Congestion Control In The Internet

Part 1:

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Rate adaptation, Congestion Control and Fairness: A Tutorial

JEAN-YVES LE BOUDEC
Ecole Polytechnique Fédérale de Lausanne (EPFL)

No book; check the pdf uploaded on Moodle: "Rate adaptation, Congestion Control and Fairness: A tutorial"

1. Congestion Collapse

In October of '86, the Internet had the first of what became a series of 'congestion collapses'. During this period, the data throughput from LBL to UC Berkeley (sites separated by 400 yards and three IMP hops) dropped from 32 Kbps to 40 bps. Mike Karels[1] and I were fascinated by this sudden factor-of-thousand drop

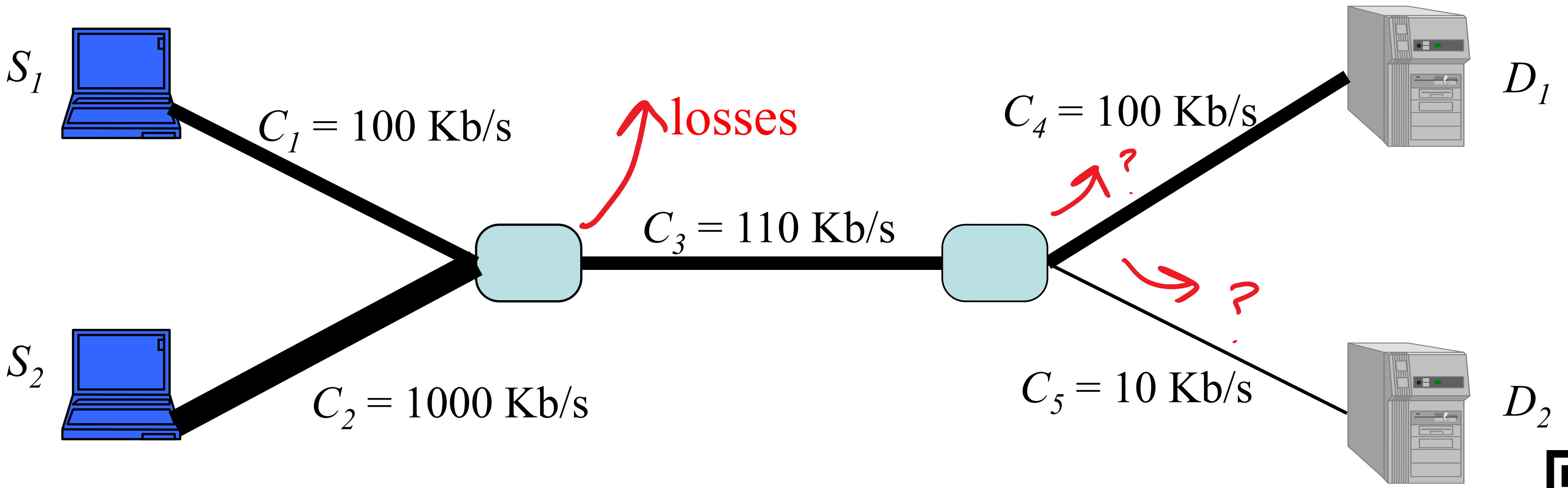
Jacobson, Van. "Congestion avoidance and control." *ACM SIGCOMM computer communication review*. Vol. 18. No. 4. ACM, 1988.

Example 1: Congestion due to greedy sources

Assume: Two flows $S_1 \rightarrow D_1$ and $S_2 \rightarrow D_2$.

Sources are greedy (i.e. send as much as they want); loss may happen

Loss is proportional to submitted traffic and links can be fully utilized



What is the max throughput attained by flow $S_1 \rightarrow D_1$?

