

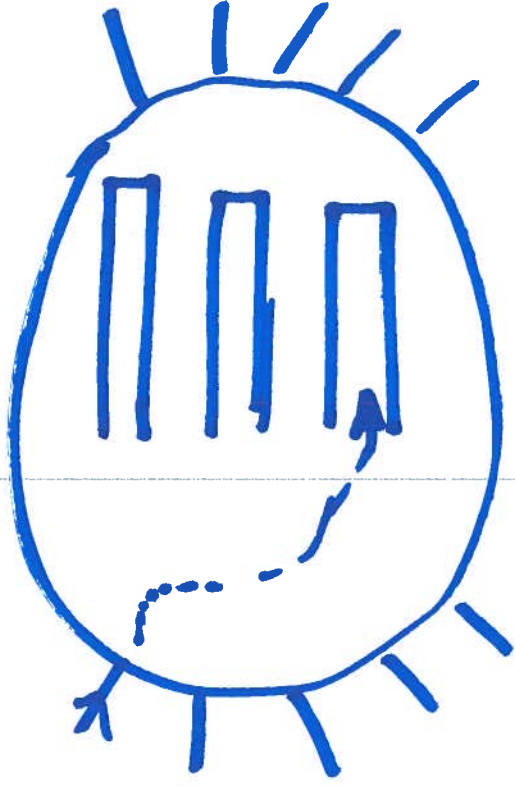
Network Layer

. Forwarding

local op.

. Routing :

Network-wide function



Datagram Networks

Routing Tables

Dest. addr.	Next hop

Table Size

$O(N)$

$N = \# \text{ of hosts}$

In-order delivery?

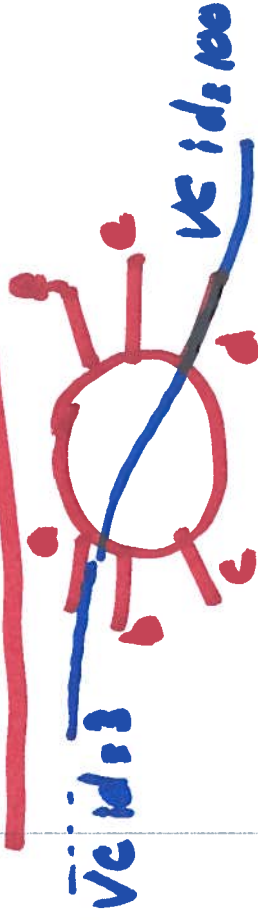
No guarantee

Route Selection (to

balance traffic among routes)?

Limited control

Virtual Circuit Nets



Incoming port #	Incoming VC #

Outgoing port #	Outgoing VC #

$O(K)$

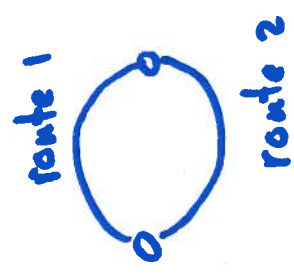
$K = \text{max \# of virtual circuits that can be accommodated}$

guaranteed

better control

Route Stability

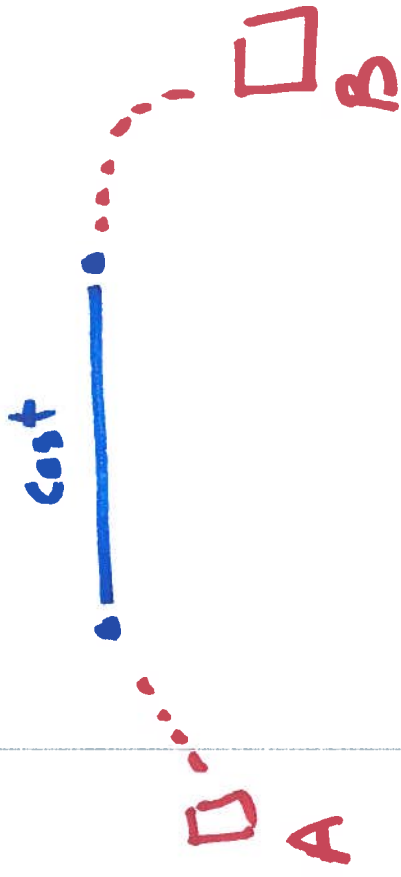
Oscillations
can occur



Better control

Link Cost Metrics

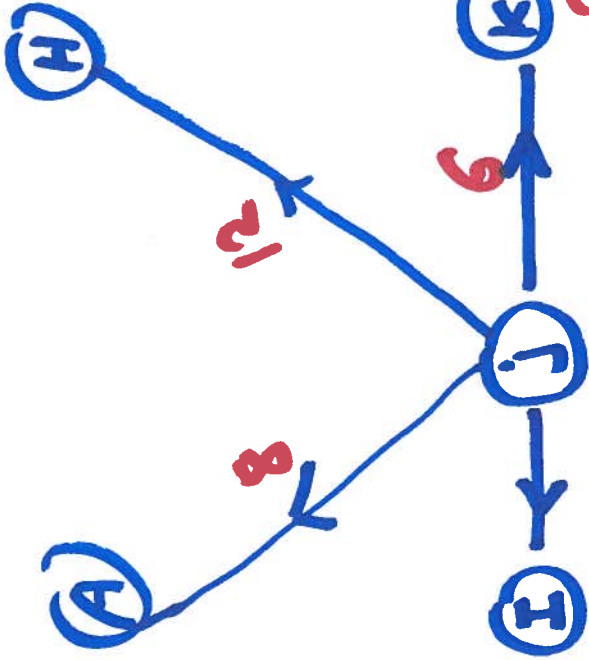
- Inverse of bandwidth
- delay
- Expense
- Error prob.



