# Network Engineering

## Lecture 8. End to end delay

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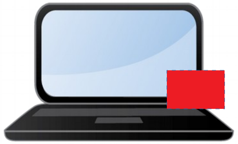
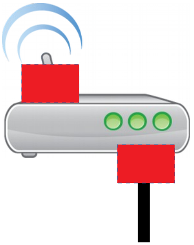
# Routers, Access Networks (Switchs/APs), Hosts

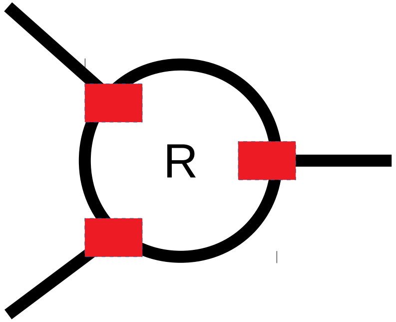
host

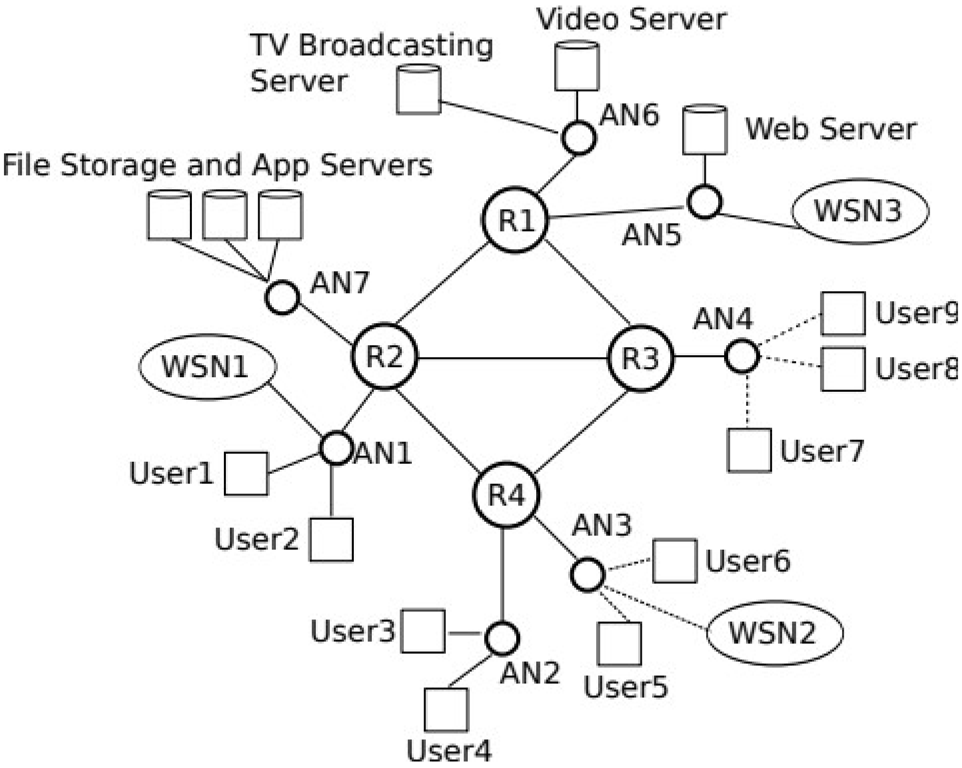


