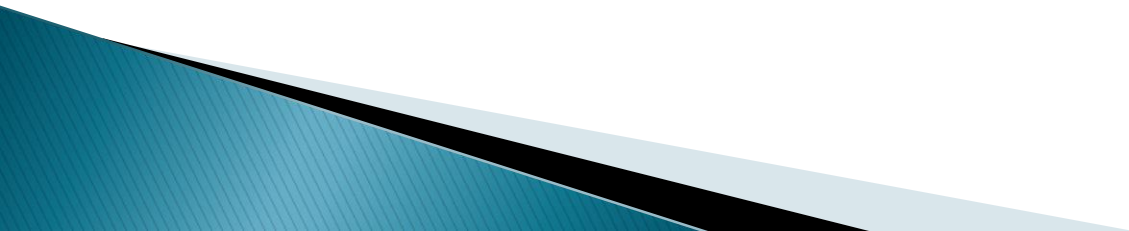


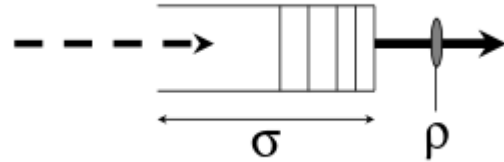
# Introduction to Computer Networks

## Traffic Streams & Scheduling



# Traffic Streams

- ▶  $\sigma$  – Buffer size.
- ▶  $\rho$  – Rate of drained traffic.

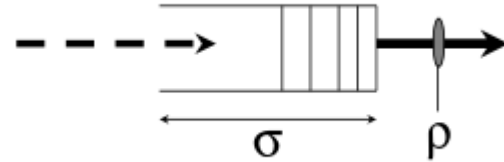


- ▶  $R(t)$ : The instantaneous rate of incoming traffic stream (bits/sec).
  - Usually assume that  $R(t) \in \{0, C_{in}\}$ .
  - $C_{in}$ : The maximum transmission rate of the incoming stream (bits/sec).
- ▶ The total incoming traffic in every interval must be at most buffer available capacity plus the total outgoing traffic in this interval.

$$\int_x^y R(t)dt \leq \sigma + (y - x)\rho$$

# Traffic Streams

- ▶  $\sigma$  – Buffer size.
- ▶  $\rho$  – Rate of drained traffic.



- ▶ A Work Conserving discipline means the network element is never idle when packets await service.
- ▶ L: maximum size (in bits) of a burst.
- ▶ The buffer size must be at least max burst receiving time multiplied by buffer filling rate.

$$\sigma \geq \frac{L}{C_{in}} (C_{in} - \rho) = L \left( 1 - \frac{\rho}{C_{in}} \right)$$

