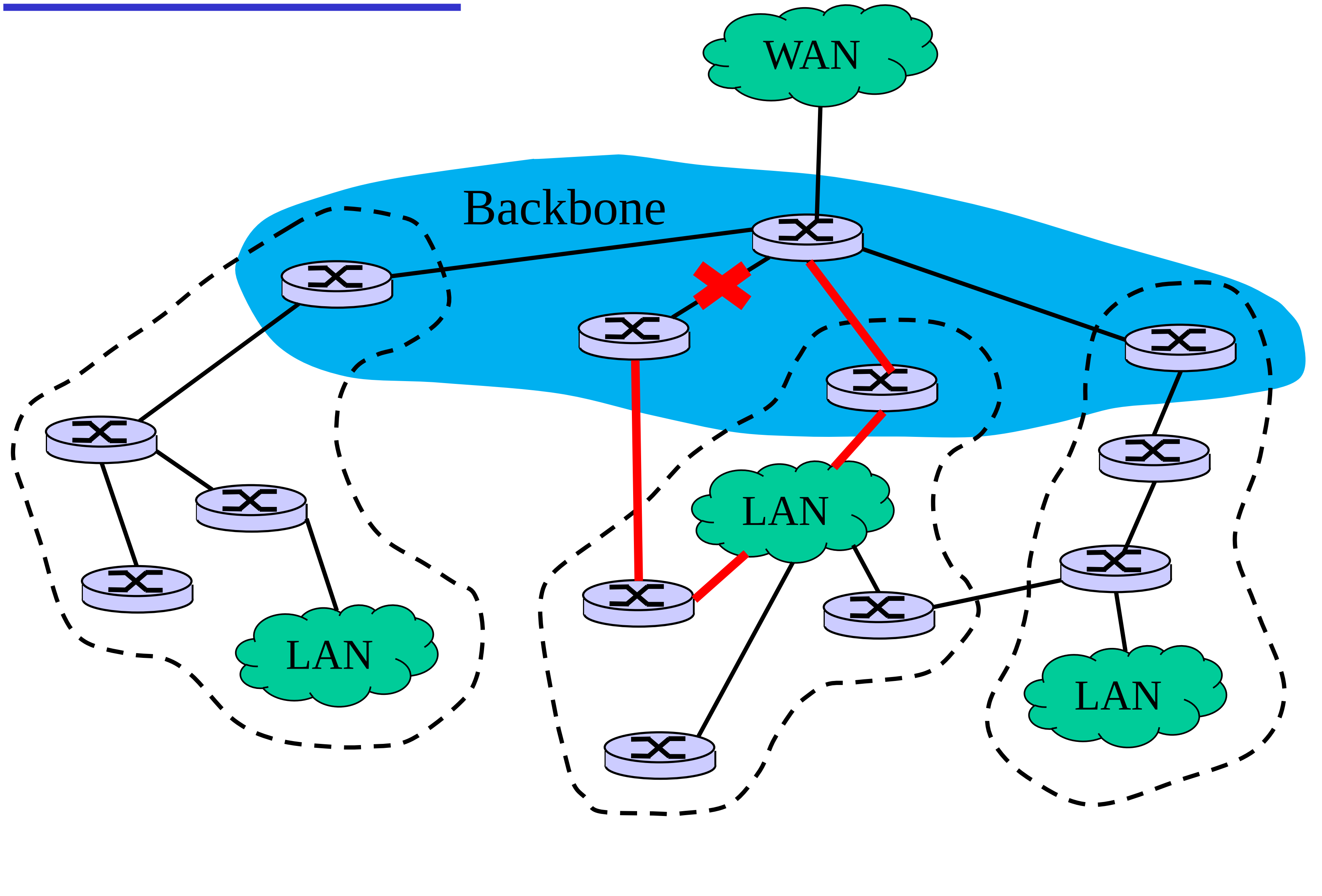


	From		
To		R1	N1
	R1		X
	N1	X	

Virtual Link

- backbone routers must be fully connected
- connectivity can be established/maintained through the configuration of virtual links
- e.g., when the link between two routers is broken, the administration may create a virtual link using a longer path (higher cost)

Virtual Link



OSPF Packets

Version	Type	Message length
Router Identification		
Area Identification		
Checksum	Authentication type	
Authentication		

- OSPF's five types of packets & functions:

Packet		Function
Hello (Type 1)	⟷	Discover/maintain neighbors
Database description (Type 2)	⟷	Summarize database contents
Link state request (Type 3)	⟷	Database download
Link state update (Type 4)	⟷	Database update
Link state acknowledgment (Type 5)	⟷	Flooding acknowledgement

