بسمه تعالی

دانشگاه علم و صنعت ایران

School of Computer Engineering

Advanced Computer Networks

Transport Layer and Congestion Control

Part 4

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Congestion Control

Congestion control and relation to resource allocation: Deeper Analysis

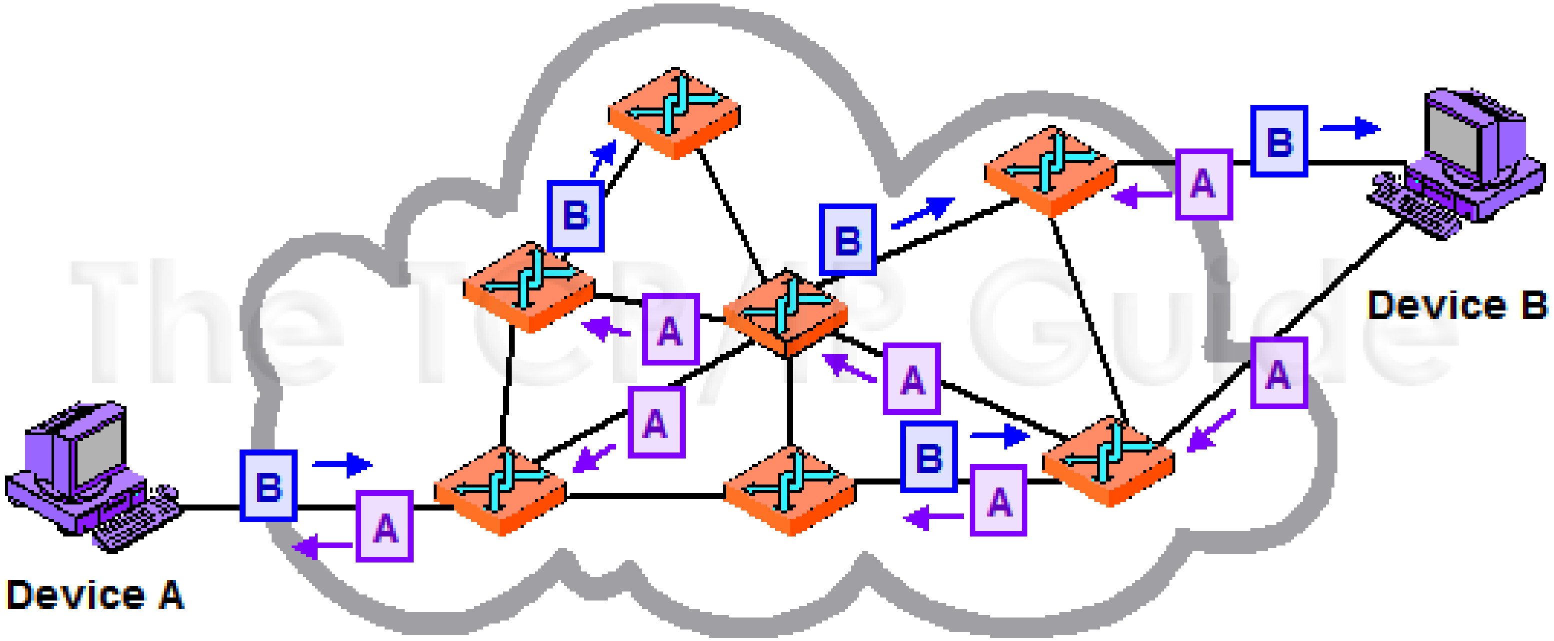
- However, it is more common for congestion control mechanisms to have some aspect of **fairness**:
  - that is, they try to share the pain among all users rather than causing great pain to a few.

➢ Thus, we see that many congestion control mechanisms have some sort of resource allocation built into them.