A. 10 kb/s B. 50 kb/s. C. 100 kb/s. D. I don't know

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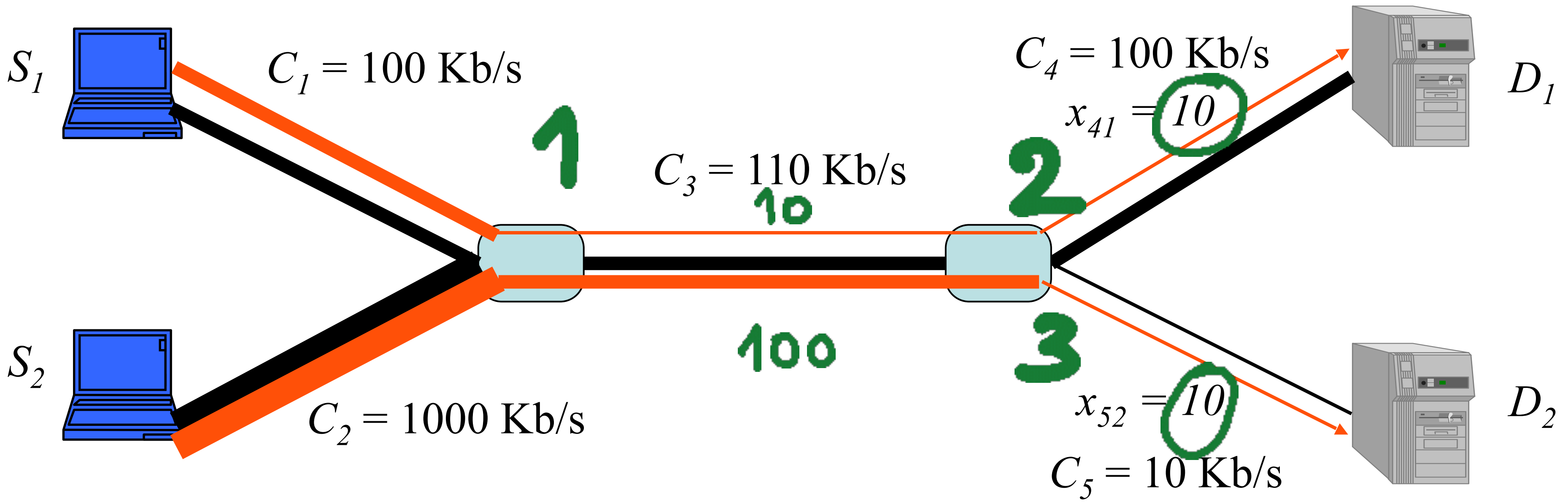
Solution

Answer A: Ratio of traffic that survives at 1: $110/(100+1000) = 10\,\%$

Ratio of traffic that survives at 2: 100%

Ratio of traffic that survives at 3: $10/100 = 10\,\%$

Both flows attain 10 kb/s even if the sources have different access links and send at different rates!



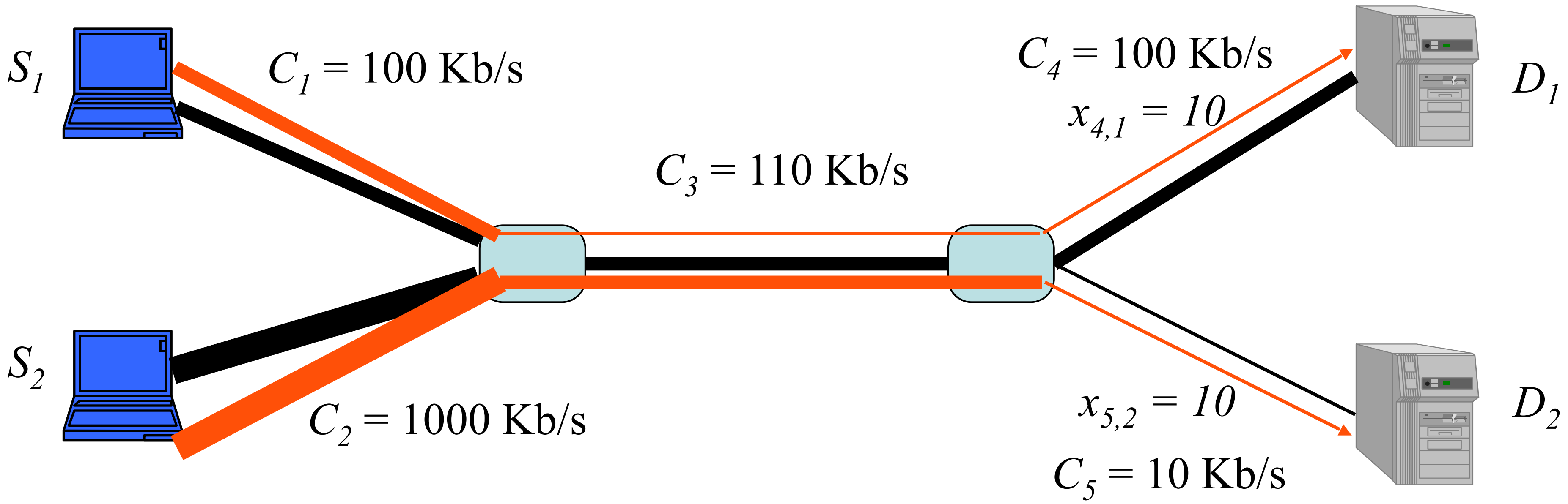
Take-home message 1: greedy sources may be *inefficient*