Hello Packet

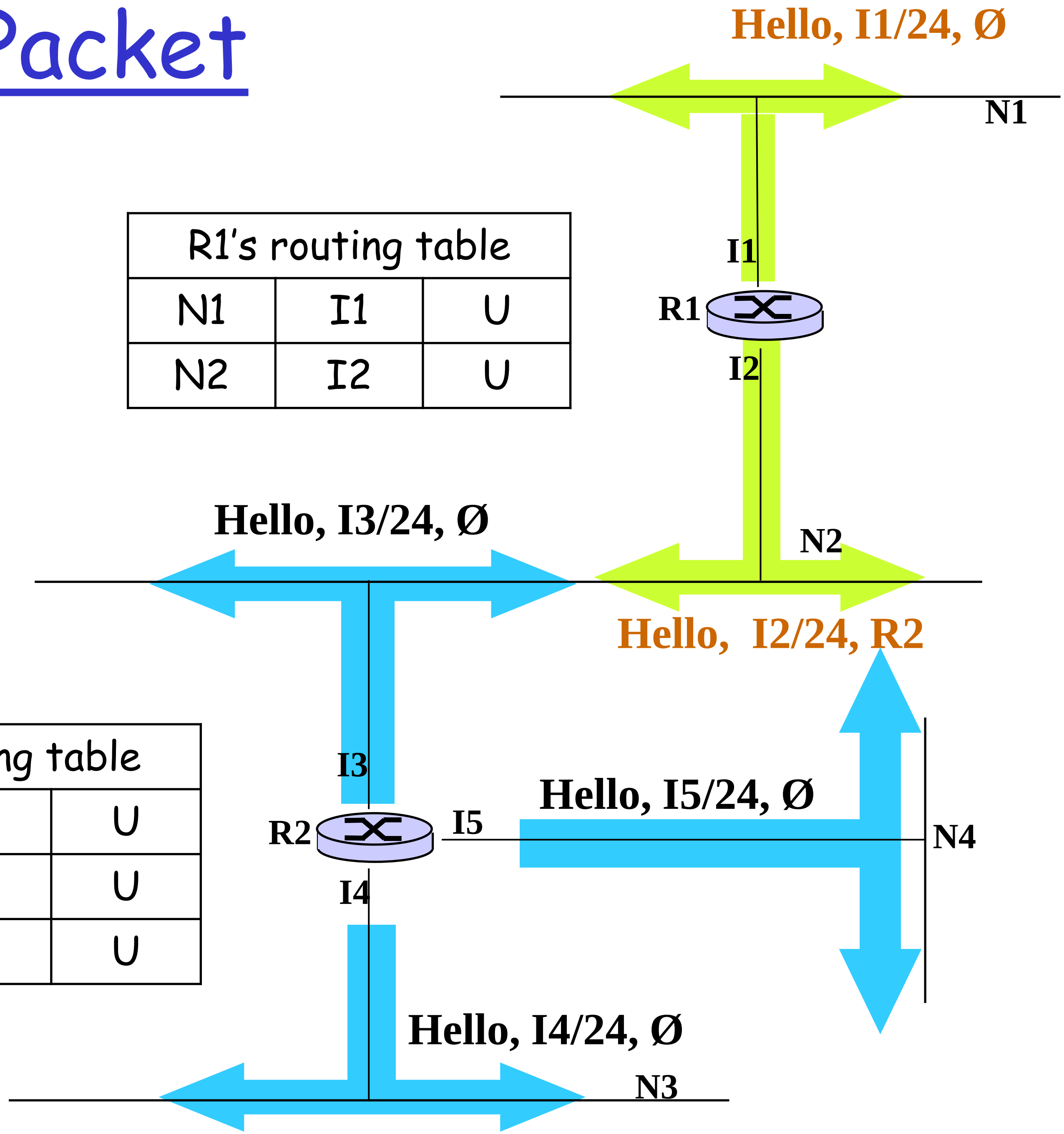
	OSPF common header 24 bytes Type: 1		
	Network mask		
	Hello interval	Options	Priority
	Router dead interval		
	Designated router IP address		
	Backup designated router IP address		
Repeated	Neighbor IP address		

- Hello interval: # of seconds between Hello packets
- Router dead interval: # of seconds before declaring a silent router down (typically 40 secs)
- Priority: used to elect DR and BDR

Hello Packet

- sent typically every 10 seconds on all router interfaces using a multicast address 224.0.0.5
  - multicast address 224.0.0.6 is used for Designated Router (DR) and Backup Designated Router (BDR) for LSAs (will discuss later)
- used to establish and maintain neighbor relationships, e.g., test reachability
- on broadcast subnets, also used to elect the DR and BDR

Hello Packet



R1's routing table		
N1	I1	U
N2	I2	U

R2's routing table		
N2	I3	U
N3	I4	U
N4	I5	U

OSPF Packets

Version	Type	Message length
Router Identification		
Area Identification		
Checksum	Authentication type	
Authentication		

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Hello (Type 1)	Discover/maintain neighbors
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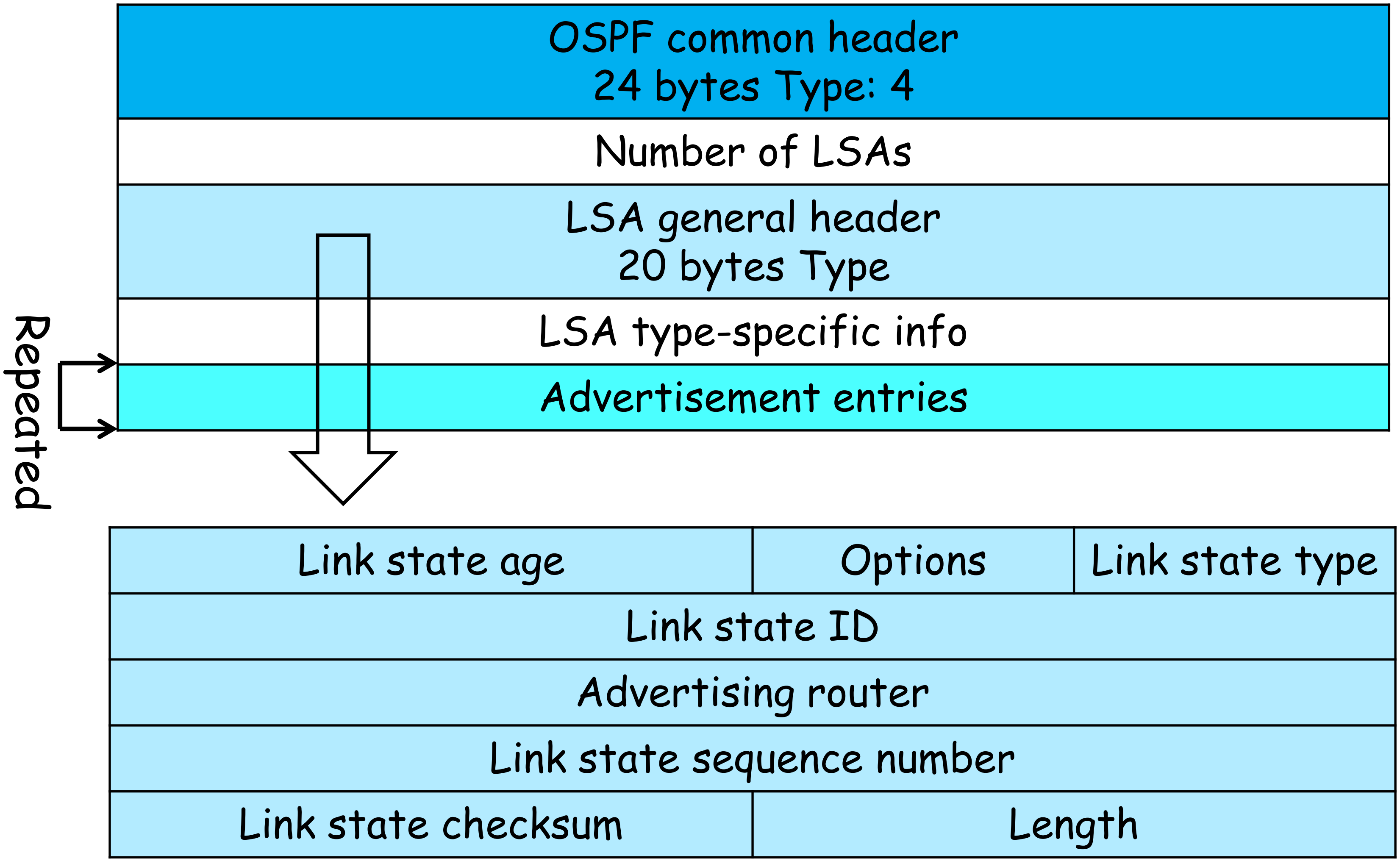
Exchange of LSA