Congestion Control

The concept of flow

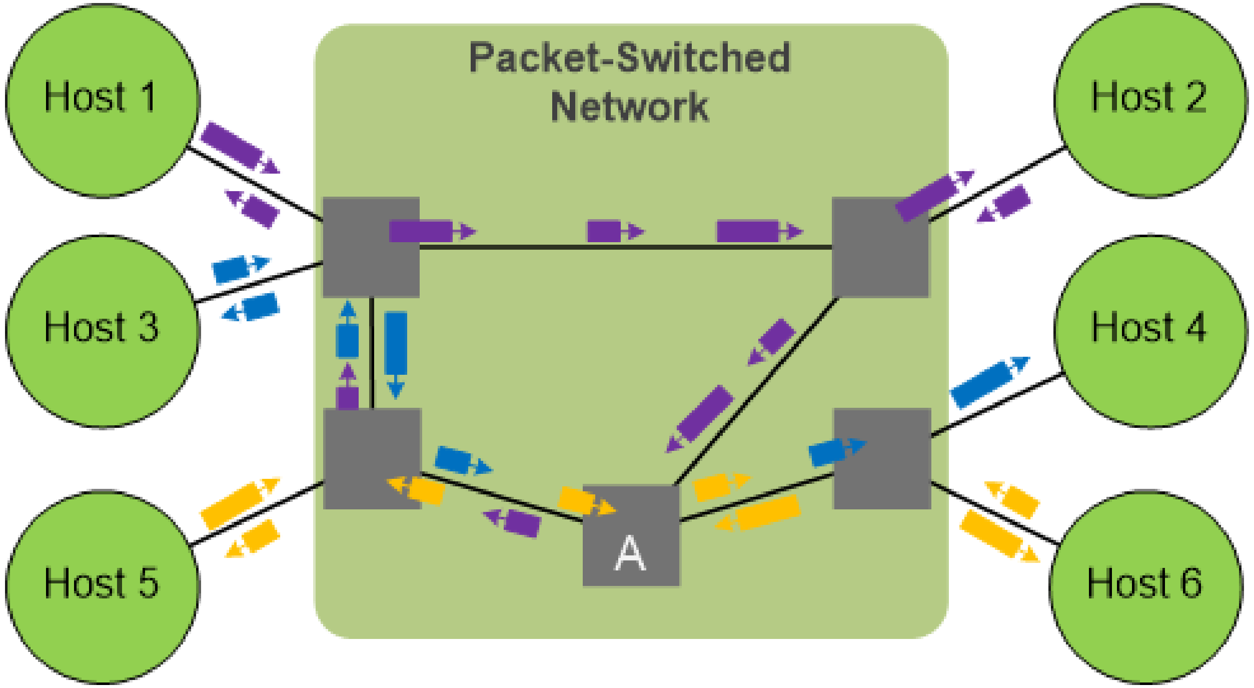
- In connectionless networks, the assumption that all datagrams are completely independent is too strong.



Congestion Control

The concept of flow

- The datagrams are certainly switched independently, but it is usually the case that a stream of datagrams between a particular pair of hosts flows through a particular set of routers.



Congestion Control

The concept of flow

- This idea of a ***flow***—a sequence of packets sent between a source/destination pair and following the same route through the network—is an important abstraction in the context of resource allocation.

- One of the powers of the flow abstraction is that flows can be defined at different granularities.
  - For example, a flow can be host-to-host (i.e., have the same source/destination host addresses) or process-to-process (i.e., have the same source/destination host/port pairs).

Congestion Control

The concept of flow

- **RFC 2722** defines traffic flow as

"an artificial logical equivalent to a call or connection."

- **RFC 3697** defines traffic flow as

"a sequence of packets sent from a particular source to a particular unicast, anycast, or multicast destination that the source desires to label as a flow. A flow could consist of all packets in a specific transport connection or a media stream. However, a flow is not necessarily 1:1 mapped to a transport connection."