DV Routing

To	A
G	18
L	29

To	I
G	31
L	33



J I memoized
delay = 10

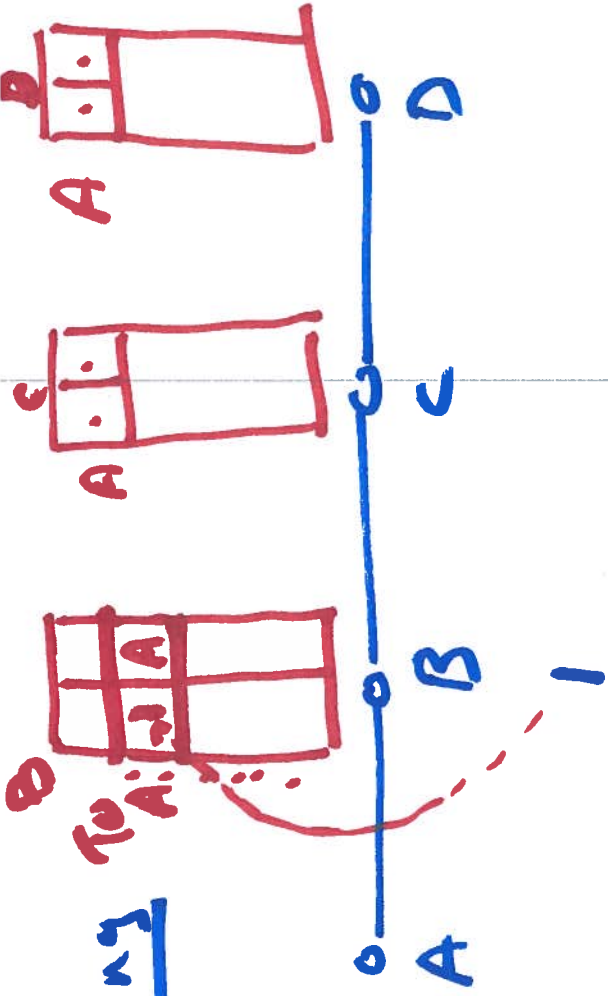
To	H
G	6
L	9

To	K
G	31
L	9

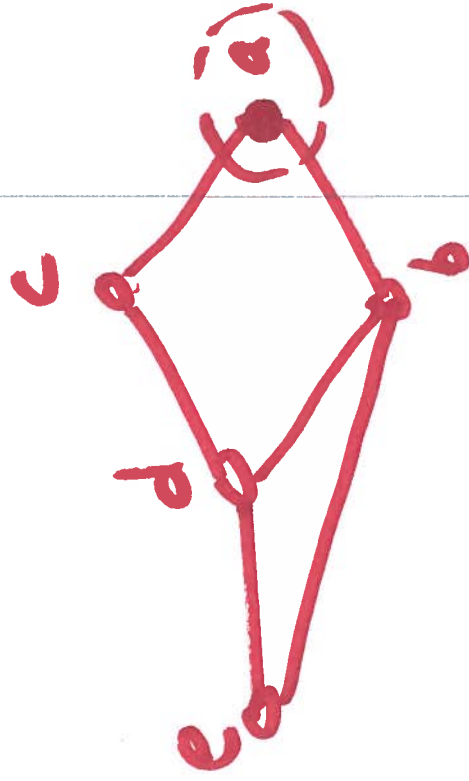