- who: each entity in an area (e.g., a router, a subnet, ABR) distributes local info in LSAs
- when: sent only under the circumstances:
  - a router discovers a new neighbor
  - a link to a neighbor goes down
  - cost of a link changes
  - basic refresh packets are sent every 30 mins
- how: distributed by reliable flooding
  - sequenced, time-stamped, and explicitly ACKed

LSA Packet General Format



LSA Packet General Format

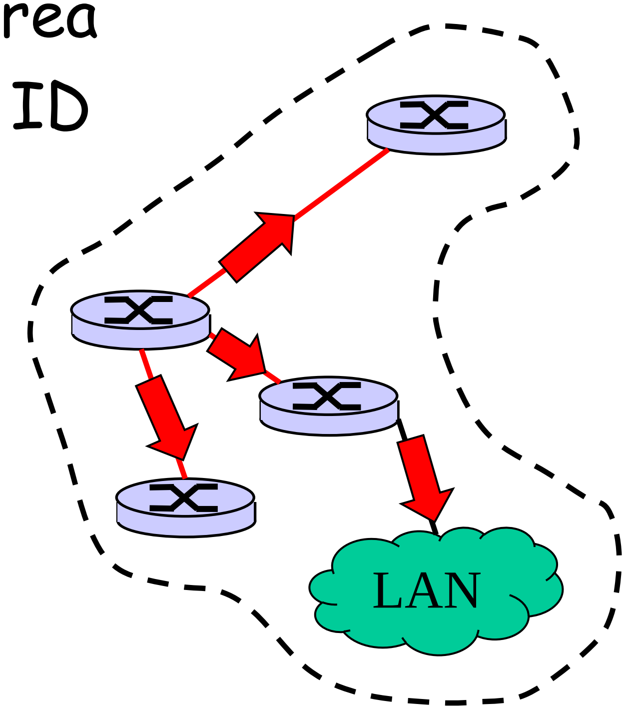
- LS age: # of seconds since the LSA was originated
- Advertising router: Router ID of the router that originates the LSA
- LS seq #: used to detect old or duplicate LSAs
- LS ID: describe LSA based on the five LS types

Link state age	Options	Link state type
Link state ID		
Advertising router		
Link state sequence number		
Link state checksum	Length	

Router Link LSA (LS Type 1)

- originated by: all routers
- flooded throughout: a single area only
  - LSA: describes the collected states of the router's interfaces to an area
  - LS ID: originator's Router ID

Routing information
Direction of the LSA



Router Link LSA Packet Format

<table>
<tr><td colspan="6">OSPF common header
24 bytes Type: 4</td></tr>
<tr><td colspan="6">Number of LSAs</td></tr>
<tr><td colspan="6">LSA general header
20 bytes LS Type: 1</td></tr>
<tr><td>0</td><td>V</td><td>E</td><td>B</td><td>0</td><td>Number of router links</td></tr>
<tr><td colspan="6">Link ID</td></tr>
<tr><td colspan="6">Link Data</td></tr>
<tr><td colspan="4">Link type</td><td># of TOS</td><td>Metric for TOS 0</td></tr>
<tr><td colspan="4">TOS</td><td>Reserved</td><td>Metric</td></tr>
</table>

Repeated

Repeated

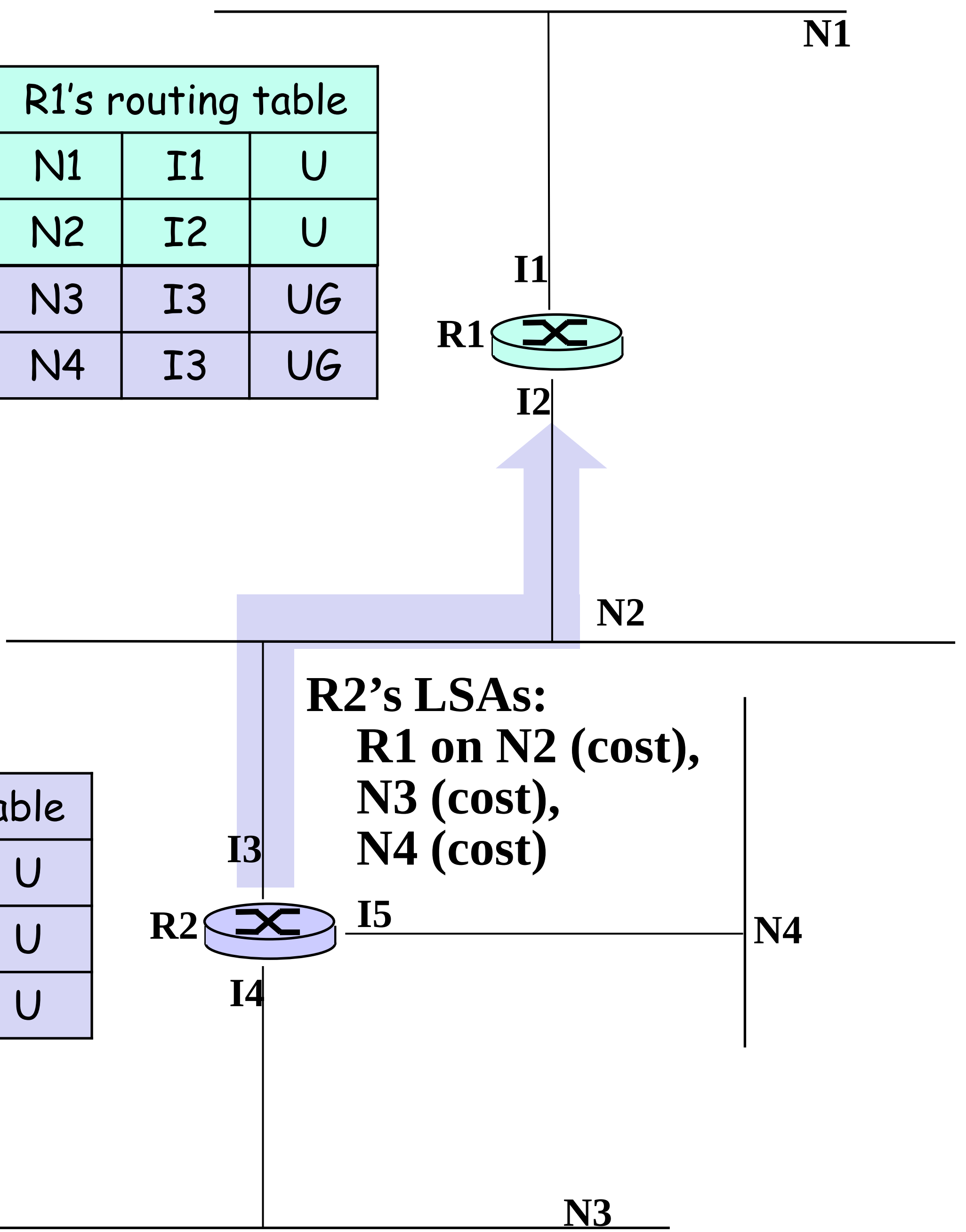
Link type		Link ID
1	Point-to-point link	Neighbor Router ID
2	Link to transit network	Interface address of DR
3	Link to stub network	IP network number
4	Virtual link	Neighbor Router ID