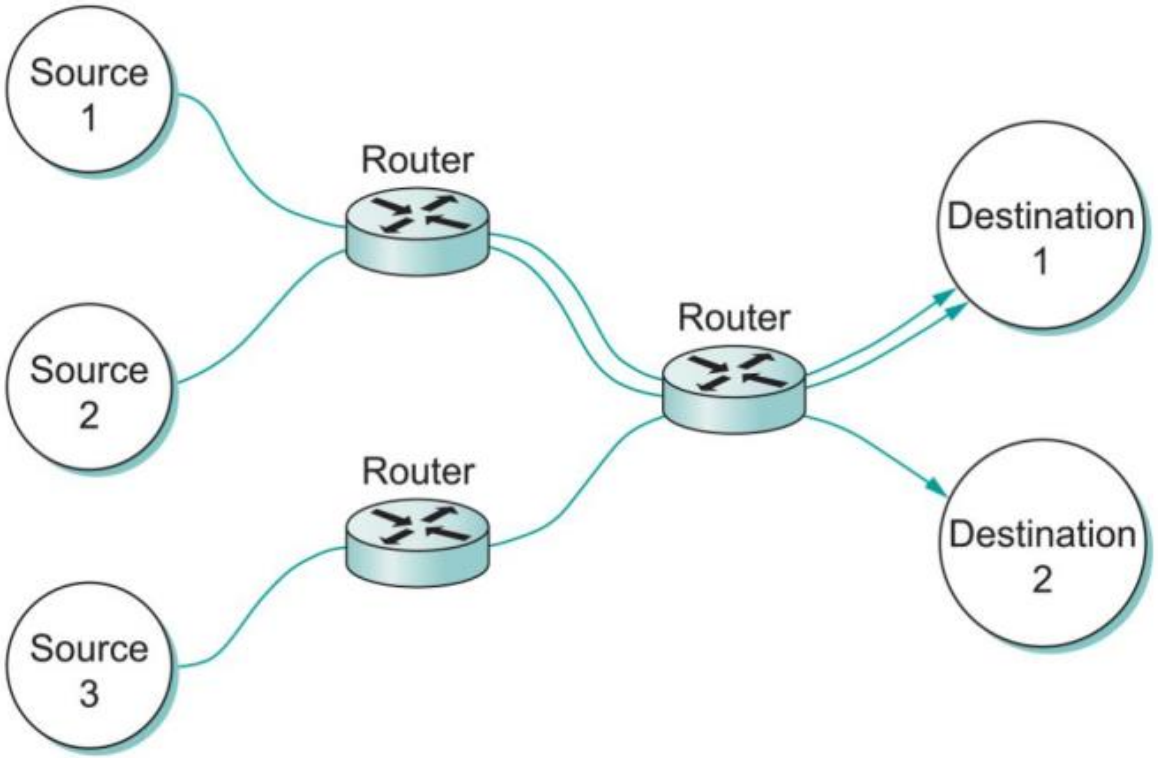
- Flow is also defined in **RFC 3917** as

"a set of IP packets passing an observation point in the network during a certain time interval."

Congestion Control

The concept of flow

- An Example: 3 Flows



Congestion Control

The concept of flow

- Note that a flow can be either:
  - **implicitly** defined
  - or **explicitly** established

- In the **implicit** case, each router watches for packets that happen to be traveling between the same source/destination pair and treats these packets as belonging to the same flow for the purpose of congestion control.

- In this case, the router acts by inspecting the addresses in the packet headers.

Congestion Control

The concept of flow

- In the explicit case, the source sends a **flow setup** message across the network, declaring that a flow of packets is about to start.
- Explicit flows are arguably no different than a connection across a connection-oriented network.
- However in this case because, even when explicitly established, a flow **does not imply** any end-to-end semantics and, in particular, **does not imply the reliable and ordered delivery of a virtual circuit**.
  - It simply exists for the purpose of resource allocation.

Congestion Control

Resource allocation taxonomy:

- Router-Centric vs. Host-Centric
- Reservation-Based vs. Feedback-Based
- Window-Based vs. Rate-Based

Congestion Control

Resource allocation taxonomy: **Router-Centric Versus Host-Centric:**

- Resource allocation mechanisms can be classified into two broad groups:
  - those that address the problem from **inside the network** (i.e., at the routers or switches)
  - those that address it from the **edges of the network** (i.e., in the hosts, perhaps inside the transport protocol).

- Since it is the case that both the routers inside the network and the hosts at the edges of the network participate in resource allocation, **the real issue is where the majority of the burden falls.**

Congestion Control

Resource allocation taxonomy: **Router-Centric Versus Host-Centric**

- In a **router-centric design**, each router takes responsibility for deciding **when** packets are **forwarded** and selecting which packets are to be **dropped**, as well as for **informing the hosts** that are generating the network traffic how many packets they **are allowed** to send.

- In a **host-centric design**, the end hosts observe the network conditions (e.g., how many packets they are successfully getting through the network) and adjust their behavior accordingly.

- Note that these two groups are not mutually exclusive.