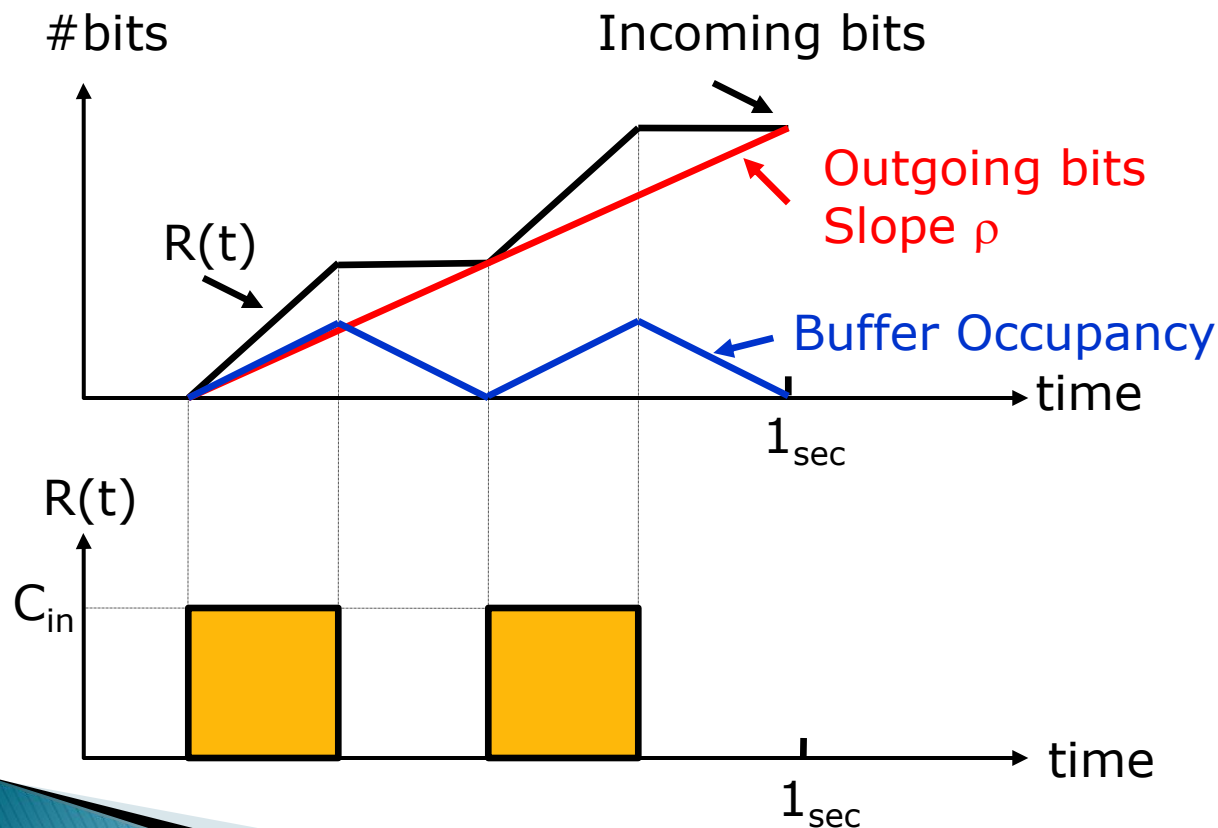
# Traffic Streams – Example

- ▶ An incoming flow has the following characteristics:
  - $C_{in} = 2048\text{bps}$
  - Packet size is 64B
  - Every second, 2 packets arrive
  - $\rho$  is constant
- ▶ Scenario A – packets are evenly distributed.
- ▶ Scenario B – packets arrive randomly.
- ▶ What is the required  $\rho$ ?
- ▶ What is the required  $\sigma$ ?

# Example – Scenario A

## packets are evenly distributed

- ▶ Graphic representation:



# Example – Scenario A

## packets are evenly distributed

- ▶ Packet size is 64B.
  - Meaning 512 bit.
- ▶ Every second, 2 packets arrive.
  - Meaning average incoming rate is 1024bps.

▶  $\Rightarrow \rho \geq 1024\text{bps}$

- Else  $\int_x^y R(t)dt \leq \sigma + (y - x)\rho$   
will not hold for finite  $\sigma$ .