R1's LSA database
R1's LSAs
R2's LSAs

R1's routing table		
N1	I1	U
N2	I2	U
N3	I3	UG
N4	I3	UG

R2's LSA database
R2's LSAs

R2's routing table		
N2	I3	U
N3	I4	U
N4	I5	U



R1's LSA database
R1's LSAs
R2's LSAs

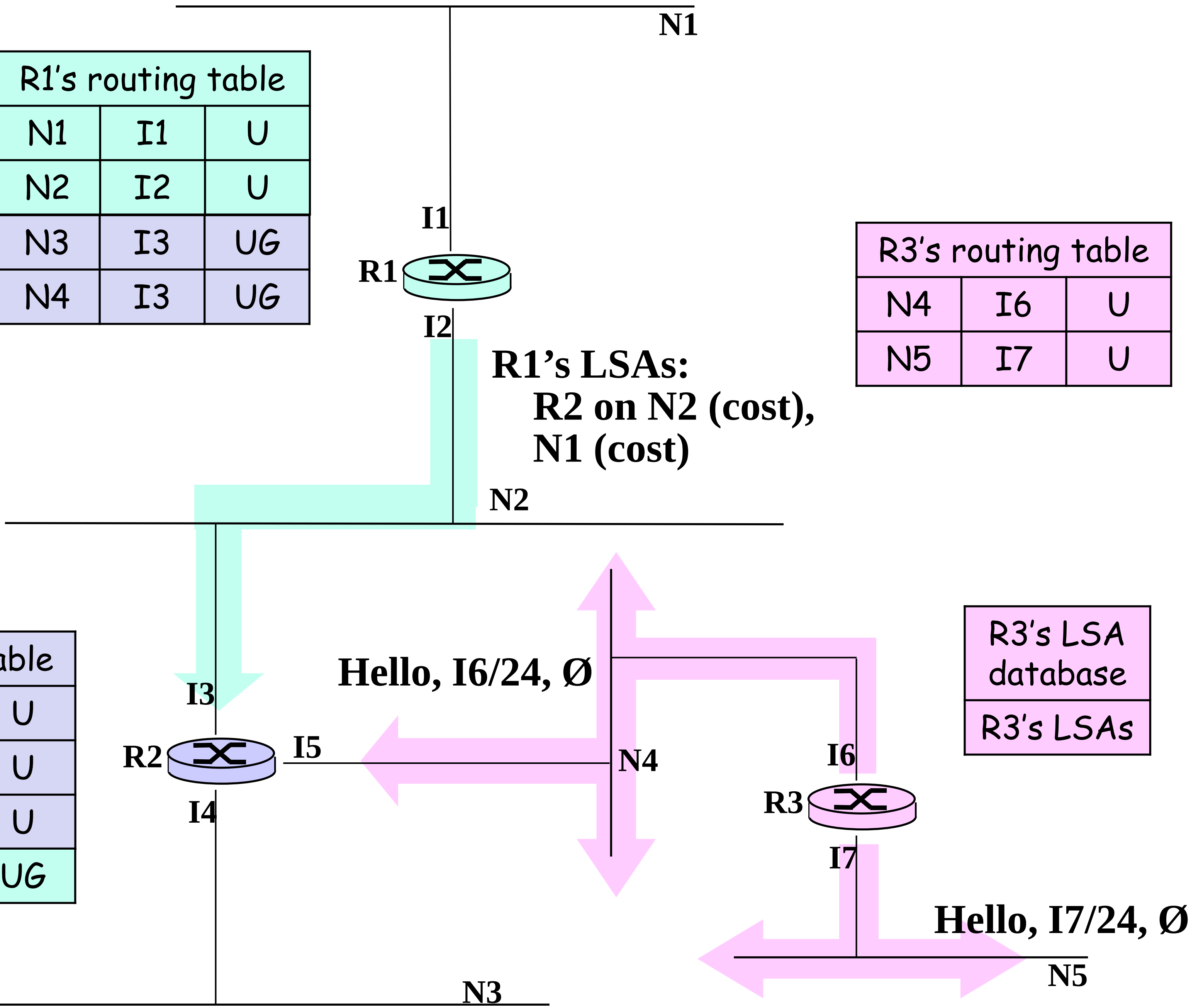
R1's routing table		
N1	I1	U
N2	I2	U
N3	I3	UG
N4	I3	UG