A better allocation is:

S_1: 100 kb/s

S_2: 10 kb/s

The problem was that S_2 sent too much (but it did not know)



Example 2: Congestion collapse

Assume: Each source sends traffic 2 hops away at rate λ

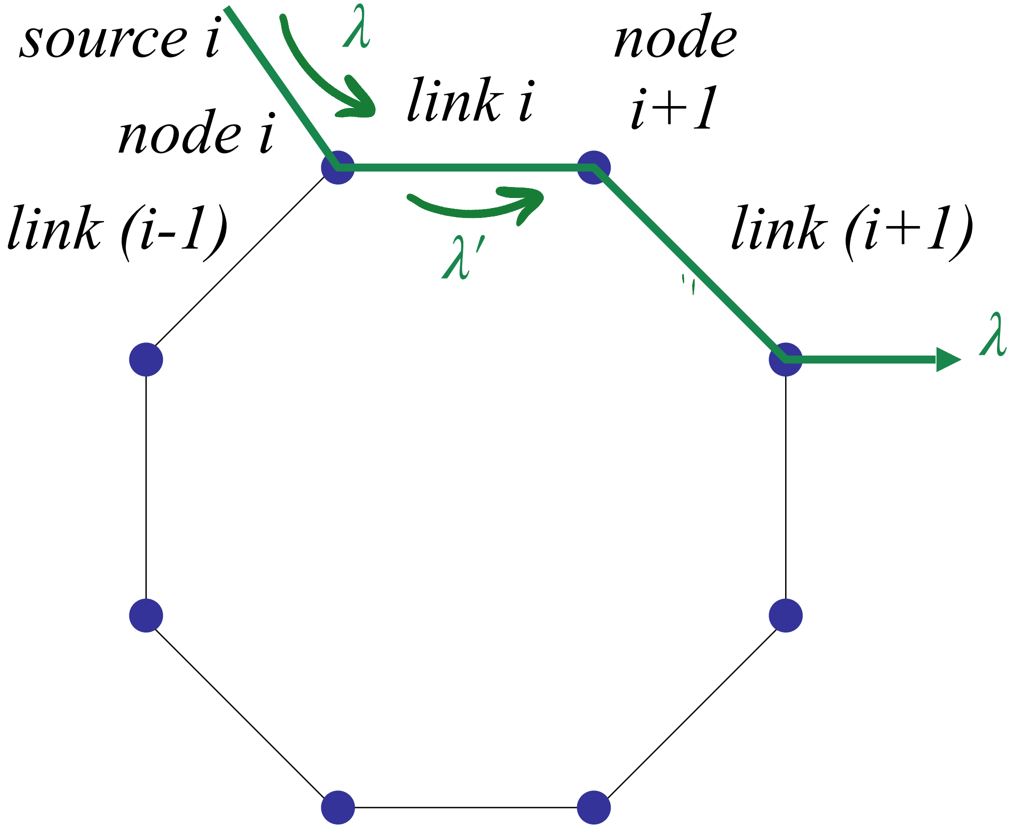
e.g., source i, at node i, sends traffic to a destination at node $i+2$

All links have the same capacity c

Loss is proportional to submitted traffic and links can be fully utilized

Let:

- λ' = the survived rate of λ at the *first* link
- λ'' = the survived rate of λ' at the *second* link = throughput



➡ *How much is λ'' (i.e. the rate at which destination $i+2$ receive traffic)?*
How much throughput each source can attain?

Solution: Attained throughput λ''

At each link i, the submitted traffic is $\lambda + \lambda'$

- If $\lambda < \frac{c}{2}$ there is no loss; so $\lambda'' = \lambda$
- If $\lambda > \frac{c}{2}$ there is loss:

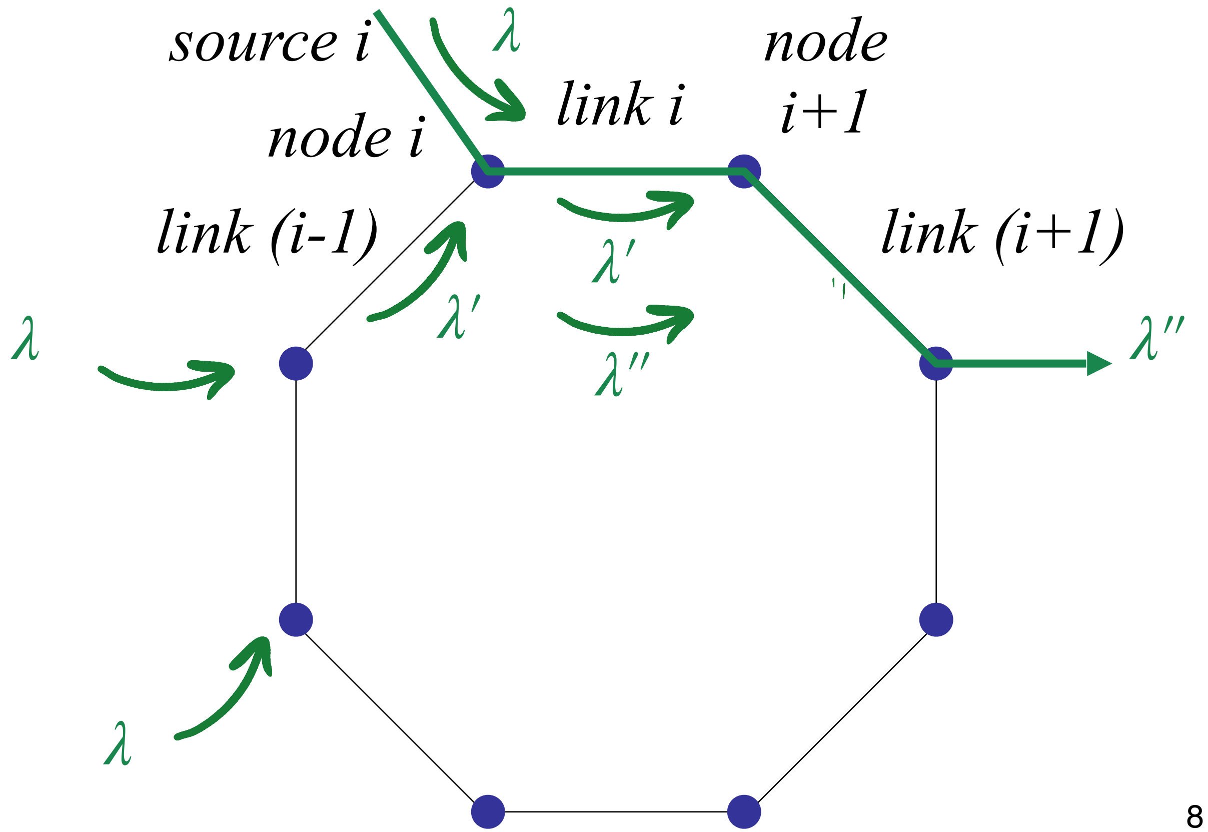
Traffic survival ratio at each node = $\frac{c}{\lambda + \lambda'}$

Due to loss proportionality:

$$\lambda' = \frac{c}{\lambda + \lambda'}\lambda \quad (1)$$

$$\lambda'' = \frac{c}{\lambda + \lambda'}\lambda' \quad (2)$$

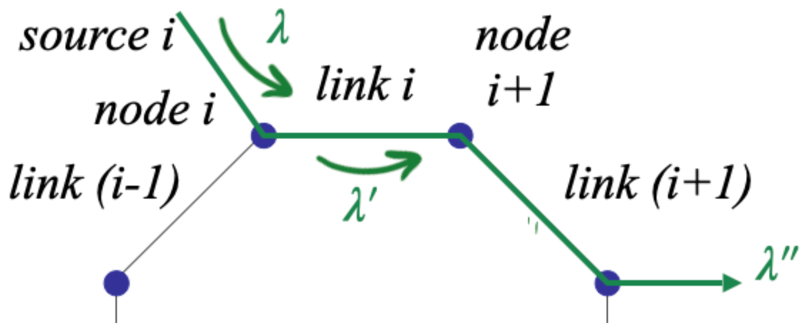
We solve (1) for λ',
plug into (2)
and obtain a solution for λ''