Congestion Control

Resource allocation taxonomy: **Reservation-Based Versus Feedback-Based**

- A second way that resource allocation mechanisms are sometimes classified is according to whether they use reservations or feedback.
- In a **reservation-based system**, some entity (e.g., the end host) asks the network for a certain amount of capacity to be allocated for a flow.
- Each router then allocates enough resources (buffers and/or percentage of the link's bandwidth) to satisfy this request.
- If the request cannot be satisfied at some router, because doing so would overcommit its resources, then the router rejects the reservation. (Admission Control)

Congestion Control

Resource allocation taxonomy: **Reservation-Based Versus Feedback-Based**

- In a **feedback-based approach**, the end hosts begin sending data without first reserving any capacity and then adjust their sending rate according to the feedback they receive.

- This feedback can be either:
  - **explicit** (i.e., a congested router sends a “please slow down” message to the host)
  - or **implicit** (i.e., the end host adjusts its sending rate according to the externally observable behavior of the network, such as packet losses).

Congestion Control

Resource allocation taxonomy: **Reservation-Based Versus Feedback-Based**

- Note that a **reservation-based** system always implies a **router-centric** resource allocation mechanism.

- On the other hand, a **feedback-based** system can imply **either** a **router**- or a **host**-centric mechanism.
  - Typically, if the feedback is **explicit**, then the router is involved, to at least some degree, in the resource allocation scheme. If the feedback is **implicit**, then almost all of the burden falls to the end host; the routers silently drop packets when they become congested.

- Reservations do not have to be made by end hosts:
  - It is possible for a network administrator (sometimes called *an orchestrator*) to allocate resources to flows or to larger aggregates of traffic.

Congestion Control

Resource allocation taxonomy: **Window-Based Versus Rate-Based**

- A third way to characterize resource allocation mechanisms is according to whether they are window-based or rate-based.
- Both flow control and resource allocation mechanisms need a way to express, to the sender, how much data it is allowed to transmit.
  - There are two general ways of doing this: with a **window** or with a **rate**.
- We have already seen **window-based** transport protocols, such as TCP, in which the receiver advertises a window (rwnd field) to the sender.
  - Specifies the buffer space the receiver and is used for the aim of flow control

Congestion Control

Resource allocation taxonomy: **Window-Based Versus Rate-Based**

- A similar mechanism—window advertisement— can be used within the network to reserve buffer space (i.e., to support resource allocation).
- TCP’s congestion control mechanisms are window-based.
- It is also possible to control a sender’s behavior using a rate—that is, how many bits per second the receiver or network is able to absorb.

Congestion Control

Resource allocation taxonomy: **Window-Based Versus Rate-Based**

- Rate-based control makes sense for many multimedia applications, which tend to generate data at some average rate and which need at least some minimum throughput to be useful.

- For example, a video codec might generate video at an average rate of 1 Mbps with a peak rate of 2 Mbps.

- Rate-based characterization of flows is a logical choice in a reservation-based system that supports different qualities of service.

Congestion Control

- Classifying resource allocation approaches at two different points along each of three dimensions, as we have just done, **would seem to suggest up to eight unique strategies.**
  - What do you think?

- While eight different approaches are certainly possible, we note that in practice, two general strategies seem to be most prevalent.
  - these two strategies are tied to the underlying service model of the network.

- The two strategies are:
  - Host-Centric Window and Feedback-based
  - Router-Centric Rate and Reservation-based

Congestion Control

- On the one hand, a **best-effort service** model usually implies that **feedback** is being used, since such a model does not allow users to reserve network capacity.

- This, in turn, means that most of the responsibility for congestion control falls to **the end hosts**, perhaps with some assistance from the routers.

- In practice, such networks use **window-based** information. This is the general strategy adopted in the **Internet**.

Congestion Control

- On the other hand, a **QoS-based** service model probably implies some form of **reservation**.

- Support for these reservations is likely to **require significant router involvement**, such as queuing packets differently depending on the level of reserved resources they require.

- Moreover, it is natural to express such reservations in terms of **rate**, since windows are only indirectly related to how much **bandwidth** a user needs from the network.

Congestion Control: Evaluation Criteria

- The final issue is one of knowing whether a resource allocation mechanism is good or not.

- There are at least two broad (among many) measures by which a resource allocation scheme can be evaluated.

    - **Effective Resource Allocation**

    - **Fair Resource Allocation**

Congestion Control: Evaluation Criteria

Effective Resource Allocation

- A good starting point for evaluating the effectiveness of a resource allocation scheme is to consider the two principal metrics of networking:
  - **throughput**
  - **delay**

- Clearly, we want **as much** throughput and **as little** delay as possible!