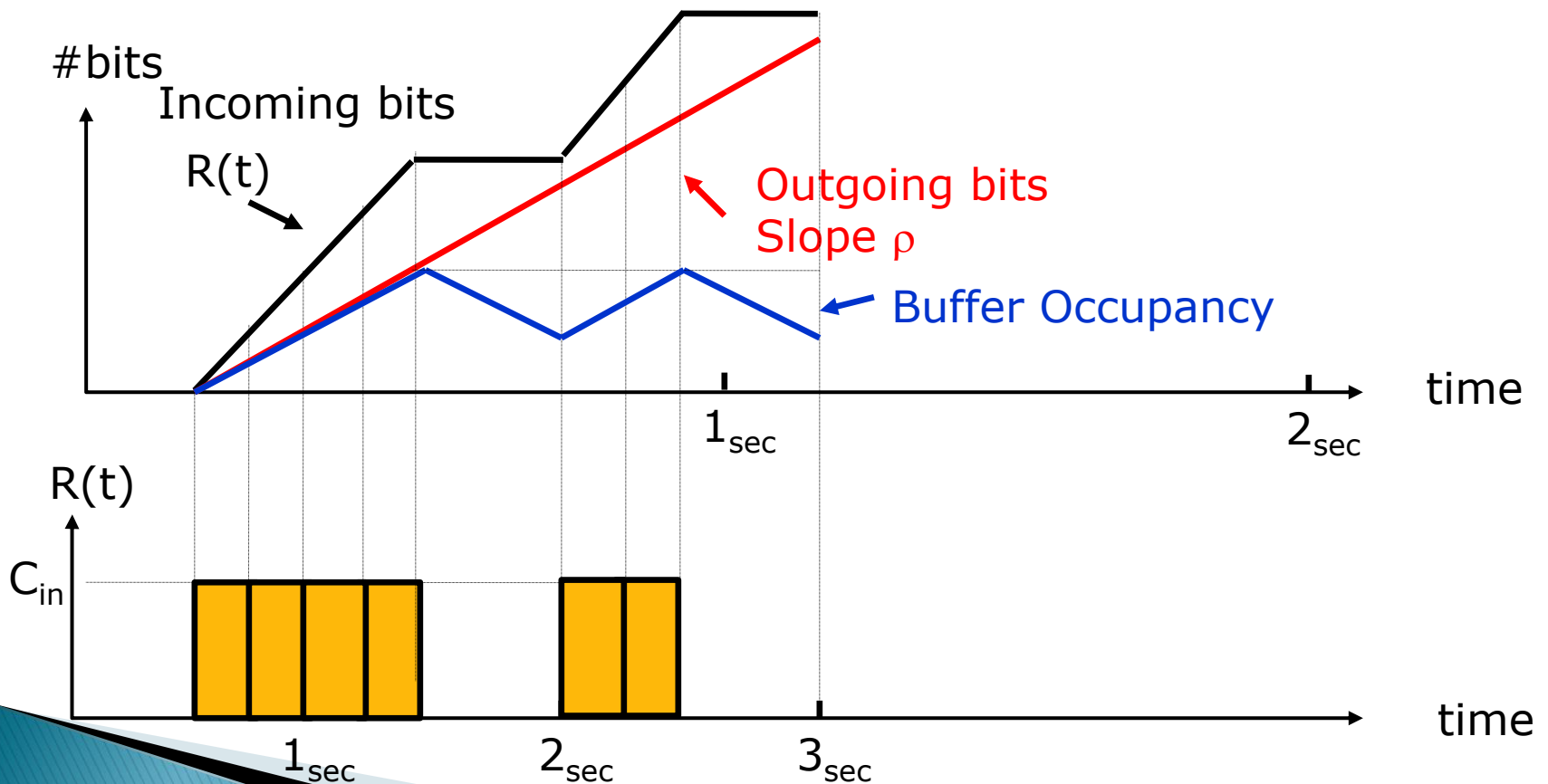
▶ Lets calculate  $\sigma$  :

$$\sigma \geq L \left( 1 - \frac{\rho}{C_{in}} \right) = 512\text{bit} \cdot \left( 1 - \frac{1024\text{bit / sec}}{2048\text{bit / sec}} \right) = 256\text{bit}$$

# Example – Scenario B

## packets arrive randomly

- ▶ Will the previous hold?
- ▶ Worst case scenario:



# Example – Scenario B

## packets arrive randomly

▶ Lets calculate  $\sigma$  : 
$$\sigma \geq L \left( 1 - \frac{\rho}{C_{in}} \right) = 512bit \cdot 4 \cdot \left( 1 - \frac{1024bit/sec}{2048bit/sec} \right) = 1024bit$$

▶ Lets check: 
$$\int_{0.5}^{1.5} R(t) = 2048bit$$
$$\sigma + (1.5 - 0.5) \cdot \rho = 1024bit + 1024bit = 2048bit$$

$$\int_{0.5}^{2.5} R(t) = 3072bit$$
$$\sigma + (2.5 - 0.5) \cdot \rho = 1024bit + 2 \cdot 1024bit = 3072bit$$