AN=switch

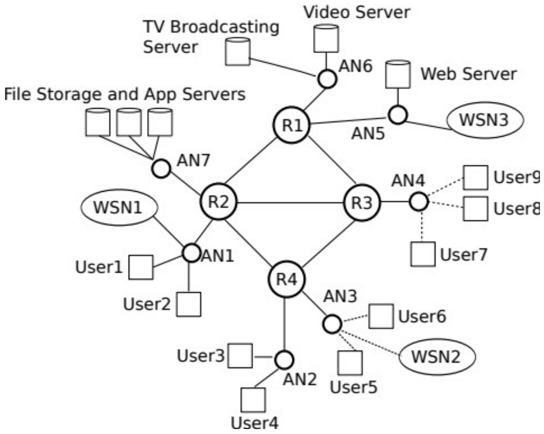


Router





# Multiple hops between sender and receiver



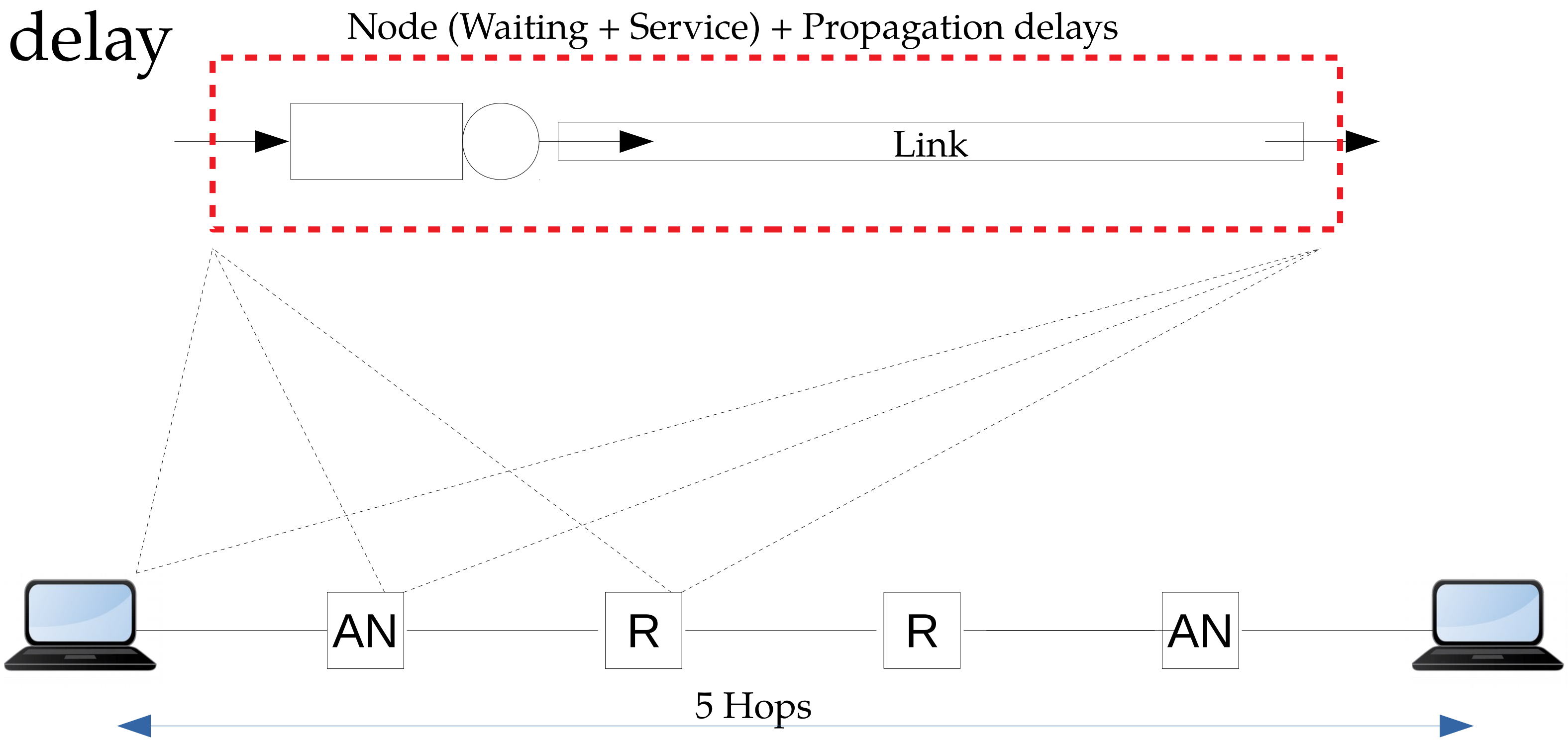
Packets traverse multiple hops from their source to their destination. For example, if User4 and User1 have VoIP conversation, their packets can traverse AN1, R2, R4 and AN2.