New estimated delay for J

To	J	next hop
G	18	H
L	15	K

DV Routing



Diameter



$$\text{dist}(a, c) = 1$$

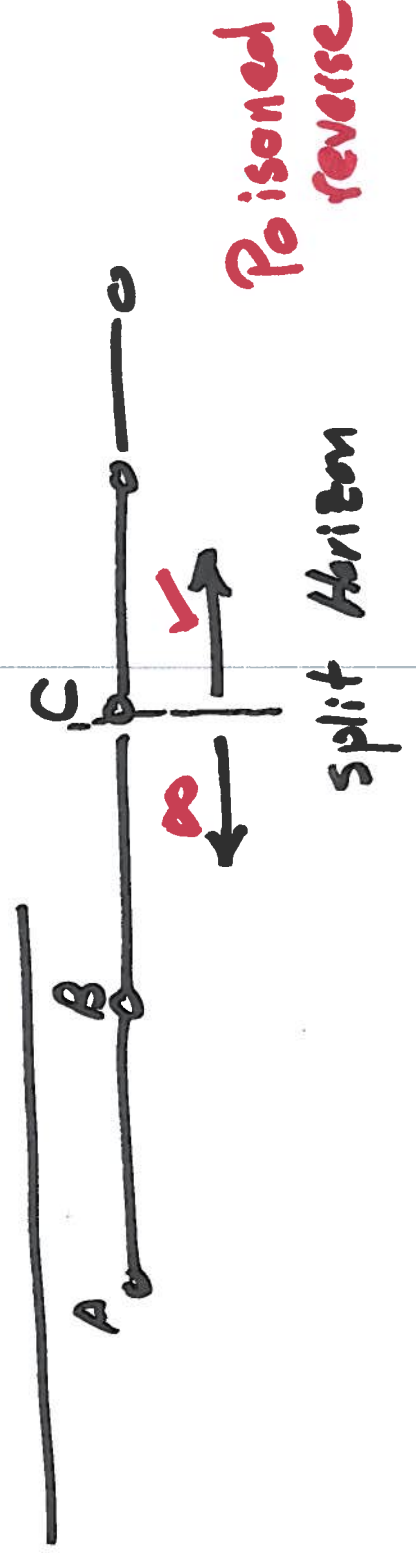
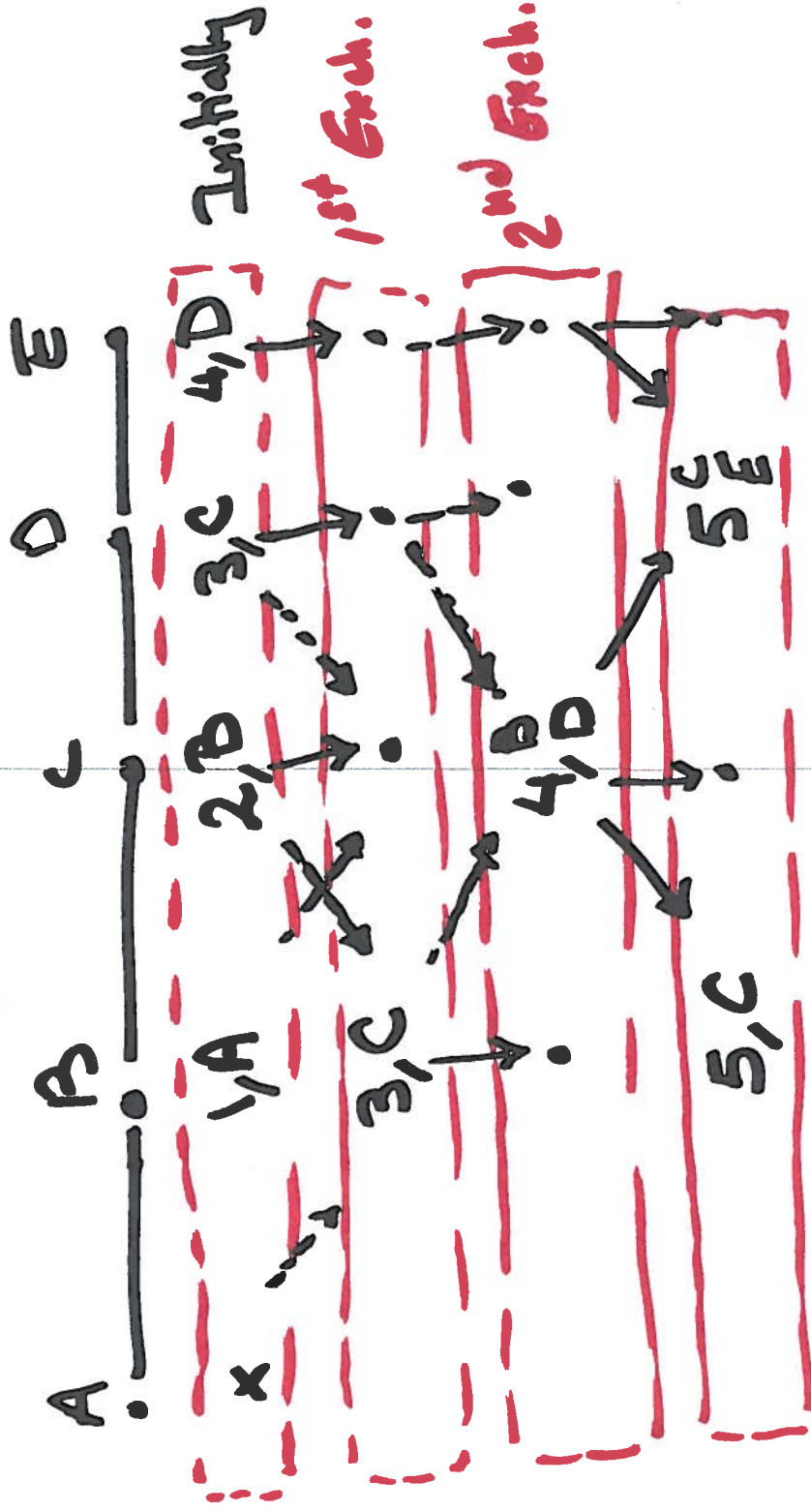
$$(a, b) = 1$$