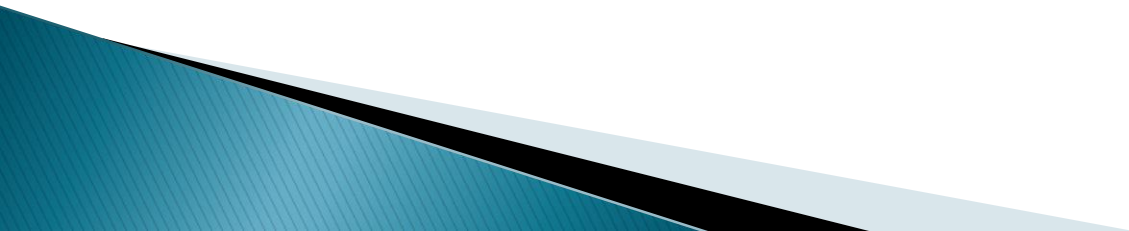
▶ And if  $\sigma$  does not change? 
$$\sigma = 256bit \geq 512bit \cdot 4 \cdot \left( 1 - \frac{\rho}{2048bit/sec} \right)$$
$$\Rightarrow \rho \geq 1792bit/sec$$

▶ Check as before.



# Introduction to Computer Networks

## Scheduling



# Scheduling

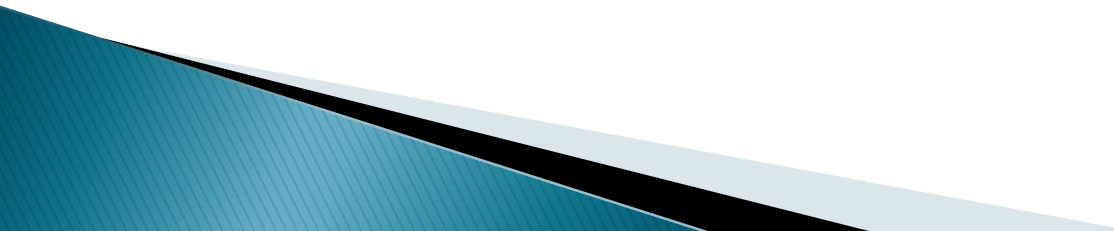
## ▶ Round Robin

- In each cycle take 1 packet from each queue.

## ▶ Weighted Round Robin

- If total weights is  $W$ , it takes  $W$  rounds to complete a cycle.
- Each flow  $i$  transmits  $w_i$  packets in a cycle.

## ▶ Deficit Round Robin

- Each flow has a credit counter.
  - Credit counter is increased by “quantum” with every cycle.
  - A packet is sent only if there is enough credit.
- 

# Example

## ▶ Flow 1:

- Packets  $A_1, A_2, A_3, \dots, A_n$
- Packet size is 64B

## ▶ Flow 2:

- Packets  $B_1, B_2, B_3, \dots, B_n$
- Packet size is 256B

## ▶ Flow 3:

- Packets  $C_1, C_2, C_3, \dots, C_n$
- Packet size is 64B, 128B, 192B ...  $64B \cdot (1 + n \% 10)$

# Example – Round Robin

- ▶ Order of Transmission:
  - A1,B1,C1,A2,B2,C2,A3,B3,C3....
- ▶ # of Bytes served from each flow over 10 cycles:
  - Total #Bytes served from A:  $64B * 10 = 640B$
  - Total #Bytes served from B:  $256B * 10 = 2560B$
  - Total #Bytes served from C:  $64B * 10 * (1 + 10) / 2 = 3520B$
  - Total #Bytes served:  $640B + 2560B + 3520B = 6720B$
- ▶ Percentage of BW served from each flow over 10 cycles:
  - A:  $640B / 6720B = 9.6\%$
  - B:  $2560B / 6720B = 38\%$
  - C:  $3520B / 6720B = 52.4\%$

