In Figure 25.3(a), a sender transmits four packets, but waits for an acknowledgement before sending each successive packet. If the delay required to send a single packet on one trip through the network is N, the total time required to send four packets is $8N$. In Figure 25.3(b), a sender transmits all packets in the window before it waits. The figure shows a small delay between successive packet transmissions because transmission is never instantaneous — a short time (usually a few microseconds) is required for the hardware to complete transmission of a packet and begin to transmit the next packet. Thus, the total time required to send four packets is $2N + \varepsilon$, where ε denotes the small delay.

To understand the significance of sliding window, imagine an extended communication that involves many packets. In such cases, the total time required for transmission is so large that ε can be ignored. For such networks, a sliding window protocol can increase performance substantially. The potential improvement is:

$$T_w = T_g \times W \qquad (26.1)$$

where T_w is the throughput that can be achieved with a sliding window protocol, T_g is the throughput that can be achieved with a stop-and-go protocol, and W is the window size. The equation explains why the sliding window protocol illustrated in Figure 25.3(b) has approximately four times the throughput of the stop-and-go protocol in Figure 25.3(a). Of course, throughput cannot be increased arbitrarily merely by increasing the window size. The capacity of the underlying network imposes an upper bound — bits cannot be sent faster than the hardware can carry them. Thus, the equation can be rewritten:

$$T_w = min(C,\ T_g \times W) \qquad (26.2)$$

where C is the underlying hardware capacity†.

25.6 Techniques To Avoid Congestion

To understand how easily congestion can occur, consider four hosts connected by two switches as Figure 25.4 illustrates.

Figure 25.4 Four hosts connected by two switches.

†Networking professionals often use the term *bandwidth* instead of capacity, but strictly speaking the term is not correct because protocols can make the effective network data rate much less than the channel bandwidth.