In this chapter we explain how the average end-to-end packet delay can be computed. To compute the end-to-end delay we have to know the following information:

- The route that the packets follow from their source to their destination. The route that a packet follows is indicated by the set of links $\mathcal{F}$ it traverses.
- The aggregate packet arrival rate to every node in the route.
- The stochastic routing vector $\boldsymbol{\alpha}$ at each network element. The stochastic routing vector indicates the probability that a packet is directed to a certain output network interface.

Node = Router / Access Network / Host

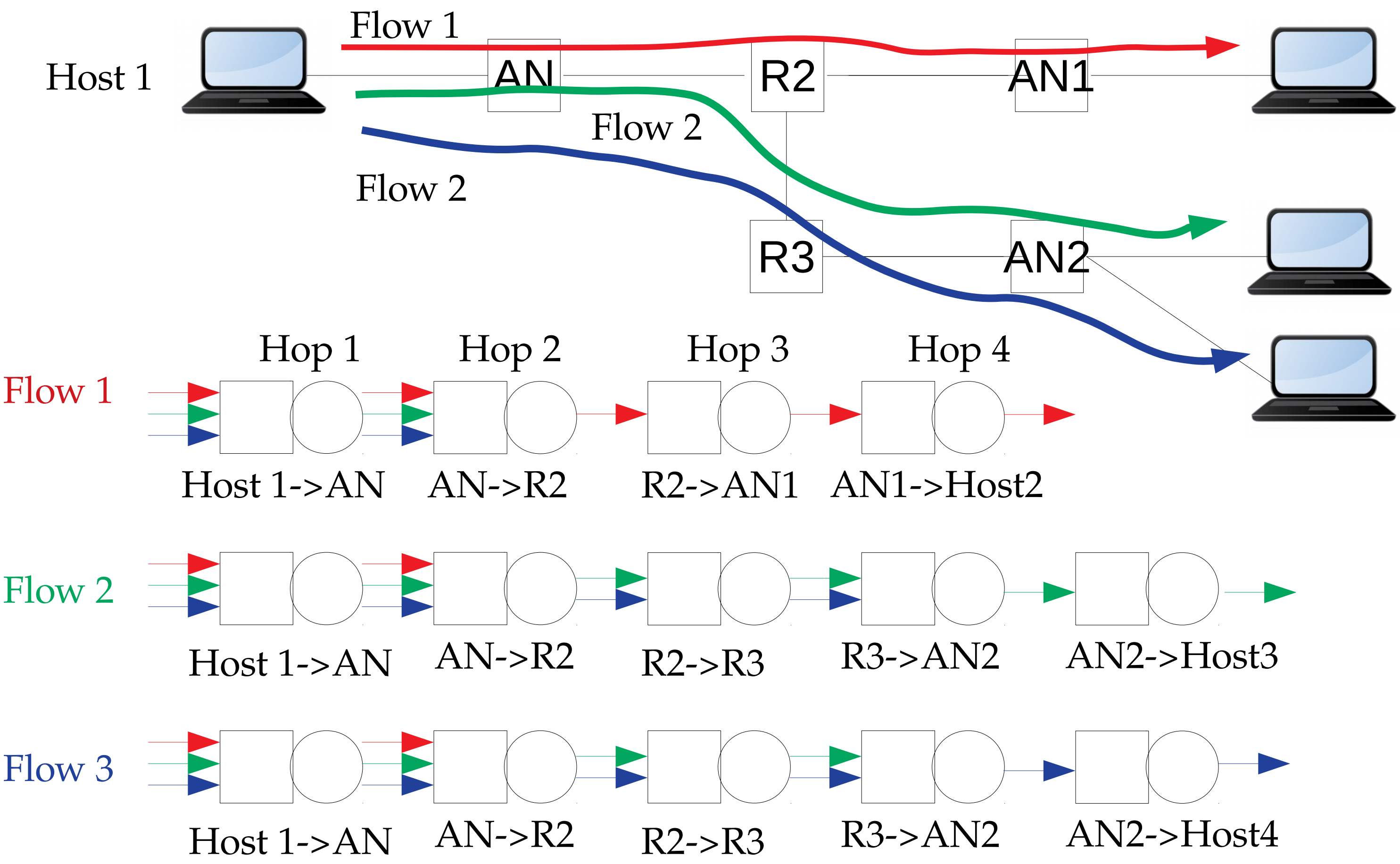
# Hop delay



Node (Waiting + Service) + Propagation delays

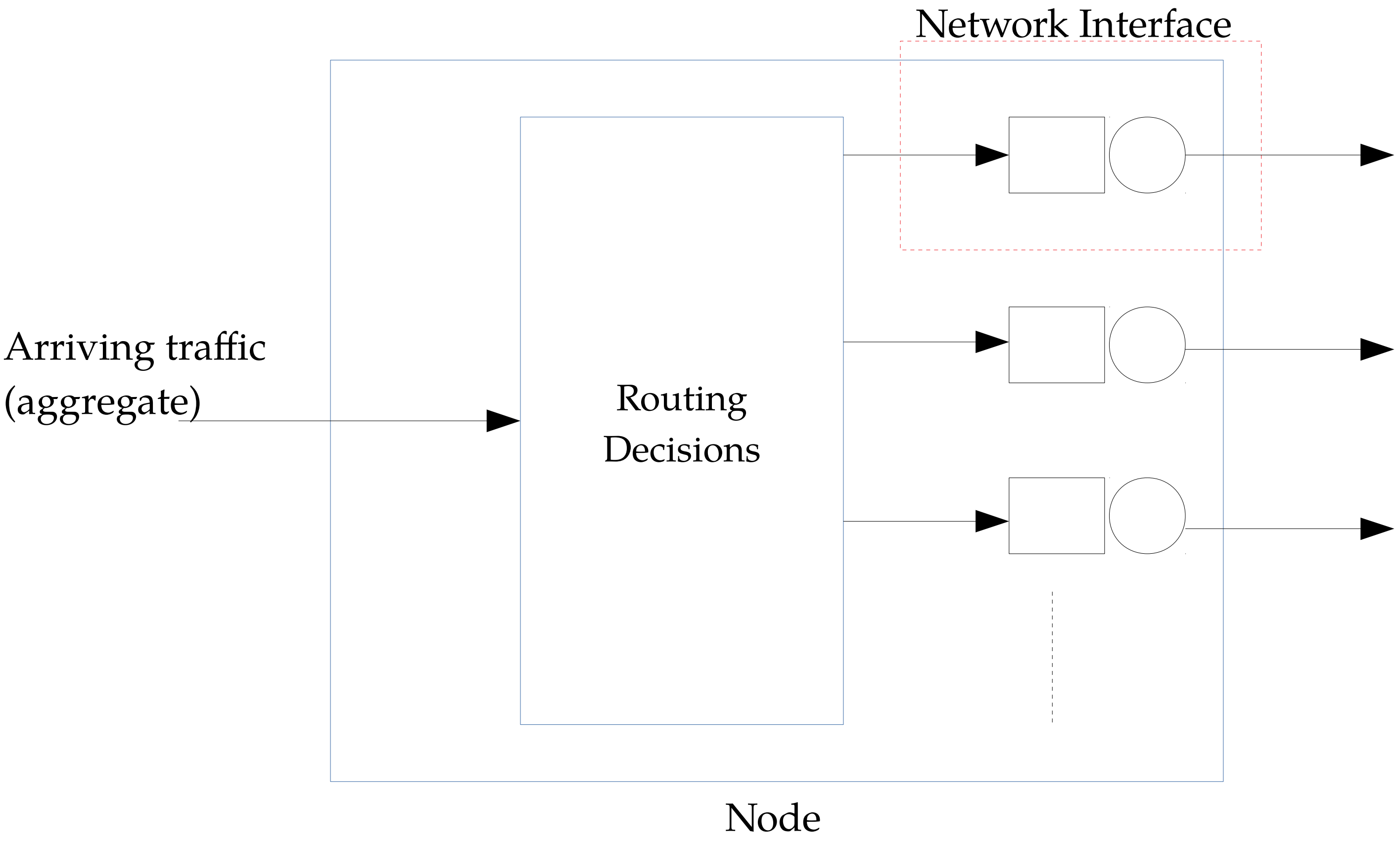
$$E[D_{\mathrm{e2e}}] = \sum_{\forall f \in \mathcal{F}} \left( E[D_{\mathrm{node}}]_f + E[D_{\mathrm{p}}]_f \right)$$