For large offered traffic load λ, the limit of throughput is 0

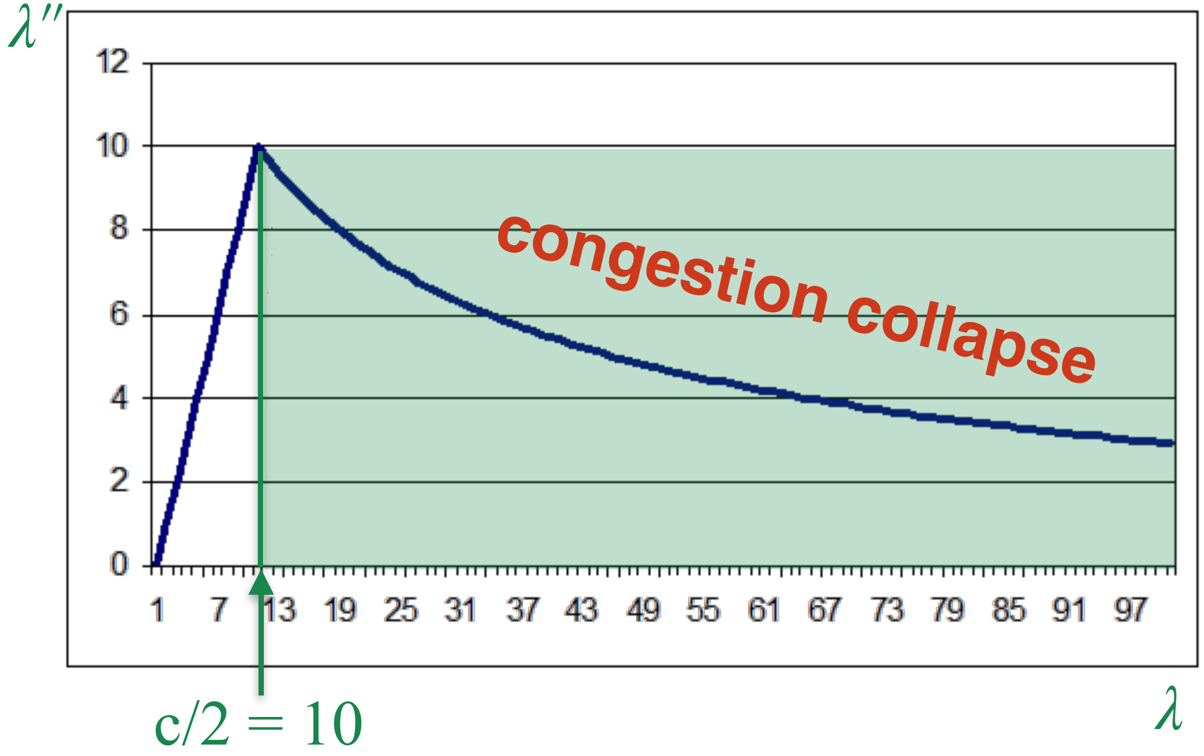
If $\lambda > \frac{c}{2}$, solving the system returns:

$$\lambda'' = c - \frac{\lambda}{2}\left(-1 + \sqrt{1 + \frac{4c}{\lambda}}\right)$$



$$\sqrt{1+u} = 1 + \frac{1}{2}u - \frac{1}{8}u^2 + o(u^2)$$

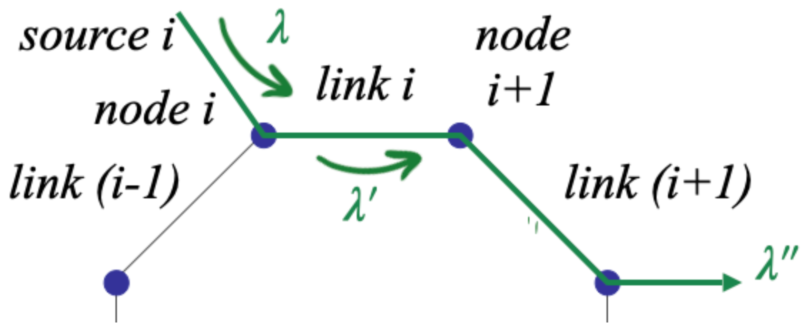
$$\lambda'' = \frac{c^2}{\lambda} + o(\frac{1}{\lambda})$$