$$(a, d) = 2$$

$$(a, e) = 3$$

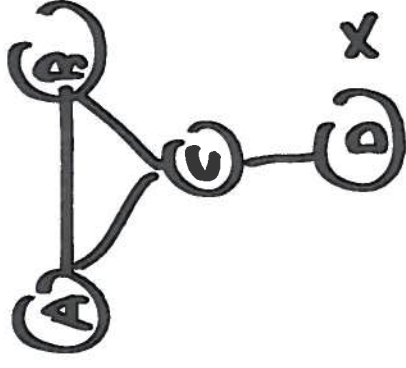
Counting to Infinity Problem

TTTT



Limitations of Split Horizon

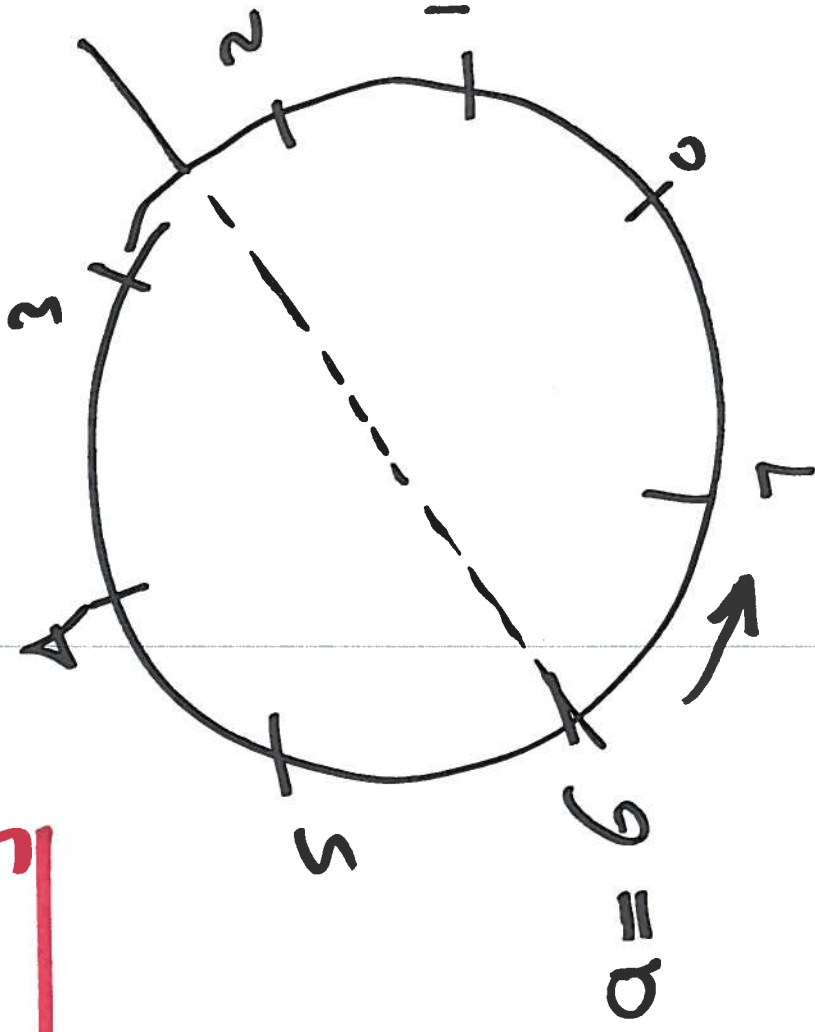
D	C	A	B
x	1,D	2,C	2,C
	∞	∞	∞
	∞	3,B	3,A
	∞	∞	∞
	4,A	∞	∞
	∞	∞	5,C
	∞	∞	6,B
	∞	∞	∞
	7,A	∞	∞



Link State Routing

$$N=8$$

$$\frac{N}{2}=4$$



$$3 < 6 < 2 < 8$$

$$a=6 < 7$$

$$|7-6| < \frac{N}{2}$$

$$< 0$$

$$|6-0| \geq \frac{N}{2}$$

$$< 1$$

$$|6-1| \geq \frac{N}{2}$$

$$< 2$$

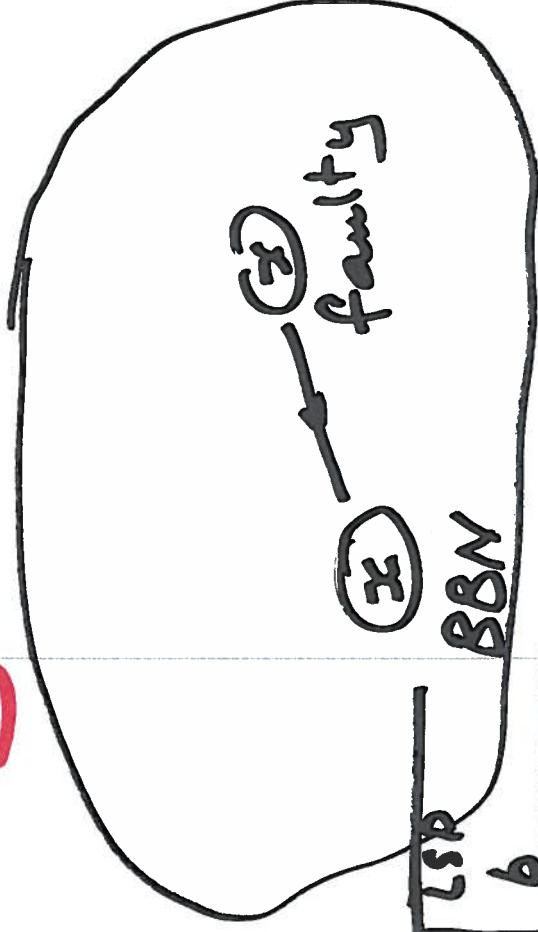
$$|6-2| \geq \frac{N}{2}$$

The Arpanet Incident

One night the ARPANET
stopped working!

Core dump

LSP	LSP	LSP	LSP	LSP
a	b	c	a	b



$a < b < c < a$
 $\uparrow \quad \uparrow \quad \uparrow$

Dividing a network into regions

Pros

- ▣ Shorter routing table

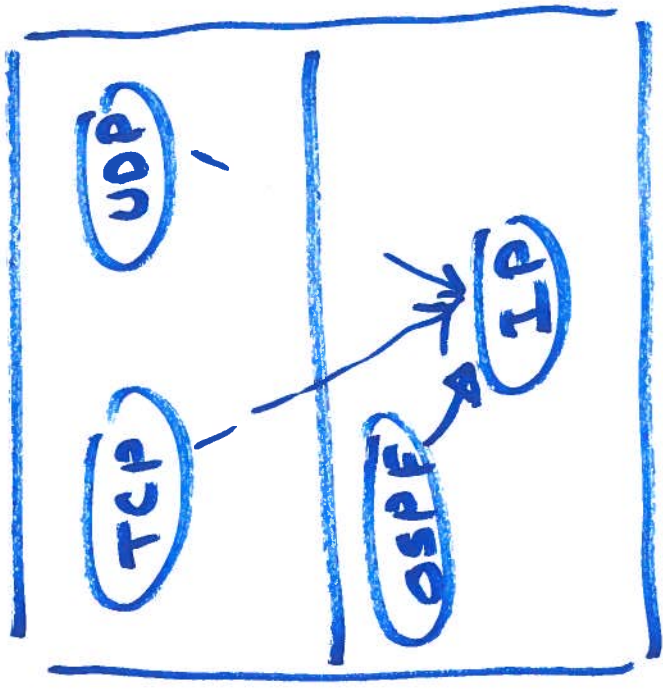
Cons

- ▣ Sacrifice optimality
- ▣ Require hierarchical addresses
- ▣ Gateway routers have to run both intra-domain & inter-domain algorithms