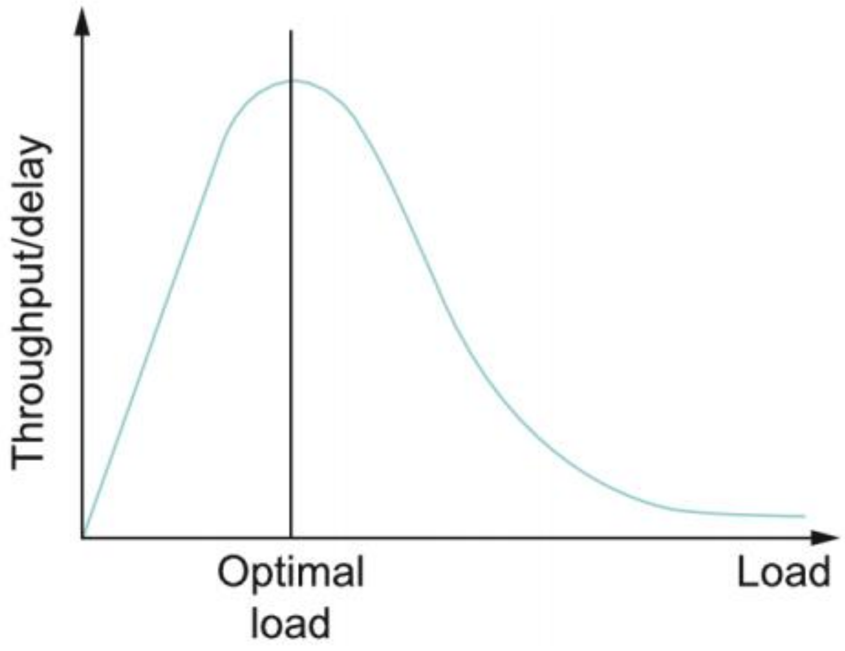
- Unfortunately, these goals are often somewhat at odds with each other.
  - One sure way for a resource allocation algorithm to increase throughput is to allow as many packets into the network as possible so as to drive the utilization of all the links up to 100%. We would do this to avoid the possibility of a link becoming idle because an idle link necessarily hurts throughput.
  - The problem with this strategy is that increasing the number of packets in the network also increases the length of the queues at each router. Longer queues, in turn, mean packets are delayed longer in the network.

Congestion Control: Evaluation Criteria

Effective Resource Allocation

- To describe this relationship, some network designers have proposed using the ratio of throughput to delay as a metric for evaluating the effectiveness of a resource allocation scheme.

New Combined Metric = Throughput / Delay



Congestion Control: Evaluation Criteria

Effective Resource Allocation

- Interestingly, **this power curve looks very much like the system throughput curve in a time-sharing computer system.**

- System throughput improves as more jobs are admitted into the system, until it reaches a point when there are so many jobs running that the system begins to thrash and the throughput begins to drop.

- As we will see later, many congestion control schemes are able to control load in only very crude ways; that is, it is simply not possible to turn the "knob" a little and allow only a small number of additional packets into the network.

Congestion Control: Evaluation Criteria

Effective Resource Allocation

- As a consequence, network designers need to be concerned about what happens even when the system is operating under extremely heavy load—that is, at the rightmost end of the curve in Throughput/Delay curve.

- Ideally, we would like to avoid the situation in which the system throughput goes to zero because the system is thrashing.

- In networking terminology, we want a system that is **stable**—where packets continue to get through the network even when the network is operating under heavy load.
  - If a mechanism is not stable, the network may experience congestion collapse.

Congestion Control: Evaluation Criteria

Fair Resource Allocation

- The effective utilization of network resources is not the only criterion for judging a resource allocation scheme.
  - We must also consider the issue of **fairness**.

- So what exactly constitutes fair resource allocation?

- For example, a reservation-based resource allocation scheme provides an explicit way to create controlled unfairness.
  - With such a scheme, we might use reservations to enable a video stream to receive 1 Mbps across some link while a file transfer receives only 10 kbps over the same link.