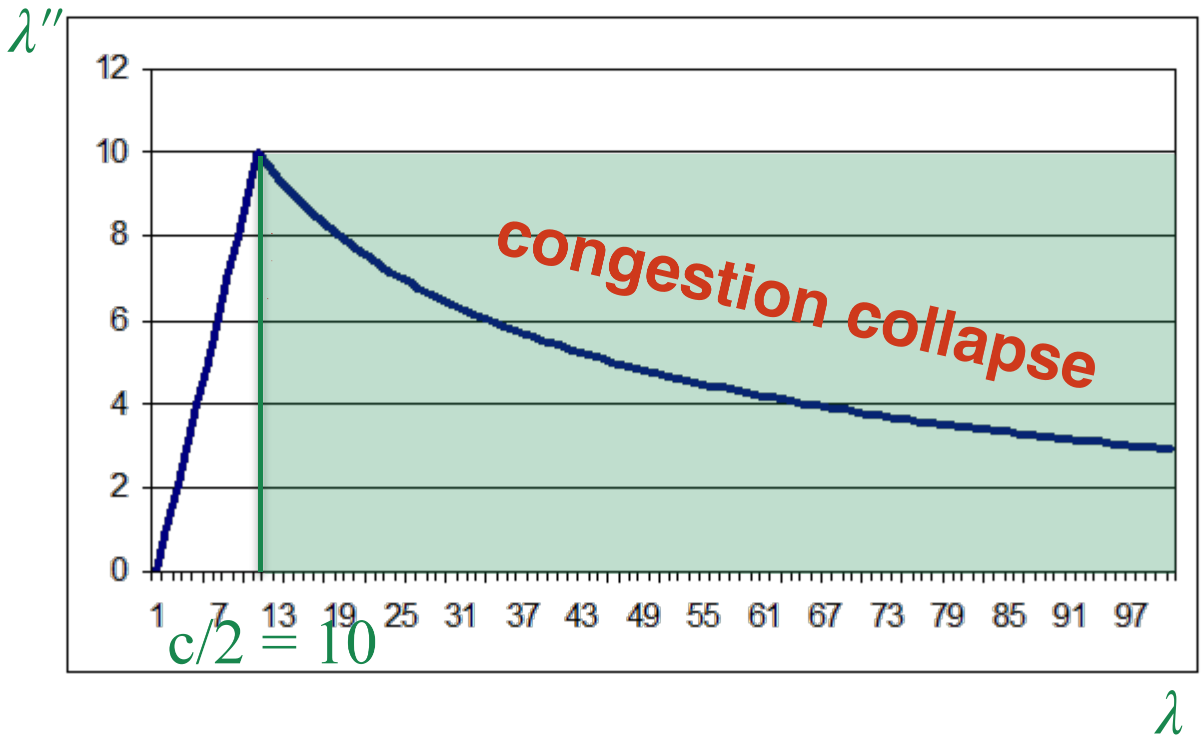


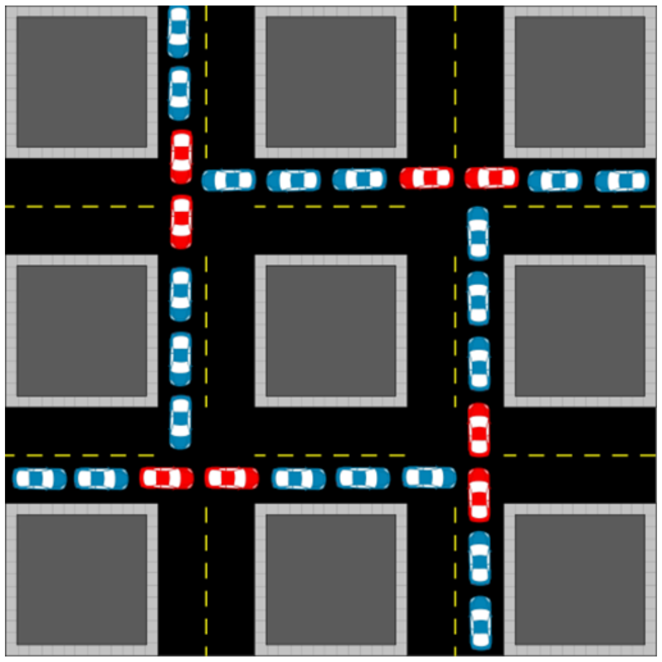
So, as λ —> +∞, throughput —> 0

Take-Home Message 2: *Congestion collapse*

- As the offered *load increases*, *throughput decreases*, may even go to 0
- Sources must limit their sending rates and *adapt* to network conditions; otherwise inefficiency or congestion collapse may occur





