Network Management Techniques to support QoS requirements for eHealth Applications

Q1: For e-health applications, specifically remote patient monitoring systems, they can be considered an inelastic application, and the QoS requirements are:

Zero Packet loss: To ensure that patient data such as their vitals (heart rate etc) are not lost in transmission, as such data is potentially life-critical and could represent the difference between saving a life and a lost life, if the emergency support arrives on time to rescue the patient.

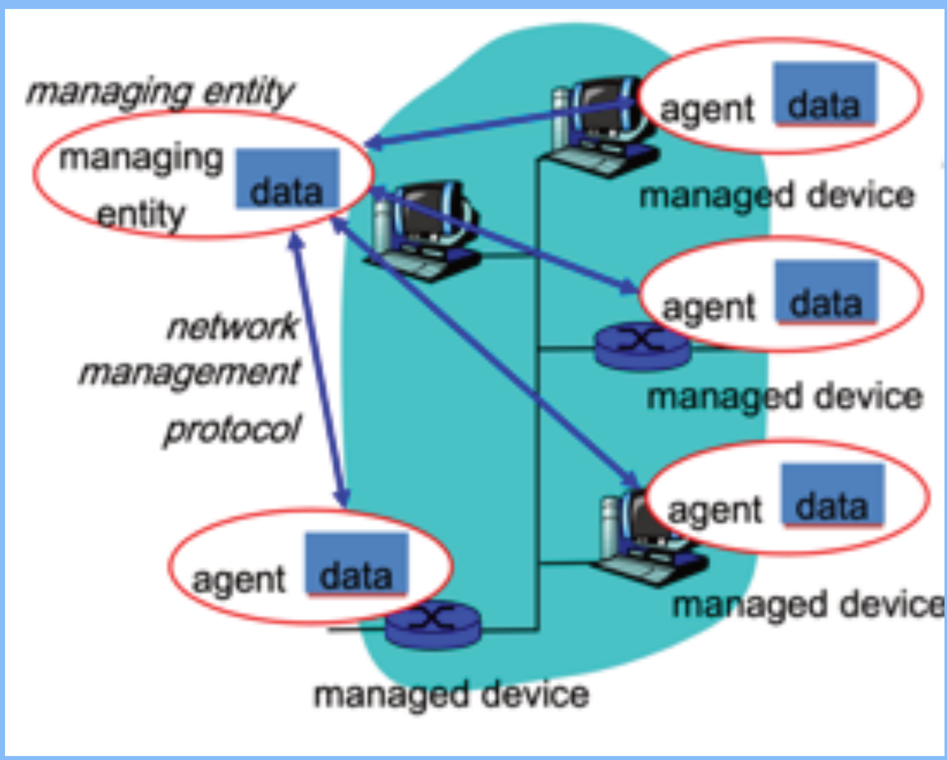
Low **Delay** / low latency: Similarly, we want to have as little delay as possible because if for example the vitals are down, we want to know immediately to send emergency assistance over and arriving earlier could be the difference between life and death for the patient.

Guaranteed **bandwidth/sustained rate**: Provide minimum bandwidth guarantee so that the network connection will not be down, which can be the difference between life and death as critical vitals information is not delivered due to network being unavailable because of congestion (if there are multiple patients on the same network), etc.

Managing entity:

- **Definition:** Managing entity is an application, typically with a human in the loop, running in a centralized network management station in the network operations. It is the locus of activity of network management which can:
  - Control the collection, processing, analysis, and/or display of network management information
  - Initiate action to control network behavior
  - Serve as an interface between human (network administrator) and network devices
  - Support fault management: To log, detect, and respond to fault conditions in the network + Immediate handling of transient network failure
- **In e-health applications,** remote monitoring devices such as trackers, vitals sign recorders can be connected on the network and be managed and monitored centrally by a managing entity, overseen by a network administrator. These can be queried with a Network management protocol
- **To support zero packet loss**, managing entity can be used to monitor packet loss rate for the monitoring devices centrally and analyze root cause of losses (queue drop or link error, etc.). It also can collect log information in the event of network failures for troubleshooting, so that packet loss is minimised. It can also alert network administrator by sending information to respond timely to contingencies.
- **To support low delay,** it can have a centralised data collection for Performance analysis: To quantify, measure, report on the delay parameters for packets. So that one can identify possible sources of congestion at the router which can result in longer delays. This data can also be used in long-term planning for varying traffic demand

The main network management techniques revolve around such a system which consists of the following components:



Managed device:

- **Definition:** a piece of network equipment (including its software) that resides on a managed network
- **In remote health monitoring systems**, these could be the vital signs trackers (such as a blood pressure cuff and biosensors, smart watches). These non-obtrusive trackers that patients can wear outside the hospital should be able to send data rapidly, including alerts in the case of deteriorations, back to healthcare providers.
- **To support zero packet loss & low delay**, these devices contain a network management agent, a process running in the managed device that communicates with the managing entity, taking loca actions at the managed device under the command and control of the managing device. This includes sending QoS-related data back to the managing entity which can be monitored for data analysis or to track any anomalous behaviour

Network Management protocol:

- **Definition:** It can allow managing entity to query status of managed devices and indirectly take actions at these device via its agent. An example is SNMP (Simple Network management protocol)
- **To support zero packet loss & low delay,** agent in the monitoring devices can use the network management protocol to inform managing entity of exceptional events (e.g., component failure or violation of performance thresholds)

Question 1 Text (for reference if the words in the infographic are too small):

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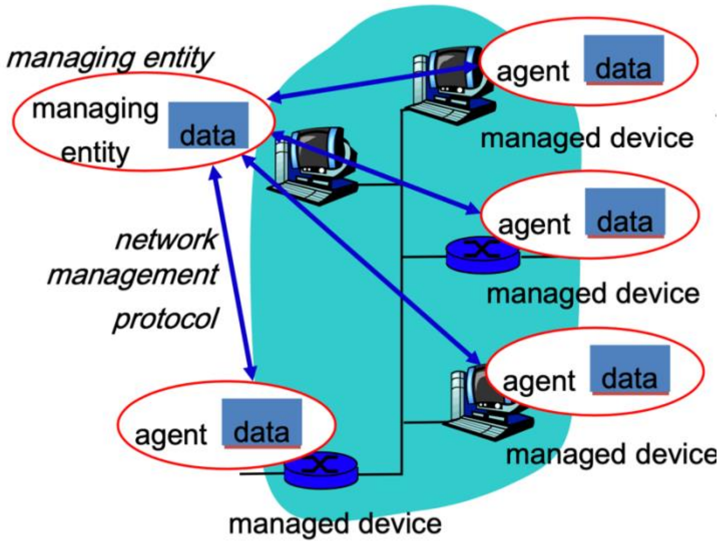

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Q2. Calculate the throughput of each source and the average throughput of the priority scheduling.

First, we can calculate the probability that each source is in the 'On' state:

Probability of On state for $S1 = \frac{10}{10+30} = 0.25 = \frac{1}{4}$

$S2 = \frac{50}{50+20} = \frac{5}{7} = 0.714$

$S3 = \frac{30}{30+60} = \frac{1}{3} = 0.333$

For S1, whenever S1 is On and generates a packet, the packet will be scheduled for transmission by the scheduler immediately, irregardless of other packets generated by other sources. Hence,

Throughput for S1 (with priority scheduling) = 0.25 * 1 = **0.25 packets per time slot**

For S2, even if it generates a packet in that time slot, that packet may be dropped. Packets from S2 are only transmitted if S1 is Off and S2 is On in that time slot. Hence,

Throughput for S2 (with priority scheduling):
= P (S1 is Off) * P (S2 is On) * 1
= 0.75 * (5/7)
= **0.538 packets per time slot**

For S3, even if it generates a packet in that time slot, that packet may be dropped. Packets from S3 are only transmitted if both S1 and S2 are Off and S3 is On in that time slot. Hence, Throughput for S3:

= P (S1 is Off) * P (S2 is Off) * P (S3 is On) * 1

= 0.75 * (2/7) * (1/3)

= **0.0714 packets per time slot**

In each timeslot, there is either 1 or 0 packet transmitted by the scheduler. To get the average throughput of the priority scheduling, we can take 1 – P(no packet is transmitted in that timeslot):

P (no packet is transmitted in a timeslot)

= P (S1 is Off) * P (S2 is Off) * P (S3 is Off)

= 0.75 * (2/7) * (2/3)

= 1/7

Average throughput of the priority scheduling:

= 1 * (1 – P(no packet is transmitted)) + 0 * P(no packet is transmitted)
= 1 * (1 - 1/7) + 0 * (1/7)
= 6/7
= 0.857 packets per time slot

Additional calculations (if there was a queue/buffer):

To get the average throughput of the priority scheduling, we can first calculate the probability for each scenario:

On/Off?			**Probability**	**Total no. of packets added to buffer**	**Probability**
Source 1	**Source 2**	**Source 3**			
On	On	On	0.25 * 0.7143 * 0.3333 = 0.059519	3	0.059519
Off	On	On	0.75 * 0.7143 * 0.3333 = 0.178557	2	0.178557
On	Off	On	0.25 * 0.2857 * 0.3333 = 0.023806	2	0.023806
On	On	Off	0.25 * 0.7143 * 0.6667 = 0.119056	2	0.119056

Off	Off	On	0.75 * 0.2857 * 0.3333 = 0.071418	1	0.071418
Off	On	Off	0.75 * 0.7143 * 0.6667 = 0.357168	1	0.357168
On	Off	Off	0.25 * 0.2857 * 0.6667 = 0.047619	1	0.047619
Off	Off	Off	0.75 * 0.2857 * 0.6667 = 0.142857	0	0.142857

Adding some of the numbers up, we get this:

Total no. of packets added to buffer	**Total Probability**
3	0.059519
2	0.321419
1	0.476205
0	0.142857

For any timeslot, the scheduler transmits either 1 packet or 0 packets. To obtain the average throughput, I would be attempting to calculate the probability that there is no packet to transmit in a timeslot. Given that there are n timeslots, we have:

At timeslot T1, probability that there is no packet to transmit (i.e. throughput for that timeslot is 0):

P(T1 no packet to transmit) = P(0 packets transmitted in T1) = 1/7

At timeslot T2, probability that there is no packet to transmit:

P(T2 no packet to transmit)
= P(0 packets transmitted in T2) * P(1 or less packets transmitted in T1)
= 1/7 * (1/7 + 0.476) = 0.0884

At timeslot T3, probability that there is no packet to transmit:

P(T3 no packet to transmit)

= P(0 packets transmitted in T3) * P(1 or less packets transmitted in T2) * P(2 or less packets transmitted in T1)
= 1/7 * (1/7 + 0.476) * (1 – 0.0595)
= 0.08315

At timeslot T4, probability that there is no packet to transmit:

= P(0 packets transmitted in T4) * P(1 or less packets transmitted in T3) * P(2 or less packets transmitted in T2)
= 1/7 * (1/7 + 0.476) * (1 – 0.0595)
= 0.08315

At timeslot T5, probability that there is no packet to transmit:

= P(0 packets transmitted in T5) * P(1 or less packets transmitted in T4) * P(2 or less packets transmitted in T3)
= 1/7 * (1/7 + 0.476) * (1 – 0.0595)
= 0.08315

…

At timeslot T_n, probability that there is no packet to transmit:

= P(0 packets transmitted in T_n) * P(1 or less packets transmitted in T_{n-1}) * P(2 or less packets transmitted in T_{n-2})
= 1/7 * (1/7 + 0.476) * (1 – 0.0595)
= 0.08315

Hence, we can see that if n >> 2, then on average, the probability that there is no packet transmitted in a timeslot is:
≈ 1/7 * (1/7 + 0.476) * (1 – 0.0595)

≈ 0.08314788

Hence, to obtain the average throughput of the scheduler, we have:

$0*(0.08314788) + 1*(1 - 0.08314788) = 1 - 0.08314788 = 0.917$ packets transmitted per timeslot

Q3.

Calculate the probability distribution of the throughput and the average throughput of the packet transmission from Node A to Node B.

Here, throughput is taken as no. of packets transmitted:

Available? (Y/N)				Probability	Throughput
R1	R2	R3	R4		
Y	Y	Y	Y	0.9756 * 0.9615 * 0.9877 * 0.9524 = 0.8824	4
N	Y	Y	Y	0.0244 * 0.9615 * 0.9877 * 0.9524 = 0.022069	3
Y	N	Y	Y	0.9756 * 0.0385 * 0.9877 * 0.9524 = 0.035333	3
Y	Y	N	Y	0.9756 * 0.9615 * 0.0123 * 0.9524 = 0.010989	3
Y	Y	Y	N	0.9756 * 0.9615 * 0.9877 * 0.0476 = 0.044101	3
N	N	Y	Y	0.0244 * 0.0385 * 0.9877 * 0.9524 = 0.000884	2
N	Y	N	Y	0.0244 * 0.9615 * 0.0123 * 0.9524 = 0.000275	2
N	Y	Y	N	0.0244 * 0.9615 * 0.9877 * 0.0476 = 0.001103	2
Y	N	N	Y	0.9756 * 0.0385 * 0.0123 * 0.9524 = 0.00044	2
Y	N	Y	N	0.9756 * 0.0385 * 0.9877 * 0.0476 = 0.001766	2
Y	Y	N	N	0.9756 * 0.9615 * 0.0123 * 0.0476 = 0.000549	2
N	N	N	Y	0.0244 * 0.0385 * 0.0123 * 0.9524 = 0.000011	1
N	N	Y	N	0.0244 * 0.0385 * 0.9877 * 0.0476 = 0.000044	1
N	Y	N	N	0.0244 * 0.9615 * 0.0123 * 0.0476 = 0.000014	1
Y	N	N	N	0.9756 * 0.0385 * 0.0123 * 0.0476 = 0.000022	1
N	N	N	N	0.0244 * 0.0385 * 0.0123 * 0.0476 = 0.000001	0

Adding the probabilities together for each of the different throughputs, we arrive with this probability distribution of the throughput:

Throughput (no. of packets transmitted)	Total Probability
4	0.8824
3	0.112492
2	0.005017
1	0.000091
0	0.000001

Average throughput of the packet transmission from Node A to Node B:

= 4 * 0.8824 + 3 * 0.112492 + 2 * 0.005017 + 1 * 0.000091 + 0 * 0.000001
= 3.877
≈ 4 packets (rounded off)

Node A as an On-Off source is in the on state for 20 ms and in the off state for 30 ms on average. Calculate the throughput from Node A to Node B.

Probability of On state:

= 20 / (20+30) = 0.4

Throughput from Node A to Node B:

= 0.4 * 3.877 = 1.5508
≈ 1.55 packets (rounded off)

Q4i)

Indicate at which time slot that each of the packets P1,...,P13 will be transmitted for each of the scheduling schemes.

Time slot	Packet Transmitted (Round Robin)	Packet Transmitted (Weighted Round Robin)	Packet Transmitted (Priority Scheduling)
1	-	-	-
2	P1	P1	P1
3	P2	P2	P2
4	P4	P3	P5
5	P5	P4	P3
6	P3	P6	P8
7	P6	P5	P7
8	P8	P7	P9
9	P7	P9	P11
10	P10	P10	P12
11	P11	P13	P4
12	P9	P8	P6
13	P13	P12	P10
14	-	P11	P13
15	P12	-	-
16	-	-	-

Q4ii)

Calculate average packet delay of each flow for each of the scheduling schemes.

First we can obtain the delay for each packet:

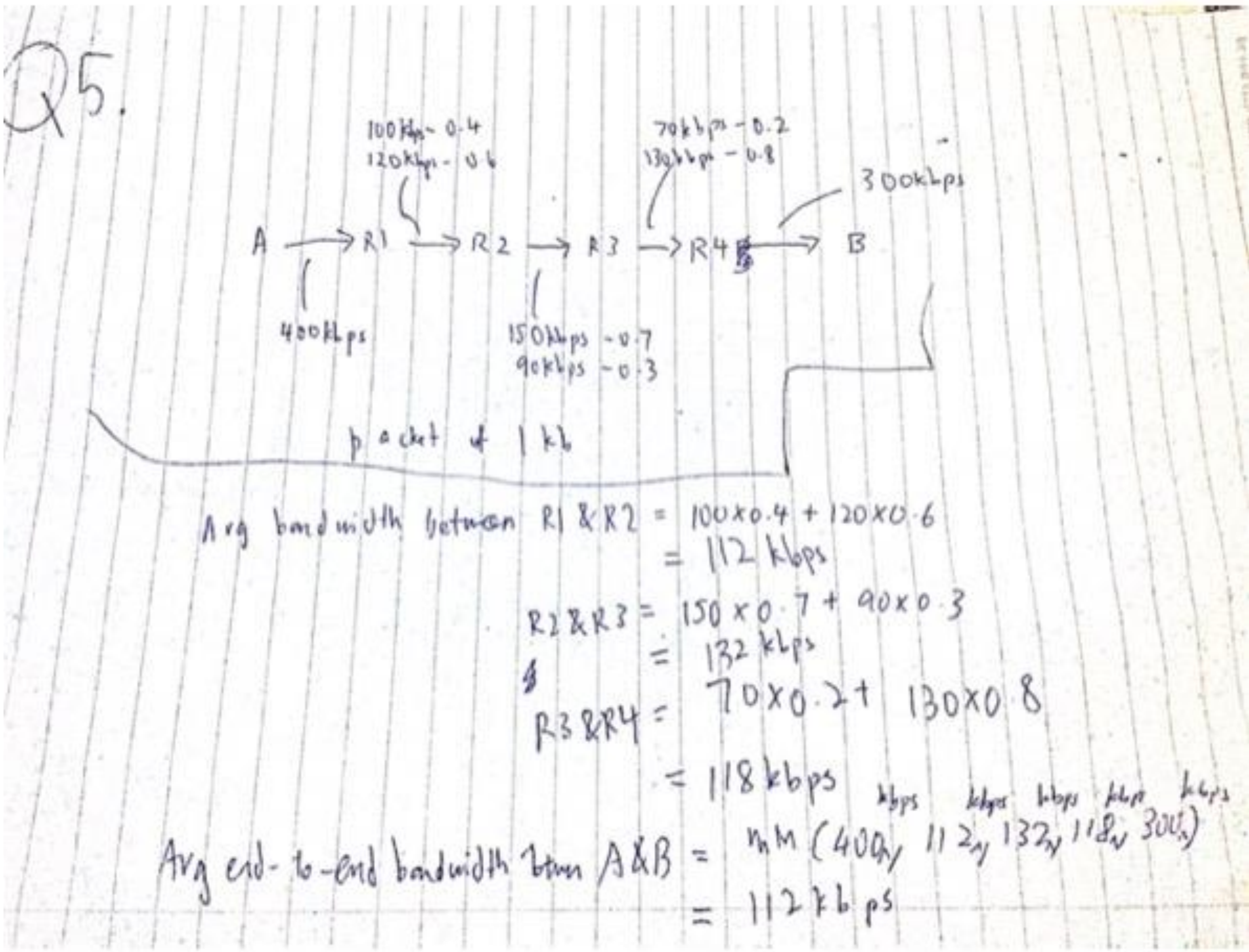
Packet	Delay (Round Robin)	Delay (Weighted Round Robin)	Delay (Priority Scheduling)
P1	1	1	1
P2	2	2	2
P3	4	2	3
P4	2	3	9
P5	2	4	1
P6	4	3	9
P7	5	4	3
P8	3	7	1
P9	6	3	2
P10	3	3	6
P11	3	6	1
P12	7	5	2
P13	5	3	6

Next we can calculate the average delay for each flow:

	Round Robin	**Weighted Round Robin**	**Priority Scheduling**
Average delay for flow 1	(1 + 2 + 3 + 3)/4 = 9/4 = 2.25	(1 + 4 + 7 + 6)/4 = 18/4 = 4.5	(1 + 1 + 1 + 1)/4 = 4/4 = 1
Average delay for flow 2	(2 + 4 + 5 + 6 + 7)/5 = 24/5 = 4.8	(2 + 2 + 4 + 3 + 5)/5 = 16/5 = 3.2	(2 + 3 + 3 + 2 + 2)/5 = 12/5 = 2.4
Average delay for flow 3	(2 + 4 + 3 + 5)/4 = 14/4 = 3.5	(3 + 3 + 3 + 3)/4 = 12/4 = 3	(9 + 9 + 6 + 6)/4 = 30/4 = 7.5

	Round Robin	**Weighted Round Robin**	**Priority Scheduling**
Average delay for flow 1	2.25	4.5	1
Average delay for flow 2	4.8	3.2	2.4
Average delay for flow 3	3.5	3	7.5

Q5. <u>Calculate the average end-to-end bandwidth between node A and node B. Calculate the average delay and end-to-end delay distribution from Node A to Node B.</u>



Considering transmission of a packet with size of 1,000 bits (1kb)

Delay from R1 --> R2 (s)	Delay from R2 --> R3 (s)	Delay from R3 --> R4 (s)	Probability
1/100	1/150	1/70	0.4*0.7*0.2=0.056
1/100	1/150	1/130	0.4*0.7*0.8=0.224
1/100	1/90	1/70	0.4*0.3*0.2=0.024
1/100	1/90	1/130	0.4*0.3*0.8=0.096
1/200	1/150	1/70	0.6*0.7*0.2=0.084
1/200	1/150	1/130	0.6*0.7*0.8=0.336
1/200	1/90	1/70	0.6*0.3*0.2=0.036
1/200	1/90	1/130	0.6*0.3*0.8=0.144

End-to-end delay distribution from Node A to Node B:

Probability	Total Time in seconds (incl fixed delay)
0.056	0.01 + 0.0067 + 0.0143 + 1/400 + 1/300 = 0.0368
0.224	0.01 + 0.0067 + 0.0077 + 1/400 + 1/300 = 0.0302
0.024	0.01 + 0.0111 + 0.0143 + 1/400 + 1/300 = 0.0412
0.096	0.01 + 0.0111 + 0.0077 + 1/400 + 1/300 = 0.0346
0.084	0.005 + 0.0067 + 0.0143 + 1/400 + 1/300 = 0.0318
0.336	0.005 + 0.0067 + 0.0077 + 1/400 + 1/300 = 0.0252
0.036	0.005 + 0.0111 + 0.0143 + 1/400 + 1/300 = 0.0362
0.144	0.005 + 0.0111 + 0.0077 + 1/400 + 1/300 = 0.0296

Combining both, we have:

Delay from R1 --> R2 (s)	Delay from R2 --> R3 (s)	Delay from R3 --> R4 (s)	Total Time in seconds (incl fixed delay)	Probability
1/100	1/150	1/70	0.0368	0.4*0.7*0.2=0.056
1/100	1/150	1/130	0.0302	0.4*0.7*0.8=0.224
1/100	1/90	1/70	0.0412	0.4*0.3*0.2=0.024
1/100	1/90	1/130	0.0346	0.4*0.3*0.8=0.096
1/200	1/150	1/70	0.0318	0.6*0.7*0.2=0.084
1/200	1/150	1/130	0.0252	0.6*0.7*0.8=0.336
1/200	1/90	1/70	0.0362	0.6*0.3*0.2=0.036
1/200	1/90	1/130	0.0296	0.6*0.3*0.8=0.144

Average delay from Node A to Node B:

= 0.0368 * 0.056 + 0.0302 * 0.224 + 0.0412 * 0.024 + 0.0346 * 0.096 + 0.0318 * 0.084 +

0.0252 * 0.336 + 0.0362 * 0.036 + 0.0296 * 0.144

= 0.0298 seconds

≈ **0.03 seconds** (rounded off)