# Example – Weighted Round Robin

- ▶  $W_A=10$ ,  $W_B=2$ ,  $W_C=5$ 
  - $W(\text{cycle}) = 17$
- ▶ Order of Transmission:
  - $A1, A2, \dots, A10, B1, B2, C1, C2, C3, C4, C5 \dots$
- ▶ # of Bytes served from each flow over 2 cycles (full run of C):
  - Total #Bytes served from A:  $64B * 10 * 2 = 1280B$
  - Total #Bytes served from B:  $256B * 2 * 2 = 1024B$
  - Total #Bytes served from C:  $64B * 5 * 2 * (1 + 10) / 2 = 3520B$
  - Total #Bytes served:  $1280B + 1024B + 3520B = 5824B$

# Example – Weighted Round Robin

- ▶  $W_A=10, W_B=2, W_C=5$ 
  - $W(\text{cycle}) = 17$
- ▶ # of Bytes served from each flow over 2 cycles (full run of C):
  - Total #Bytes served from A:  $64B \cdot 10 \cdot 2 = 1280B$
  - Total #Bytes served from B:  $256B \cdot 2 \cdot 2 = 1024B$
  - Total #Bytes served from C:  $64B \cdot 5 \cdot 2 \cdot (1+10)/2 = 3520B$
  - Total #Bytes served:  $1280B + 1024B + 3520B = 5824B$
- ▶ Percentage of BW served from each flow over 2 cycles :
  - A:  $1280B/5824B = 22\%$
  - B:  $1024B/5824B = 17.6\%$
  - C:  $3520B/5824B = 60.4\%$

# Example – Deficit Round Robin

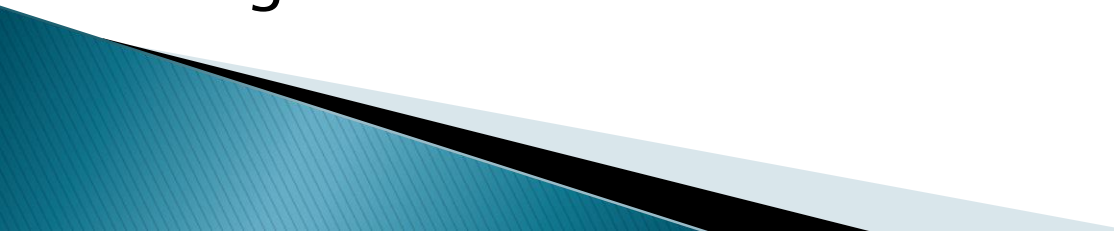
- ▶ Quantum=64B
  - Flow A: Packet size = Quantum  $\Rightarrow$  will transmit every cycle.
  - Flow B: Packet size = Quantum\*4  $\Rightarrow$  will transmit every 4 cycles.
  - Flow C: Packet n size = Quantum\*n  $\Rightarrow$  will transmit on n-th cycle.
  - Flow C will need  $1+2+..+10=55$  cycles to send 10 packets.
- ▶ Order of Transmission:
  - A1,C1,A2,A3,C2,A4,B1,A5,A6,C3,....
    - A is served on cycles 1,2,3,4...
    - B is served on cycles 4,8,12,16...
    - C is served on cycles 1,3,6,10,....

# Example – Deficit Round Robin

- ▶ # of Bytes served from each flow over 10 cycles:
  - Total #Bytes served from A:  $64B * 10 = 640B$
  - Total #Bytes served from B:  $256B * 2 = 512B$
  - Total #Bytes served from C:  $64B * 4 * (1 + 4) / 2 = 640B$
  - Total #Bytes served:  $640B + 512B + 640B = 1792B$
- ▶ Percentage of BW served from each flow:
  - A:  $640B / 1792B = 35.7\%$
  - B:  $512B / 1792B = 28.6\%$
  - C:  $640B / 1792B = 35.7\%$
- ▶ Is this fair to B?
- ▶ Selecting the observation period is important!