R2's LSA database
R2's LSAs
R1's LSAs

R2's routing table		
N2	I3	U
N3	I4	U
N4	I5	U
N1	I2	UG

R3's routing table		
N4	I6	U
N5	I7	U

R3's LSA database
R3's LSAs

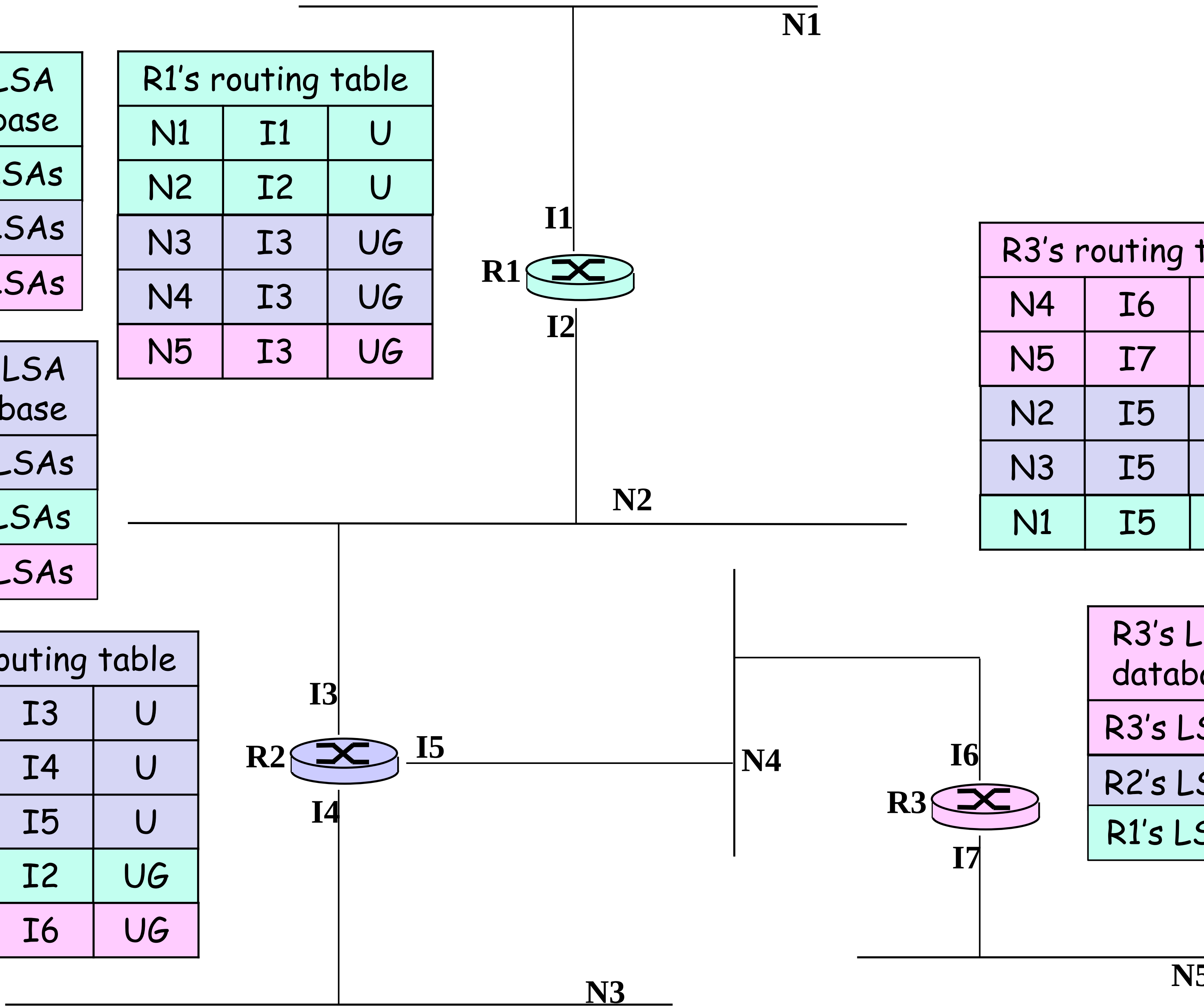


R1's LSA database
R1's LSAs
R2's LSAs
R3's LSAs

R1's routing table		
N1	I1	U
N2	I2	U
N3	I3	UG
N4	I3	UG
N5	I3	UG

R2's LSA database
R2's LSAs
R1's LSAs
R3's LSAs

R2's routing table		
N2	I3	U
N3	I4	U
N4	I5	U
N1	I2	UG
N5	I6	UG



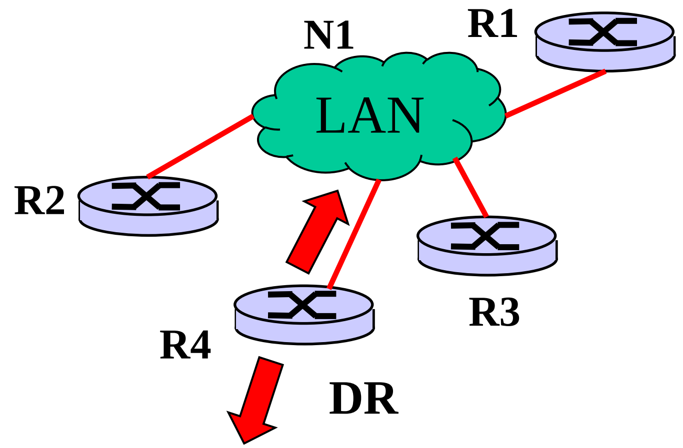
R3's routing table		
N4	I6	U
N5	I7	U
N2	I5	UG
N3	I5	UG
N1	I5	UG

R3's LSA database
R3's LSAs
R2's LSAs
R1's LSAs

Network Link LSA (LS Type 2)