OSPF

Transport

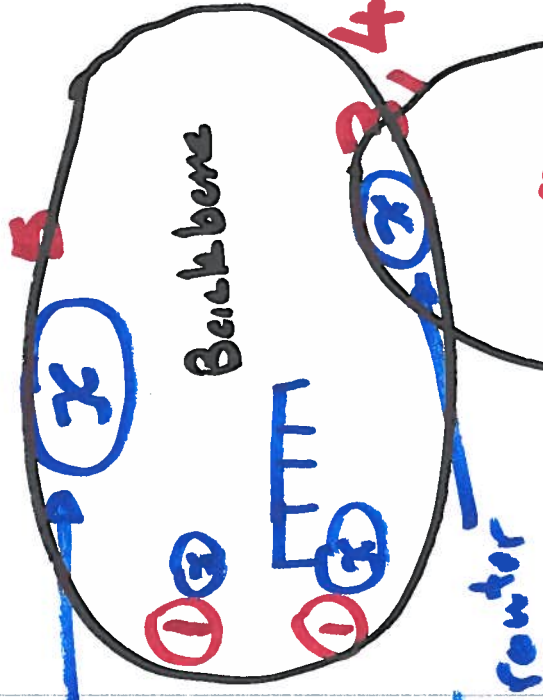
Network



LS Adv. in OSPF

- Link Costs: inverse bandwidth, delay, BER, \$

AS boundary router

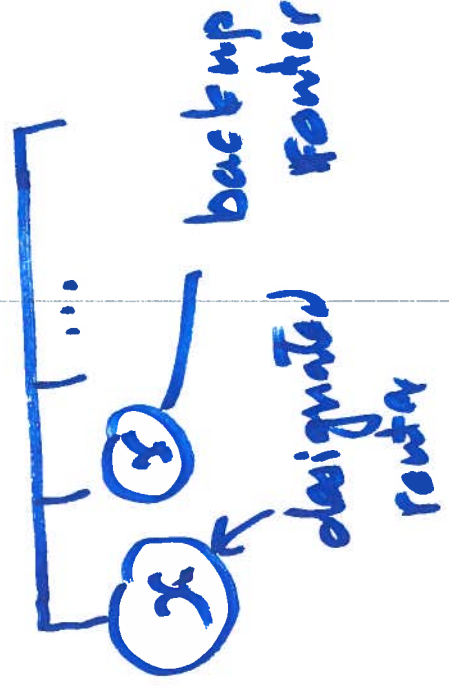


1. Router Link Adv.

Info about links + LAN

2. Net. Links

More info about LANs



3. Network Summary

- Generated by area border routers
- Describe networks reachable from outside the area