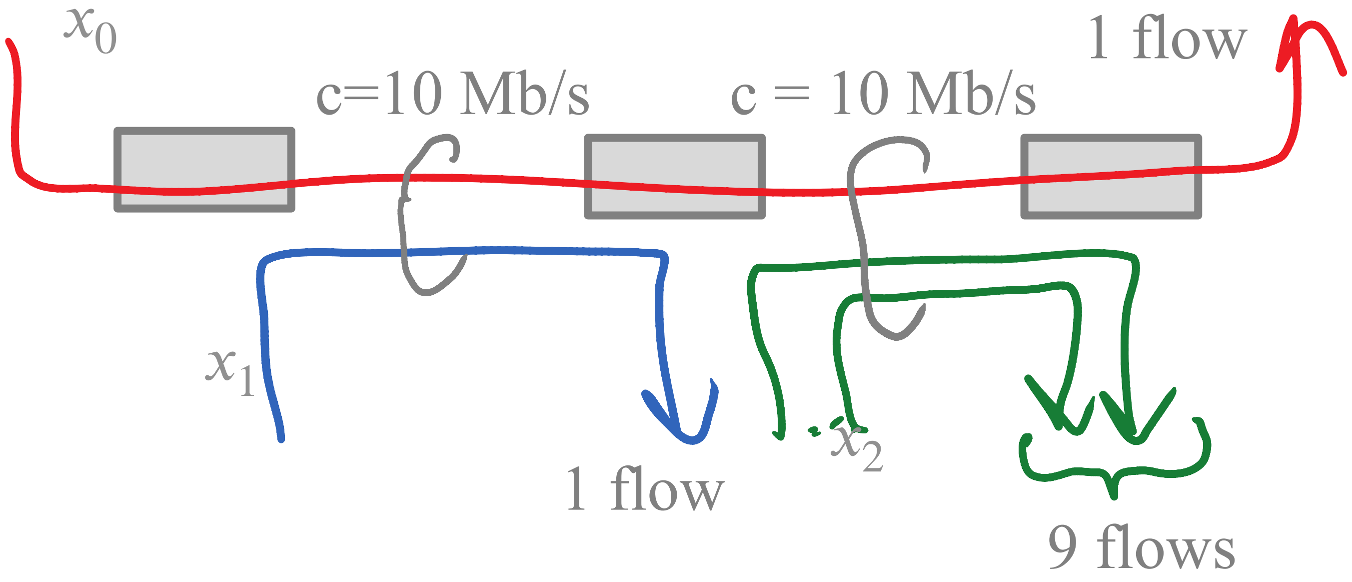


2. Efficiency vs Fairness

A network should be organized so as to avoid inefficiency, but being *maximally efficient* may cause other *problems*

Example: what is the maximum total throughput in this network ?

A. 5 Mb/s
B. 10 Mb/s
C. 20 Mb/s
D. None of the above
E. I don't know



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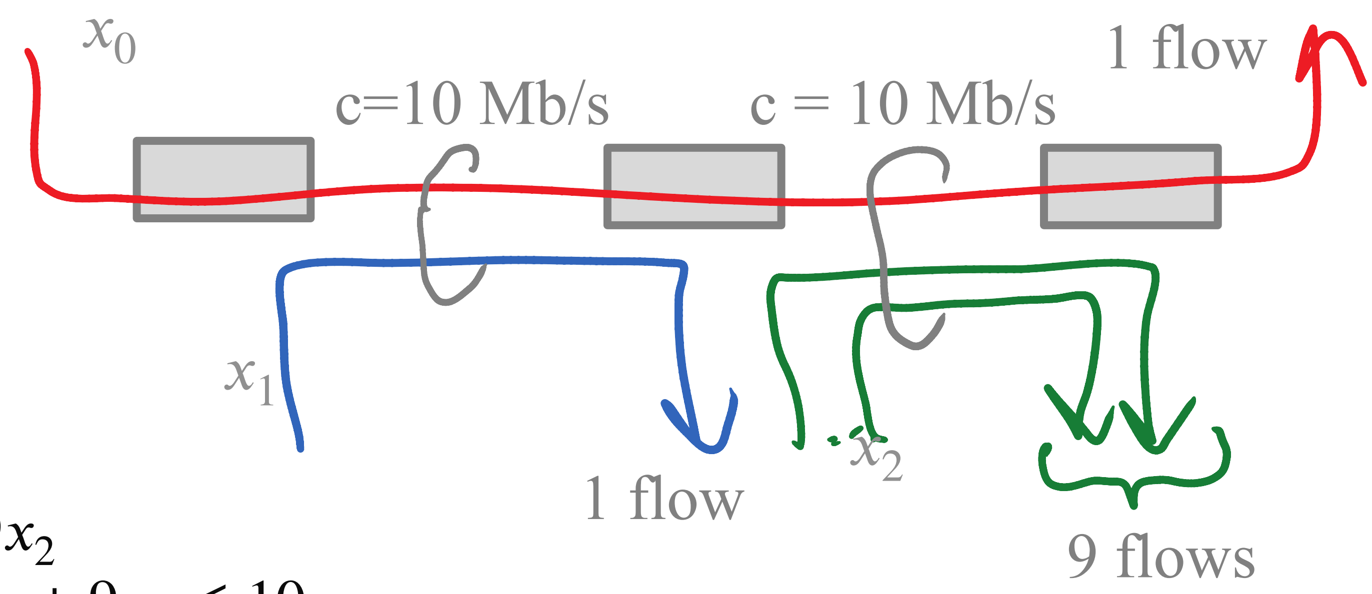
Solution