# End to end representation (per flow)

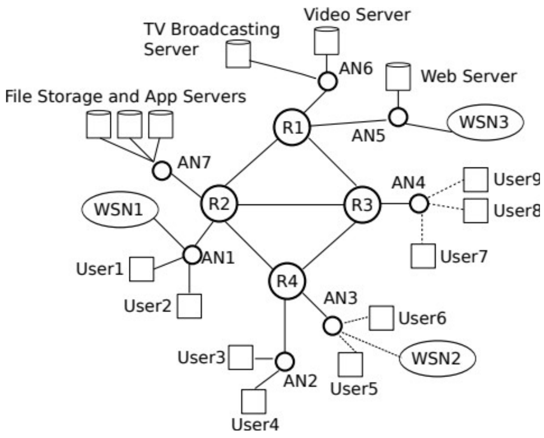


We must consider the route the packets follow, and the interfaces they share

# Router / Access Network / Host model



# Example



**End to End delay for a video transmission**

Consider that User9 is watching a video transmitted by the video server connected to AN6. The route that the packets follow has 5 hops (Video Server, AN6, R1, R3, AN4 and User9). Each hop is modeled by an M/M/1 queue as shown in Figure 6.2.

Given that $\lambda = 200$ packets/second, and $E[L] = 2000$ bits, compute the expected end-to-end packet delay.

**Solution:** We have to compute the $E[D_{\text{hop}}] = E[D] + E[D_p]$ for each hop:

Note that by referring to a M/M/1 queue we indicate that packet arrivals follow
A Poisson process, and that packet sizes are exponentially distributed.

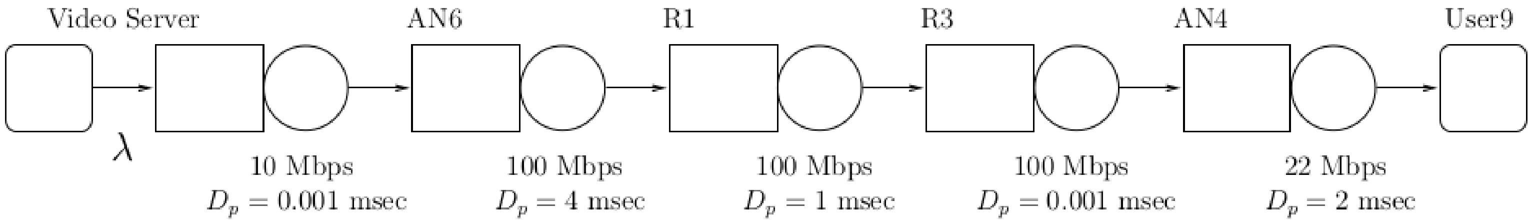


Figure 6.2: Network for Example 1

- $E[D_{\text{hop,VS}}] = \frac{1}{\frac{10E6}{2000} - 200} + 0.001 \cdot 10^{-3} = 2.0933 \cdot 10^{-4}$ seconds.
- $E[D_{\text{hop,AN6}}] = \frac{1}{\frac{100E6}{2000} - 200} + 4 \cdot 10^{-3} = 0.0040201$ seconds.
- $E[D_{\text{hop,R1}}] = \frac{1}{\frac{100E6}{2000} - 200} + 1 \cdot 10^{-3} = 0.0010201$ seconds.
- $E[D_{\text{hop,R3}}] = \frac{1}{\frac{100E6}{2000} - 200} + 0.001 \cdot 10^{-3} = 2.1080 \cdot 10^{-5}$ seconds.
- $E[D_{\text{hop,AN4}}] = \frac{1}{\frac{22E6}{2000} - 200} + 2 \cdot 10^{-3} = 0.0020926$ seconds.

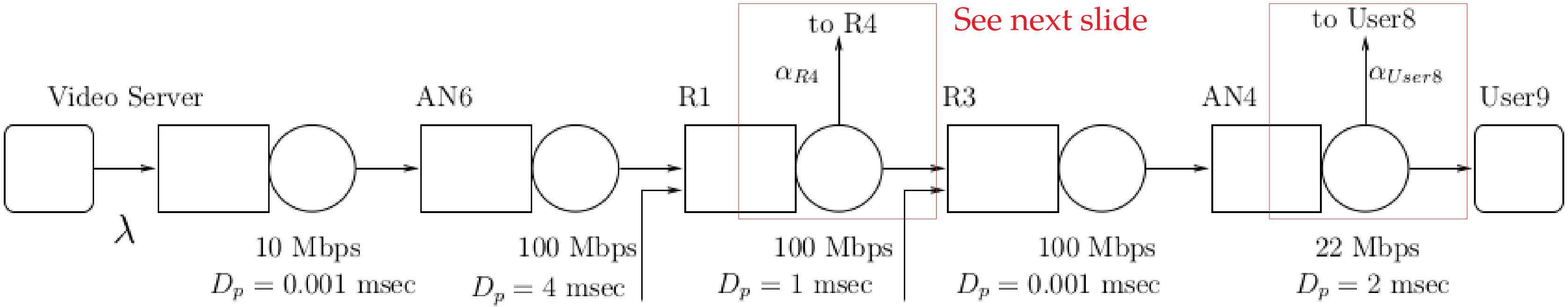
Finally, the end-to-end delay is computed by adding all the previous delays, and the result is:

$$E[D_{\text{e2e}}] = 7.3632 \ \ \text{msecs}$$

# Background Traffic

In this second example, there appears background traffic in the same route of the video packets, as shown in Figure 6.3. Consider that the average packet length is $E[L] = 2000$ bits and that

$$\alpha_{R4} = \frac{\lambda_{B1}}{\lambda_{B1} + \lambda} = 0.99593 \qquad \alpha_{User8} = \frac{\lambda_{B2}}{\lambda_{B2} + \lambda} = 0.92308$$



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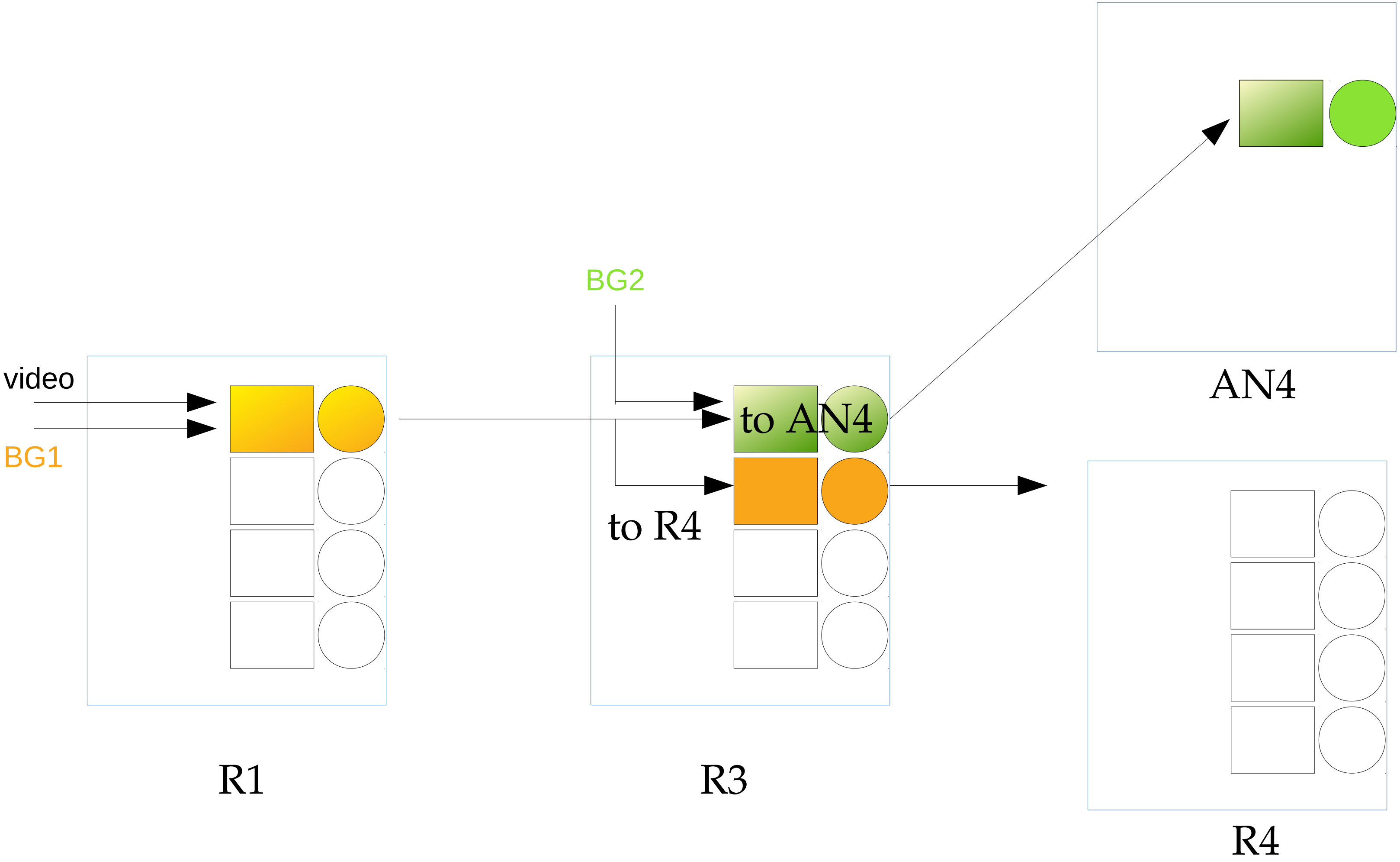
$\lambda_{B1} = 49000$ packets/second (goes through R4)

$\lambda_{B2} = 2400$ packets/second (goes to User 8)



*AN4 is a Wireless AP (single Network interface)*

- $E[D_{\text{hop,VS}}] = \frac{1}{\frac{10E6}{2000} - 200} + 0.001 \cdot 10^{-3} = 2.0933 \cdot 10^{-4}$ seconds.
- $E[D_{\text{hop,AN6}}] = \frac{1}{\frac{100E6}{2000} - 200} + 4 \cdot 10^{-3} = 0.0040201$ seconds.
- $E[D_{\text{hop,R1}}] = \frac{1}{\frac{100E6}{2000} - (49000+200)} + 1 \cdot 10^{-3} = 0.0022500$ seconds.
- $E[D_{\text{hop,R3}}] = \frac{1}{\frac{100E6}{2000} - (2400+200)} + 0.001 \cdot 10^{-3} = 2.2097 \cdot 10^{-5}$ seconds.
- $E[D_{\text{hop,AN4}}] = \frac{1}{\frac{22E6}{2000} - (2400+200)} + 2 \cdot 10^{-3} = 0.0021190$ seconds.

Finally, the end-to-end delay is computed by adding all the previous delays, and the result is:

$$E[D_{\text{e2e}}] = 8.6206 \quad \text{msecs}$$