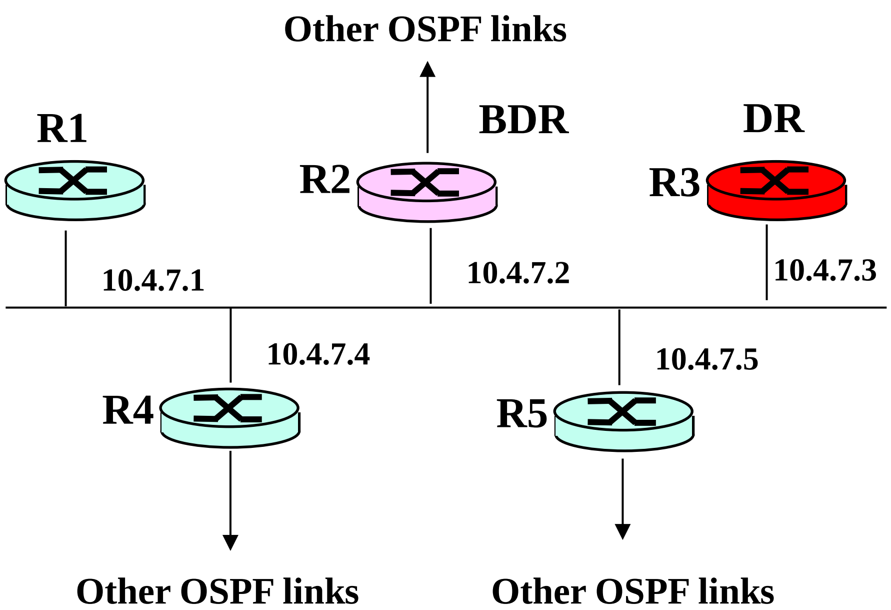
- originated by: designated router
- flooded throughout: a single area only
  - LSA: list of routers connected to the network
  - LS ID: IP address of the designated router

Routing information
Direction of the LSA

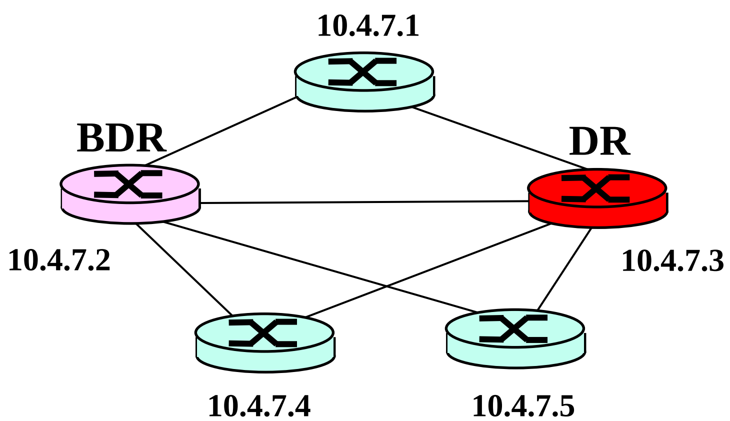


The use of designated routers

- physical topology:



- logical topology:

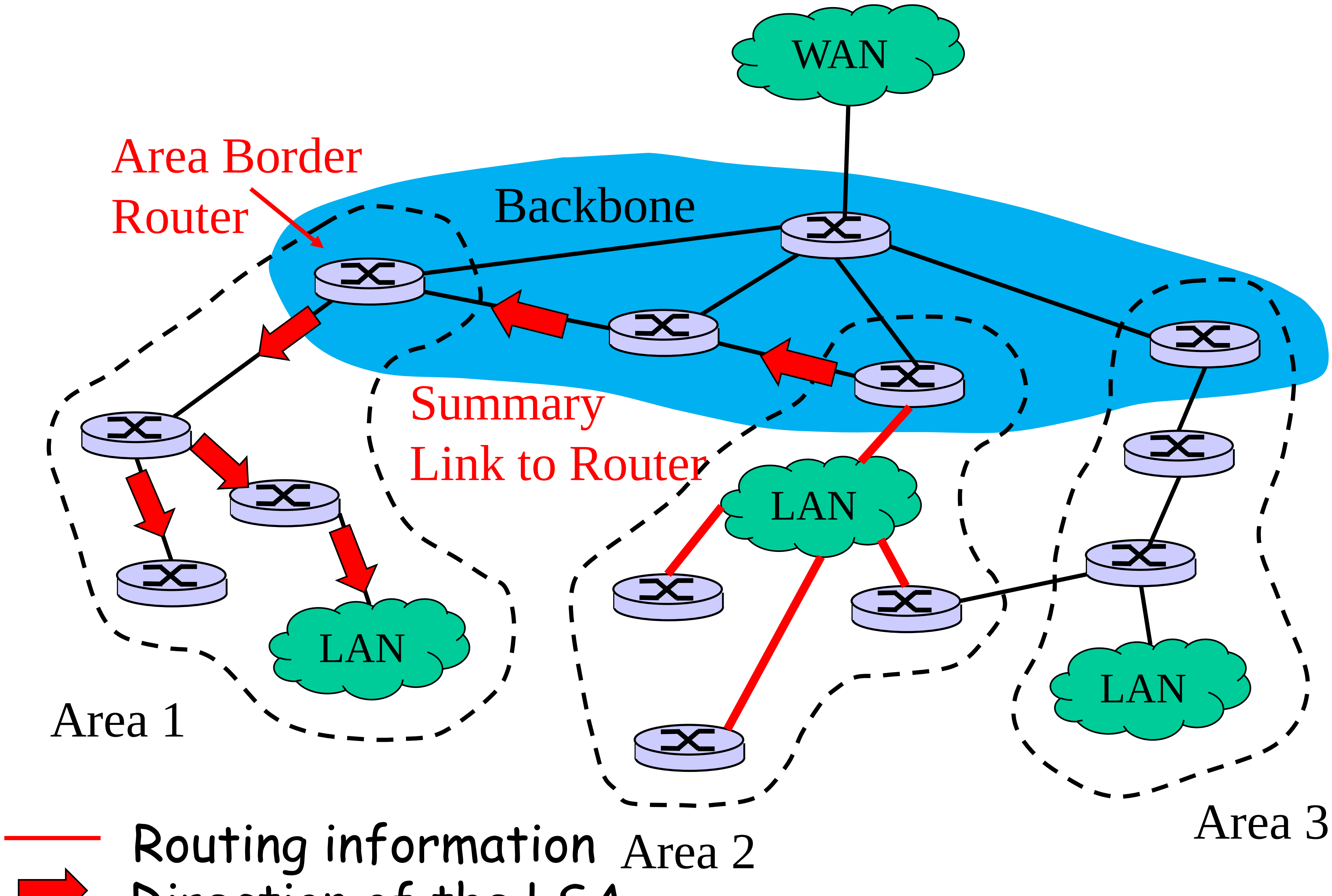


- If R5 receives a LSA from other OSPF links, it conveys the LSA to DR and BDR using 224.0.0.6
- DR & BDR send network link LSA using 224.0.0.5