# Online Algorithms

- ▶ Previous slides assumed that FIFOs are always full, and the scheduler just needs to rotate between them.
  - ▶ Online algorithms have no knowledge of the future.
  - ▶ Make the best choice based on what you know NOW.
  - ▶ Like in real life...
  - ▶ This obviously changes the results of scheduling algorithms.
- 

# Online Algorithms – Example

- ▶ Assume the following arrival pattern:

Time	0	5	10	15	17	20	25	30	35
Flow A	A1				A2	A3	A4		A5
Flow B		B1		B2		B3	B4		B5
Flow C			C1		C2	C3		C4	C5

- ▶ Transmission rate is 100B/Sec.
- ▶ Flow A sends 100B packets.
- ▶ Flow B sends 200B packets.
- ▶ Flow C sends 500B packets.

# Online Algorithms – Example

- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using RR?

Time	0	5	10	15	17	20	25	30	35
Flow A	A1				A2	A3	A4		A5
Flow B		B1		B2		B3	B4		B5
Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):
  - A1(0),B1(5),C1(10),B2(15),C2(17),A2(22),B3(23),C3(25),  
A3(30),B4(31),C4(33),A4(38),B5(39),C5(41),A5(46).

# Online Algorithms – Example

- ▶ What will be the transmission order using WRR, with optimal weights (for a long duration)?

Time	0	5	10	15	17	20	25	30	35
Flow A	A1				A2	A3	A4		A5
Flow B		B1		B2		B3	B4		B5
Flow C			C1		C2	C3		C4	C5

- ▶ Optimal weights are in reverse ratio to packet sizes (100:200:500), meaning 10:5:2.
- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), C2(17), C3(22), A2(27), A3(28),  
A4(29), B3(30), B4(32), C4(34), C5(39), A5(44), B5(45).

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Flow\Time	0	5	10	15	17	20	25	30	35
Flow A	A1				A2	A3	A4		A5
Flow B		B1		B2		B3	B4		B5
Flow C			C1		C2	C3		C4	C5

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
200	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 0

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),

Time = 1



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),

Time = 1

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),

Time = 5

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
200	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),

Time = 5

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 7

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 10

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 10

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
300	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 10

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
400	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 10



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
500	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5),

Time = 10

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10),

Time = 15

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10),

Time = 15

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
200	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10),

Time = 15

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),

Time = 17

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15),

Time = 17

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
200	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),

Time = 17

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),

Time = 18



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), A2(17),

Time = 18

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), A2(17),

Time = 18

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
500	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),

Time = 18

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), A2(17), C2(18),

Time = 23

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
200	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),C2(18),

Time = 23

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23),

Time = 24

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),C2(18),A3(23),

Time = 24

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),C2(18),A3(23),

Time = 24



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23),

Time = 24

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
200	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):  
A1(0),B1(5),C1(10),B2(15),A2(17),C2(18),A3(23),

Time = 24

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 26

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 26

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
200	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 26

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 27

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
200	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 27

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
300	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 27

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26),



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
300	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 27

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
200	Flow B		B1		B2		B3	B4		B5
300	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 27

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
300	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 29

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
400	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 29

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
500	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 29

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 34

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 34

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
500	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 34

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29),



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 39

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
200	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 39

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 40

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 40

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
100	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 40

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
100	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 40

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
200	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 40

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
100	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 42

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39), B5(40),



# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
500	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 42

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39), B5(40),

# Online Algorithms – Example

- ▶ A : 100B, B : 200B, C : 500B.
- ▶ A : 1sec, B : 2sec, C : 5sec.
- ▶ What will be the transmission order using DRR, with weights 2:1:1, and a 100B quantum?

Credit	Flow	0	5	10	15	17	20	25	30	35
0	Flow A	A1				A2	A3	A4		A5
0	Flow B		B1		B2		B3	B4		B5
0	Flow C			C1		C2	C3		C4	C5

- ▶ Packet (transmission start time):

Time = 47

A1(0), B1(5), C1(10), B2(15), A2(17), C2(18), A3(23), B3(24),  
A4(26), B4(27), C3(29), C4(34), A5(39), B5(40), C5(42).