Answer C



Total throughput $\theta = x_0 + x_1 + 9x_2$

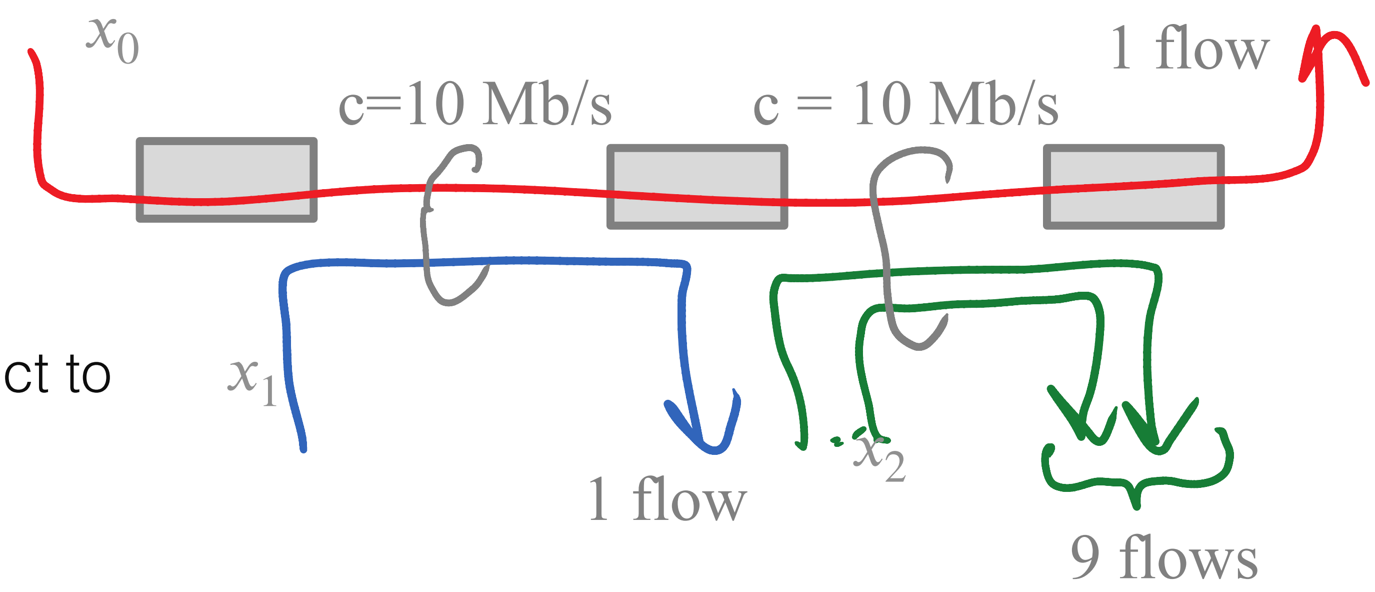
Maximize $\theta = x_0 + x_1 + 9x_2$
subject to $x_0 + x_1 \leq 10,\ x_0 + 9x_2 \leq 10$
over $x_0 \geq 0,\ x_1 \geq 0\ x_2 \geq 0$

The max can be obtained *by linear programming*, or directly here *by inspection*:

- $\theta \leq\ 20$ because $x_0 + x_1 \leq 10, 9x_2 \leq 10 - x_0$ and $x_0 \geq 0$
- $\theta = 20$ is achieved with $x_1 = 10$ and $x_2 = 10/9$

therefore the max is 20 Mb/s

Solution



And we can also prove that this is the only maximizing allocation:

Find all $x_0 \geq 0$ $x_1 \geq 0$ $x_2 \geq 0$ subject to

$x_0 + x_1 \leq 10$ (1)

$x_0 + 9x_2 \leq 10$ (2)

$x_0 + x_1 + 9x_2 = 20$ (3)

By (1) and (3): $9x_2 \geq 10$

Compare to (2): $9x_2 = 10$

Thus $x_0 = 0$ (and $x_1 = 10$, $x_2 = 10/9$)

Max is achieved only if $x_0 = 0$ —> rather *unfair*

➡ We need to qualify the *tradeoff between efficiency and fairness*