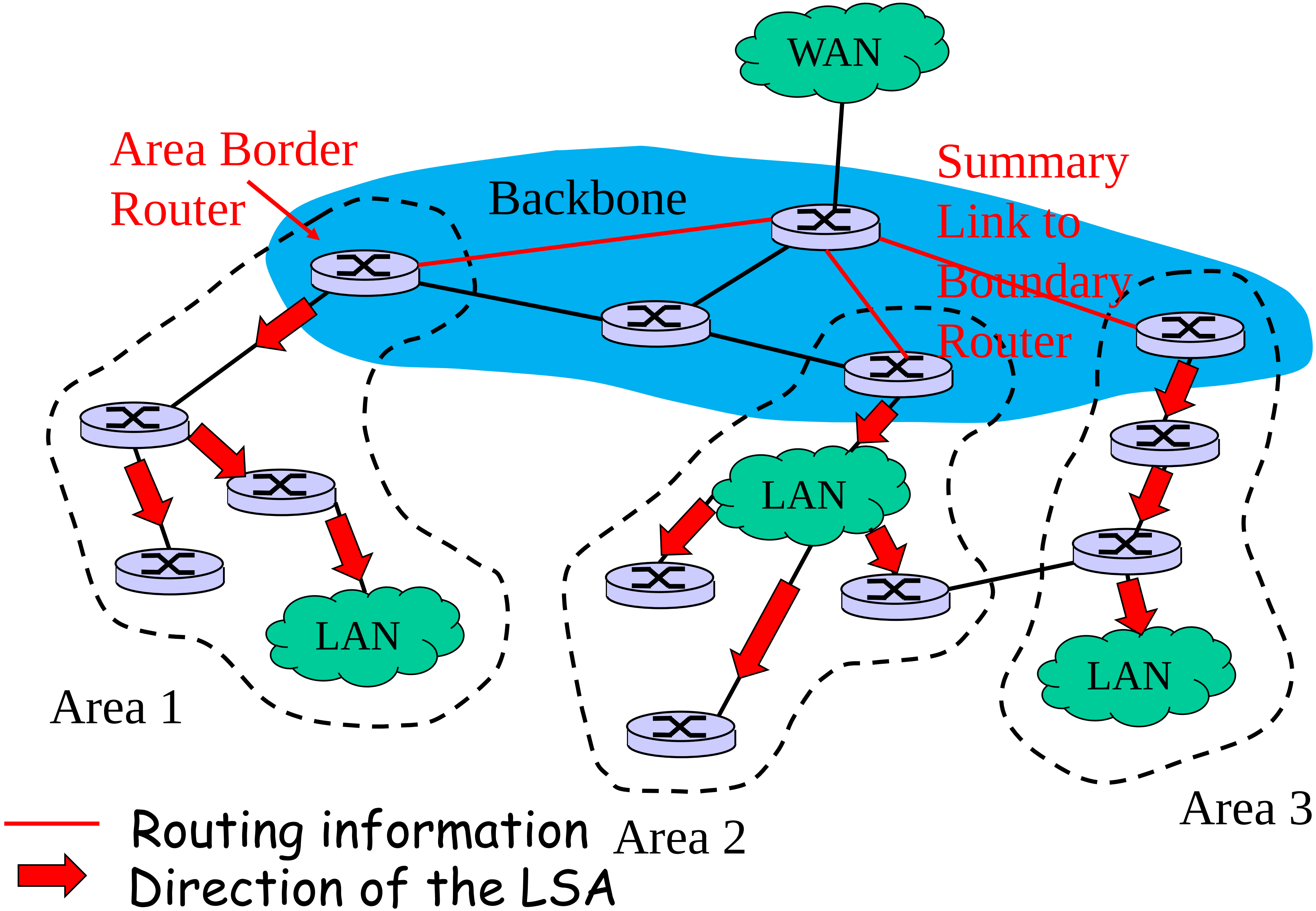
Summary Link LSA (LS Type 3 & 4)

- originated by: area border routers
- flooded throughout: LSA's associated area
- LSA: describes a route to a destination outside the area, yet still inside the AS
- type 3: routes to networks
  - LS ID: address of the subnet (in another area)
- type 4: routes to AS boundary routers
  - LS ID: IP address of the AS boundary router

Summary Link to Network LSA (LS Type 3)