Congestion Control: Evaluation Criteria

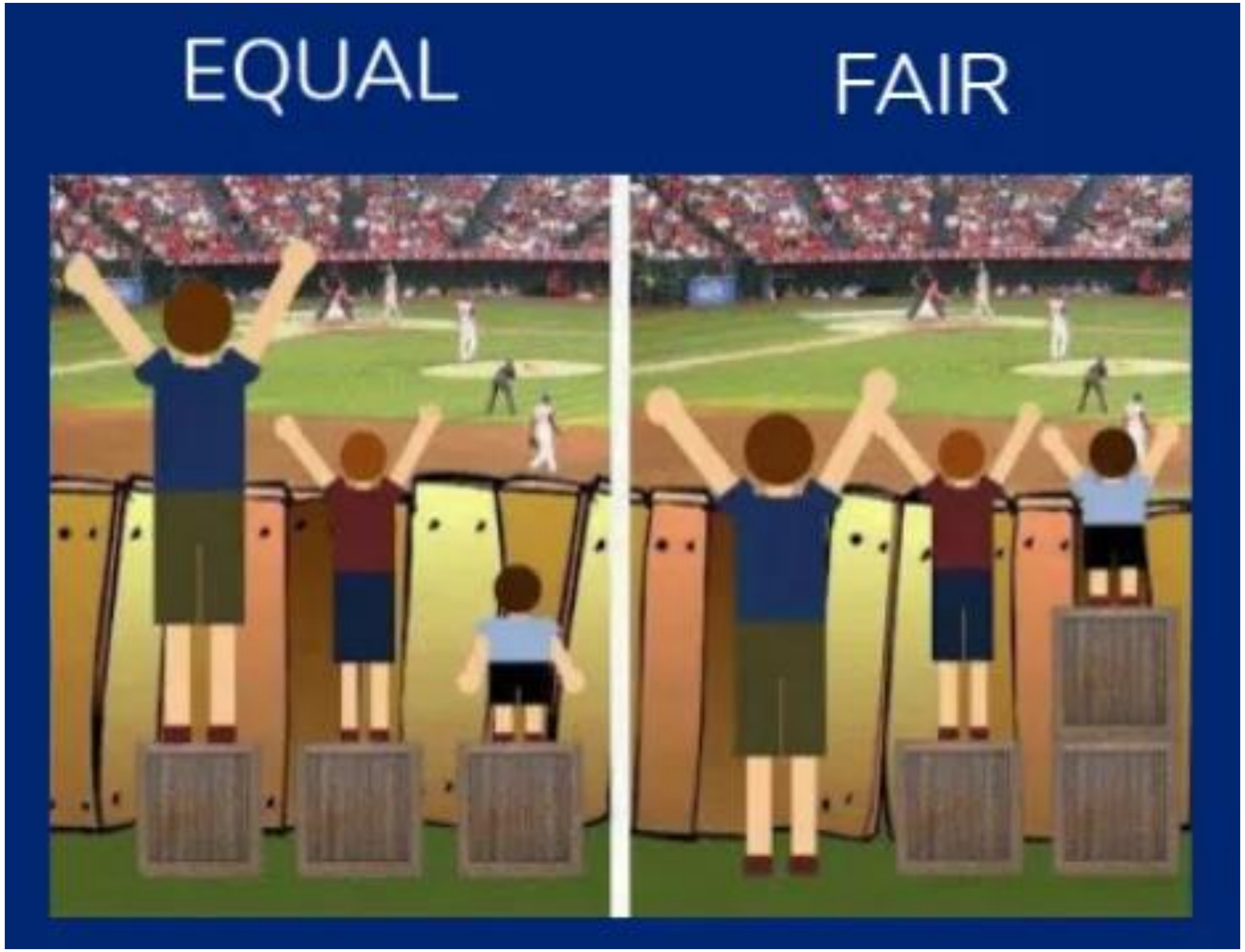
Fair Resource Allocation

- In the absence of explicit information to the contrary, when several flows share a particular link, we would like for each flow to receive **an equal share of the bandwidth.**
- This definition presumes that a fair share of bandwidth means an equal share of bandwidth.
- But even in the absence of reservations, equal shares may not equate to fair shares.

Congestion Control: Evaluation Criteria

Fair Resource Allocation

- equality vs fairness



Congestion Control: Evaluation Criteria

Fair Resource Allocation

- Should we also consider the length of the paths being compared?
- For example, as illustrated in the Figure, what is fair when one four-hop flow is competing with three one-hop flows?