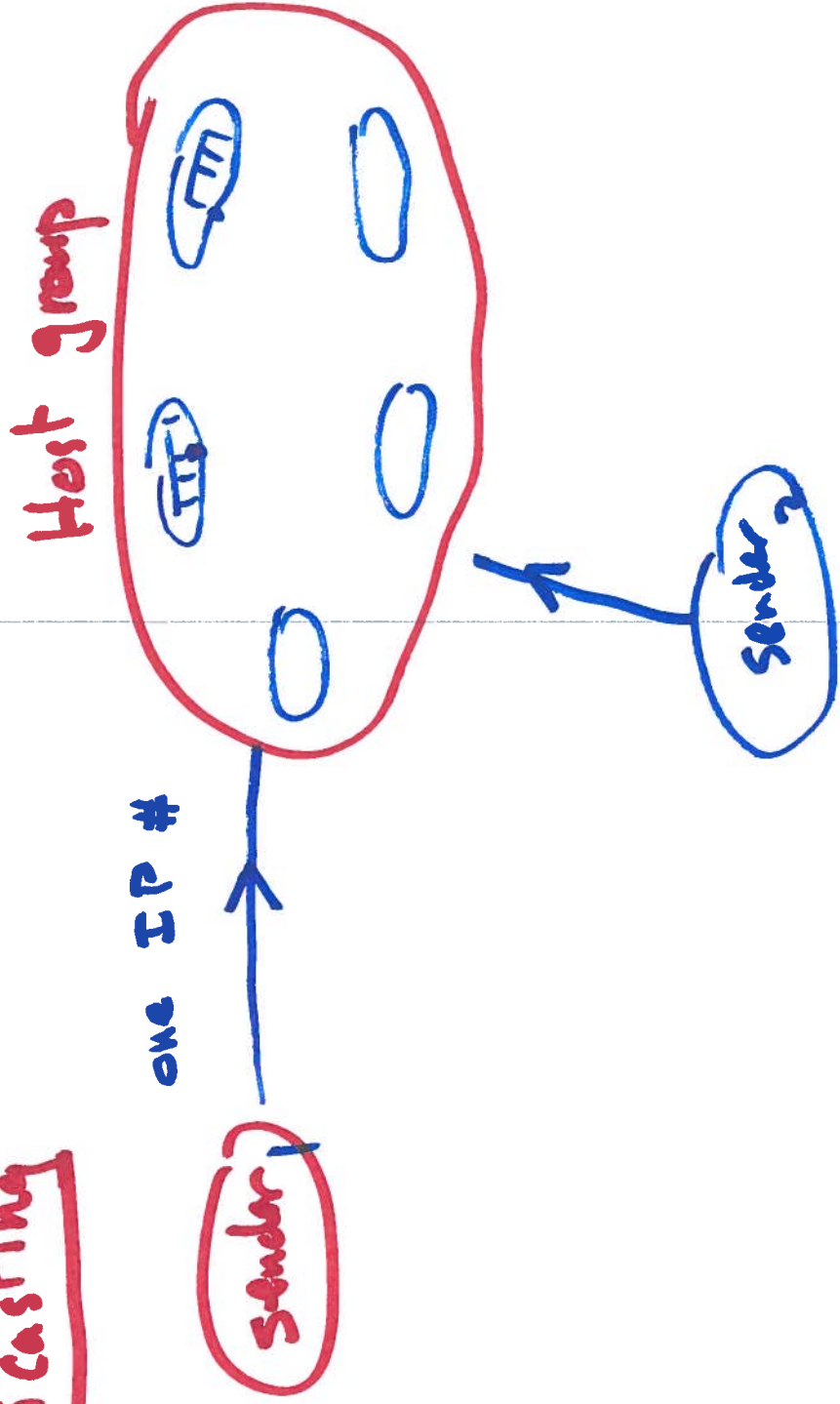
4. AS Boundary Router Summary

- Cost of reaching an AS boundary router by the source

5. AS External Link Adm.

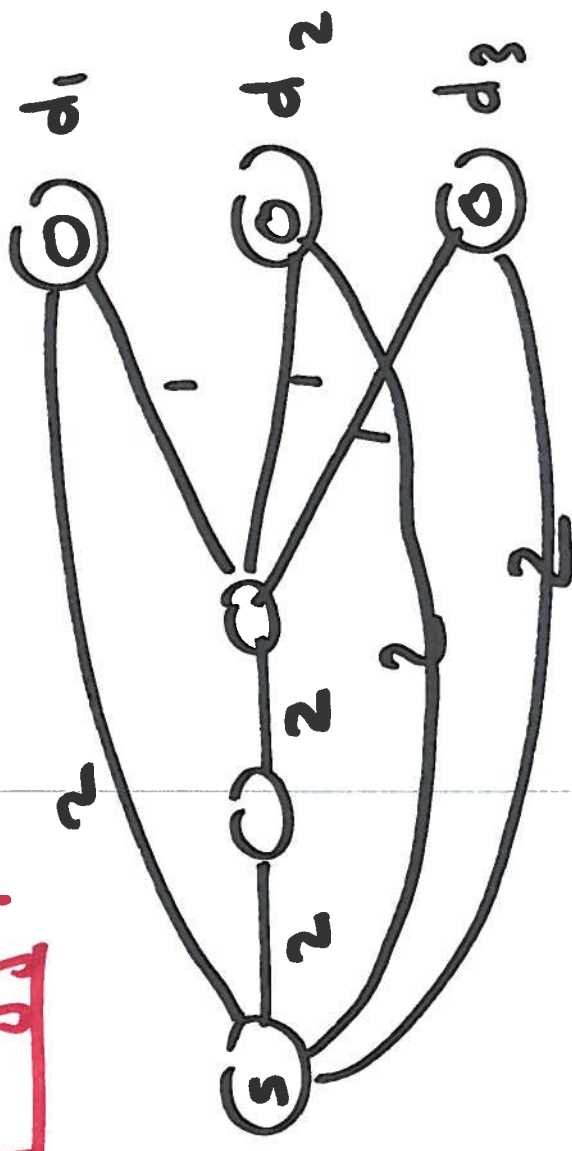
- Generated by AS boundary routers
- Cost to destinations outside the AS

Multicasting



What to minimize in choosing

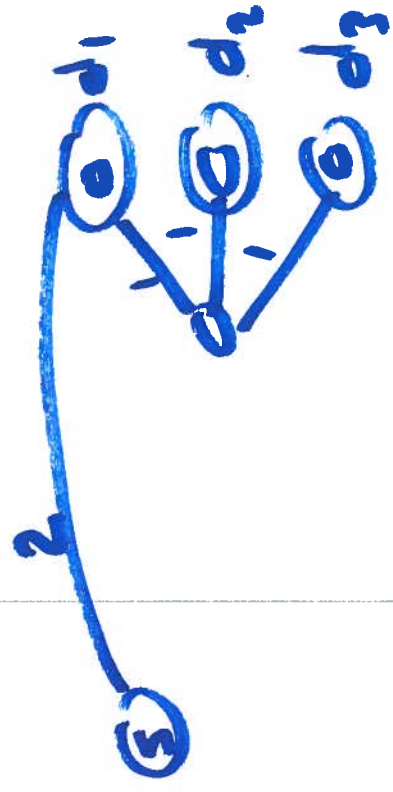
a multicast topology?