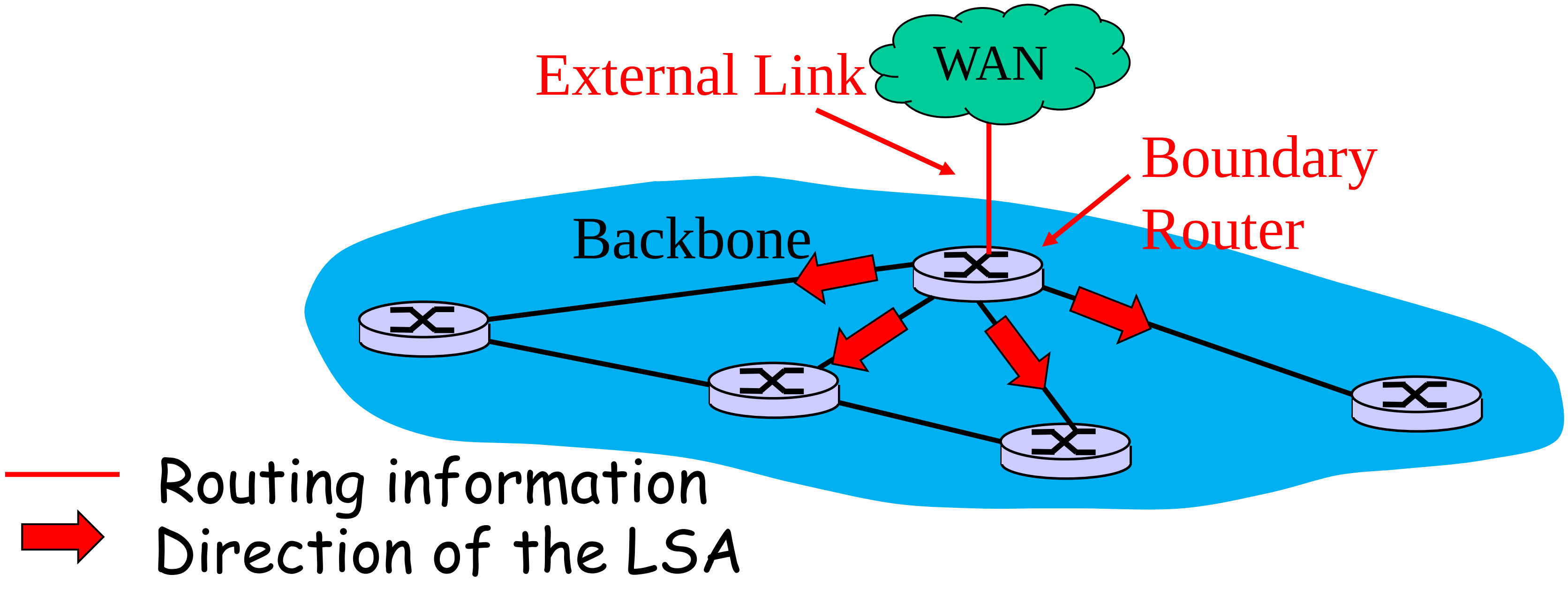


Summary Link to AS boundary router LSA (LS Type 4)



External Link LSA (LS Type 5)

- originated by: AS boundary router
- flooded throughout: the entire AS
  - LSA: the cost to each network outside the AS
  - LS ID: address of external network



OSPF Packets

Version	Type	Message length
Router Identification		
Area Identification		
Checksum		Authentication type
Authentication		

- OSPF's five types of packets & functions:

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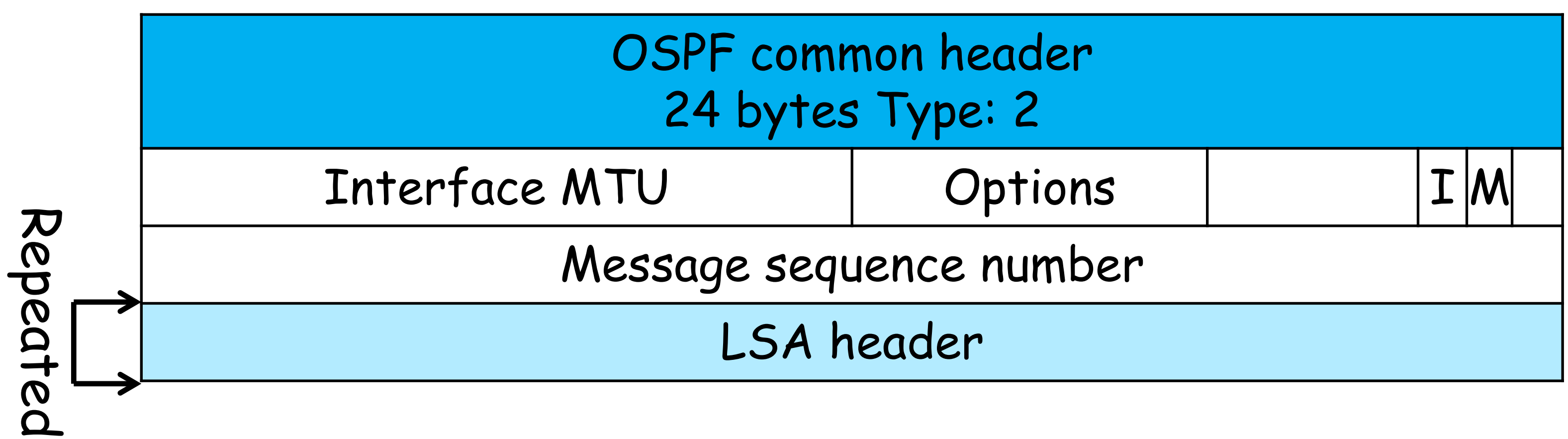
Link state acknowledgment (Type 5)	Flooding acknowledgement

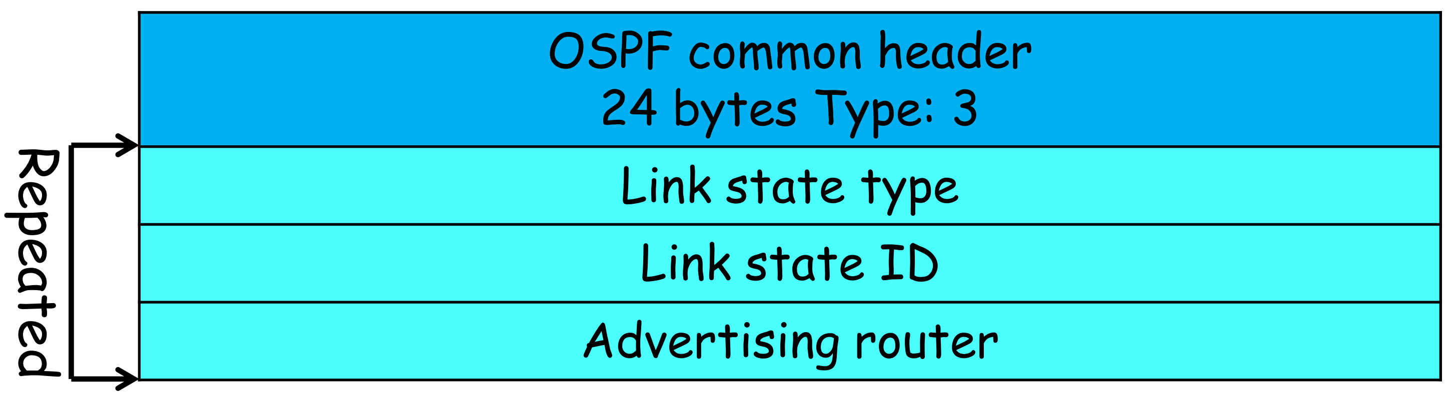
Database Description Message

- obtained at initialization from "adjacency"
  - neighbor router of point-to-point or virtual link
  - designated router of a subnet
- describe the link-state database
- multiple packets may be used



Link State Request Packet

- from database description packets, routers might find LSA missing or outdated
- used to get specific LSA information
- answered with a link state update packet



Link State Acknowledgment Packet

- OSPF uses IP directly, without reliability
- reliable flooding of LSAs is achieved by sequence numbers and LSA ACKs
- routers must acknowledge the receipt of every link state update packet

OSPF common header 24 bytes Type: 5
LSA general header 20 bytes

OSPF Packets

Version	Type	Message length
Router Identification		
Area Identification		
Checksum	Authentication type	
Authentication		

- OSPF's five types of packets & functions: