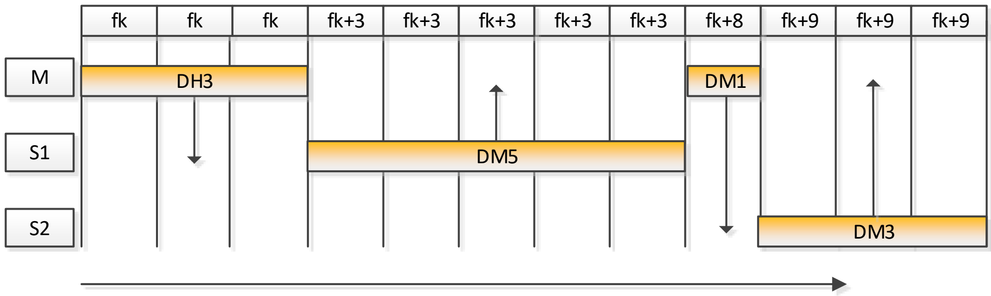
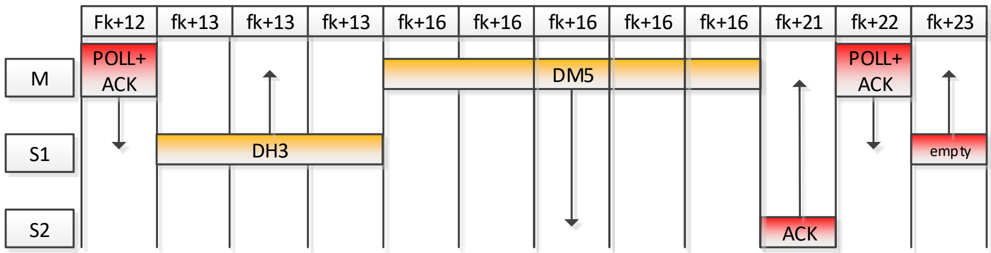
1.

a)





b)

If we start by the configuration DM5_MS+DM5_SM, we get a throughput from slave to master of 286720 bit/s, which is not enough. It is thus necessary to reduce the size of the packet sent by the master, resulting in a DM3_MS+DM5_SM configuration. With this configuration, we have (knowing that $t_{slot} = 625\ \mu s$):

$$throughput_{SM} = \frac{224\times8}{(3+5)\times625\times10^{-6}} = 358400\ bit/s > 300000\ bit/s$$

$$throughput_{MS} = \frac{121\times8}{(3+5)\times625\times10^{-6}} = 193600\ bit/s$$

It is useless to test other configurations, since they will necessarily lead to insufficient throughput from slave to master, or a lower throughput from master to slave.

c)

Each piconet follows a different FHSS pseudo-random sequence of carrier frequencies, which is a function of the master's MAC address. Consequently, the probability of collision in a slot is very small and, when there is a collision, the packet can be recovered by means of the ARQ mechanism.

2.

a)

MQTT supports the publish and subscribe paradigm by nature, based on a Broker entity, with which the subscribers of a topic perform a priori registration. When it receives a publish notification for a topic, the Broker forwards it to all subscribers of that topic.

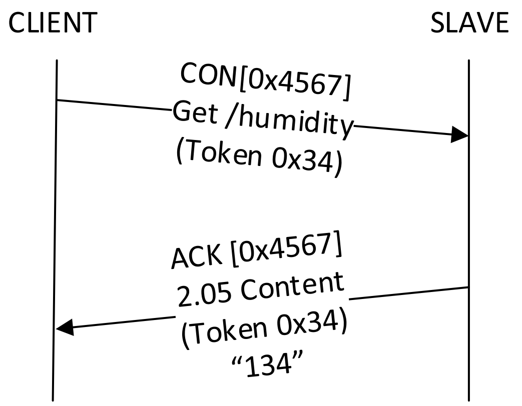
On the other hand, COAP is RESTful oriented, not supporting publish and subscribe services in a direct way. Note: in order to solve this limitation, there are proposals to extend COAP in order to directly support publish and subscribe services: https://datatracker.ietf.org/doc/draft-koster-core-coap-pubsub/

b)

MQTT assumes that the transport protocol is TCP, since it needs guaranteed delivery at the transport layer. However, a variant of MQTT called MQTT for Sensor Networks (MQTT-SN) was developed to operate on top of UDP.

In contrast, CoAP implements its own reliable message delivery service, being ready to operate on top of UDP.

c)



3.

a)

$$A = \lambda \cdot h = 5 \cdot 5 = 25$$

From the table, it can be concluded that 40 channels are enough to provide the required level of service.

b)

From the Erlang B table, it can be concluded that for 40 channels, the blocking probability is 0,02 when $A = 31$. This is the offered traffic. The carried traffic is:

$$C = (1 - P) \cdot A = (1 - 0{,}02) \cdot 31 = 30{,}38$$

c)

The following measures are possible:

- Cell splitting: creating smaller cells to cover the whole (e.g., spaces with higher user density) or part of the target area.
- Cell sectorization: mounting directional antennas in the base station in order to create orthogonal sectors, assigning more frequencies to those sector that present higher user density.

4.

a)

$$m \cdot g \cdot \left(\frac{R}{r}\right)^2 = m \cdot r \cdot \omega^2 \Leftrightarrow h = r - R \approx 35852\ km$$

b)

$\theta = 10º$

$h = 35852\ km$ (calculated in a))

$\frac{R}{R+h} = \frac{\cos(\beta + \theta)}{\cos(\theta)} \Leftrightarrow \beta = 71{,}4º$

c)

From b), at a latitude of 60º, $\theta > 10º$, which means that communication is not hampered by the elevation angle. However, one must check if locations at that latitude can still belong to the satellite's footprint, which depends on the satellite's antenna divergence angle.

This problem amounts to calculating the Footprint's half arc over the surface of the Earth, which we will call β_{div}. This can be approximately solved by assuming that the Earth is locally flat, calculating the Footprint's radius, and then dividing by the perimeter of the Earth.

$G = 40dBi = 10000$

$\lambda = \frac{c}{f} = 0{,}3m$

$A_{eff} = \frac{\lambda^2}{4\pi} \mathrm{G} \approx 71{,}62\ \mathrm{m}^2$

$\alpha_{div} = 0{,}5 \cdot \frac{2\pi}{\sqrt{G}} \approx 0{,}063\ rad$

$Footprint_{raius} = \alpha_{div} \cdot h \approx 1126323\ m$

$\beta_{div} = \frac{Footprint_{radius}}{2 \cdot \pi \cdot R} \cdot 360° \approx 10{,}1°$

This means that only latitudes below 10,1° (in the best case, when the longitude of he Footprint's center is exactly the same) are encompassed by the satellite's footprint. Consequently, we can consider that no signal is received at 60° of latitude, since it is already out of the satellite's beam projection.

The angle β_{div} could also be calculated (and more precisely) based on the Law of Sines:

$$\frac{R}{\sin(\alpha_{div})} = \frac{R+h}{\sin(\theta_{div}+90º)} = \frac{R+h}{\cos(\theta_{div})} \Leftrightarrow \theta_{div} \approx 77{,}98°$$

θ_{div} represents the elevation angle at the Footprint's limit.

$$\beta_{div} = 180º - \alpha_{div} - (\theta_{div} + 90º) \approx 11{,}99°$$