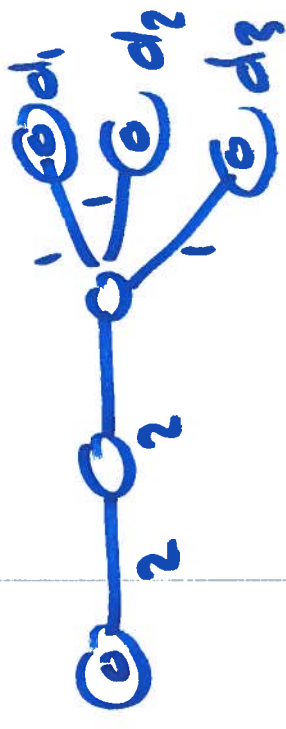
Ideally,
we want

Hard

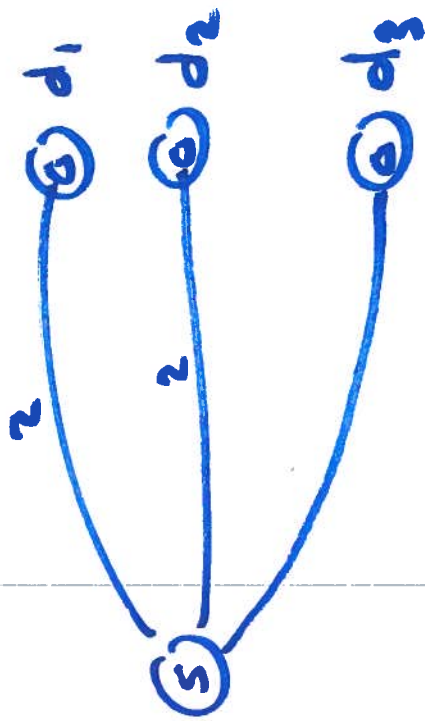
$$W_{\text{Steiner}} = 5$$



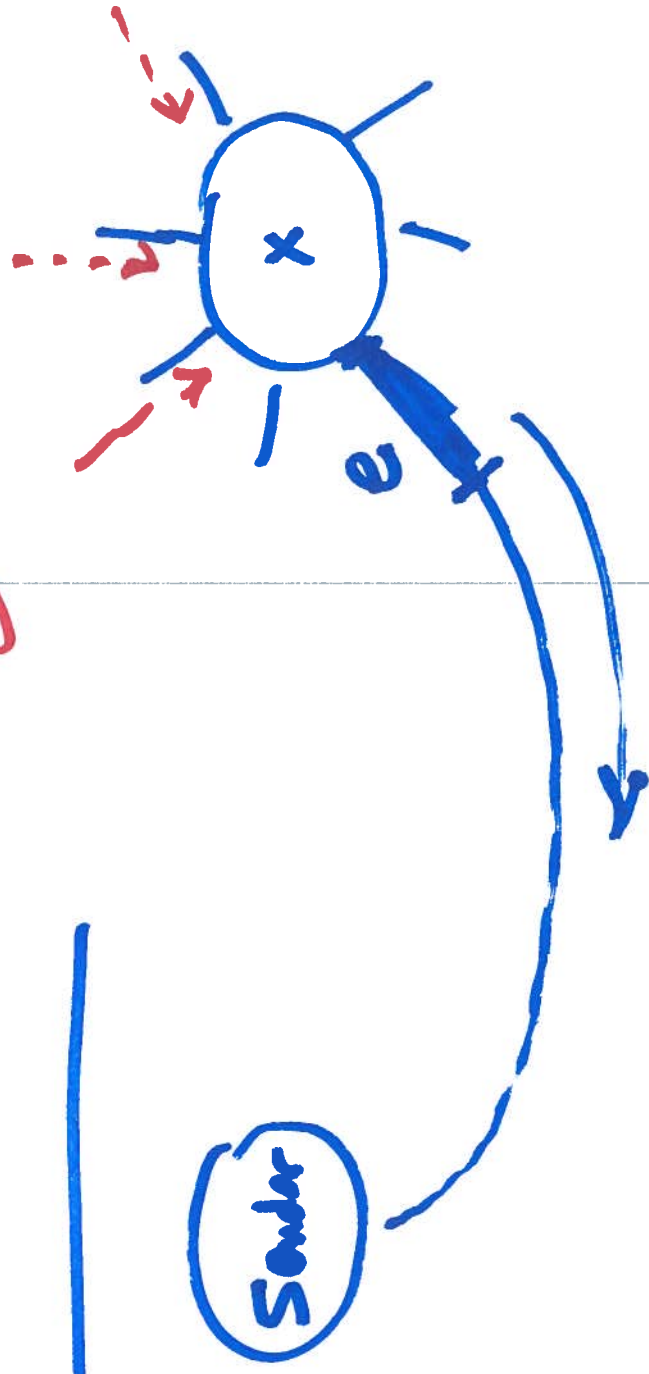
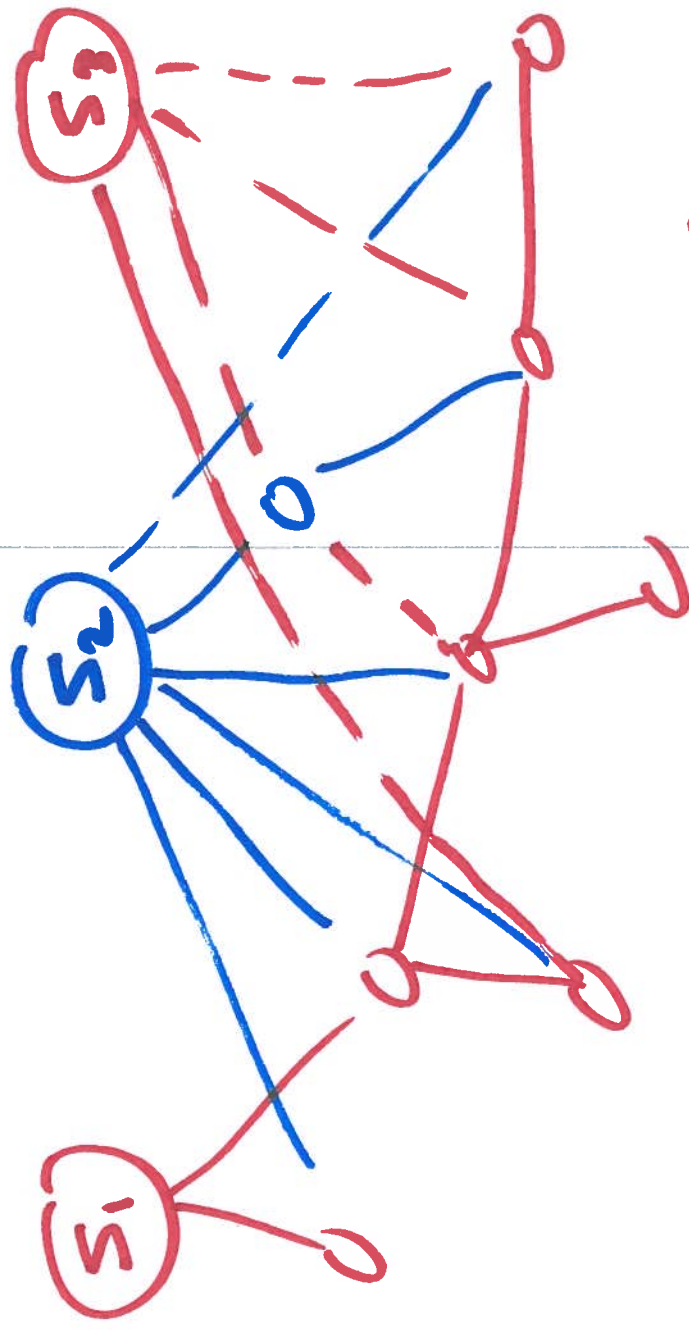
$$W_{\text{MST}} = 7$$



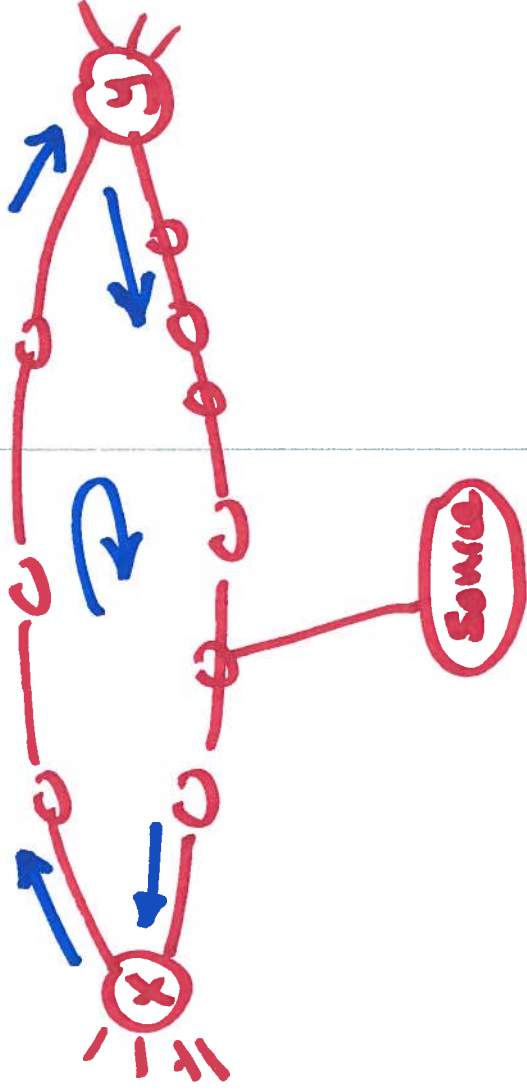
$$W_U = 6$$



Source Based Trees



Does RPF avoid looping?



RPF Messages

Ex: check 24
pkts

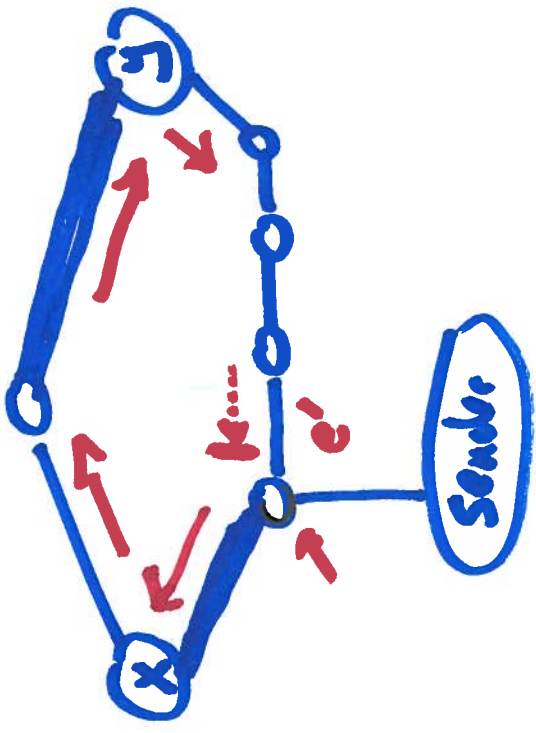
$n = 7$ nodes

$m = 9$ links

of pkts = 12 pkts ✓

Can this be
written as
 $f(n, m)$?

RPF rule aims at avoiding loops



Counting messages

n : # of nodes
 m : # of edges

$$\underbrace{n-1}_{\text{accepted}} + \underbrace{2(m-n+1)}_{\text{blocked}}$$