Problem 1 – Path loss

- If the sensitivity of a receiver is -100dB and the transmitting power is 10dBm, what is the maximum communication distance that can be supported if the losses follow the free-space model.
  - Assume the reference distance is $d_0 = 1m$ and that $PL(d_0) = 1\ dB$
- $PL[dB] = 10 \log \frac{P_{T_x}}{P_{R_x}}$
- $P_{RX} = -100dB \Rightarrow P_{RX} = 10^{-\frac{100}{10}} * 1W = 10^{-10}W$
- $P_{TX} = 10dBm \Rightarrow P_{TX} = 10^{\frac{10}{10}} * 1mW = 10mW = 10^{-2}W$

- $PL[dB] = PL(d_0) + 20\log(\frac{d}{d_0})$
- $PL(d_0) + 20\log\left(\frac{d}{d_0}\right) = 1 + 20\log(d) = 10\log\left(\frac{10^{-2}}{10^{-10}}\right) \Rightarrow 20\log(d) = 79 \Rightarrow d = 10^{\frac{79}{20}} \Rightarrow d = 8.912km$

- Or $PL[dB] = P_{TX}[dB] - P_{RX}[dB] = -20 - (-100) = 80$
- $PL[dB] = PL(d_0) + 20\log\left(\frac{d}{d_0}\right) \Rightarrow 79 = 20\log(d) \Rightarrow d = 10^{\frac{79}{20}} = \cdots$

Problem 2 – Shannon's theorem

- A channel follows Shannon's theorem and utilizes bandwidth BW. The SNR = 20dB. If the SNR increases to 100dB, how much the channel capacity will change?

$$C = Blog_2\left(1 + \frac{S}{N}\right)$$

- Attention: SNR is given in dB here!
- $SNR = 20dB = 100$
- $C = BWlog_2(1 + 100) = 6.65BW$
- $SNR = 100dB = 10^{10}$
- $C' = BWlog_2(1 + 10^{10}) = BWlog_2 10^{10} = 33.22BW$
- $C' \approx 5C$

Piconet Question

- What is the maximum number of hops for packet transmission between any pair of devices within a scatternet that contains 21 devices, where the Master device of each piconet belongs only to one piconet and piconets contain as many devices as possible?
- (B) Revisit the same question if a device shared between two piconets can assume both roles Master and Slave.

Piconet answer

- Since two piconets must share a device and piconet must be as full as possible, then we can have $P_1 = \{M_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8\}$, $P_2 = \{M_9, S_8, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}\}$, *(so two piconets contain 15 devices where S_8 is the shared device)*
- *and* $P_3 = \{M_{16}, S_{15}, S_{17}, S_{18}, S_{19}, S_{20}, S_{21}\}$ *(Scatternet 1)*
- *or* $P_3 = \{M_{16}, S_{15}, S_{17}, S_{18}, S_{19}, S_{20}, S_{21}, \mathbf{S_6}\}$ *(Scatternet 2)*
- *In Scatternet 1,* there are up to **six hops** as all communication in piconets is performed through Master devices and a device cannot assume both roles as described in the first part of the problem. For example: $S_3 \to M_1 \to S_8 \to M_9 \to S_{15} \to M_{16} \to S_{20}$
- *In Scatternet 2,* there are up to **four hops** as each pair of piconets shares a device. For example: $S_3 \to M_1 \to S_8 \to M_9 \to S_{11}$ *or* $S_3 \to M_1 \to \mathbf{S_6} \to M_{16} \to S_{20}$
- However, note that Scatternet 2 arrangement wouldn't work for 22 devices as that would lead to four piconets and we desire to have as full piconets as possible. The price you may pay for this is an additional hop.

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Piconet answer (B)

- Since we are now allowed to have a device that can be Master in one piconet and slave in another, then we can have $P_1 = \{M_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8\}$, $P_2 = \{M_8/S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}\}$, *and*
- *and* $P_3 = \{M_{15}/S_{15}, S_{16}, S_{17}, S_{18}, S_{19}, S_{20}, S_{21}\}$ *(Scatternet 1)*
- *or* $P_3 = \{M_6/\mathbf{S_6}, S_{15}, S_{16} , S_{17}, S_{18}, S_{19}, S_{20}, S_{21}\}$ *(Scatternet 2)*
- *In Scatternet1,* there are up to **four hops**. For example: S_3 -> M_1 -> M_8/S_8 -> M_{15}/S_{15} -> S_{20}
- *In Scatternet 2,* there are up to **three hops**. For example: S_3 -> M_1 -> M_8/S_8 -> S_{11} or S_{14} -> M_8/S_8 -> M_{15}/S_{15} -> S_{20}
- *Note we discourage the case where a device belongs to more than two piconets as this requires too many resources and increases significantly its energy expenditure.*
- *Subscripts notate the index of a device*

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Problem 3 – Path losses

- (A) An IoT system for smart agriculture is based on LoRaWAN where the uplink power is 10 dBm and the receiver sensitivity is -100 dBm. If the log-distance path loss model (as described by the expression below in dB) is applicable, determine whether uplink communication can be performed at 50 km from the receiver

$$P_{Rx} = P_{Tx} - 10log\left(\frac{d}{d_0}\right)^{3.5}, \quad d_0 = 100 \text{ m}$$

- (B) The installation of new facilities in the area introduces a shadow effect equal to X_σ = 10 dB. Determine the maximum distance for uplink communication with the given uplink power and receiver sensitivity

Problem 3 – Path losses answer

- (A) The resulting receiver power at *d* = 50 km based on the above model is

$$P_{Rx}[dB] = P_{Tx}[dB] - 10log\left(\frac{50000}{100}\right)^{3.5} = (10 - 30) - 35\log(500) = (-20 - 94.5)$$

$$= -114.5\ dB\ or - 84.5\ dBm > \ -100\ dBm$$

- Part B

$$P_{Rx}[dB] = P_{Tx}[dB] - 10log\left(\frac{d_{max}}{d_0}\right)^{3.5} - X_\sigma => (-100 - 30)$$

$$= \ (10 - 30) - 35\log\left(\frac{d_{max}}{d_0}\right) - 10\ [dB] => (-100) = -35\log\left(\frac{d_{max}}{d_0}\right) => \ d_{max}$$

$$= d_0 * 10^{\frac{100}{35}} \cong 72\ km$$

Problem 4 – LoRaWAN communication

- If the DC = 1%, then what is the latest time that an ACK packet can reach the ED from the GW if NbTrans = 3 and SF = 8? Assume LoRaWAN class A devices, where the RECEIVE_DEL1 = 1 sec and RECEIVE_DEL2 = RECEIVE_DEL1 + 1 sec, and ACK_TIMEOUT = 1 sec

SF	ToA (ms)	Bit rate (bps)
7	113	5470
8	195	3125
9	349	1760
10	616	980
11	1150	440
12	2138	250

Problem 4 – LoRaWAN communication answer

- Since the end device should obey the DC and only one channel is used, this retransmission should occur after approximately $100 \times ToA$
- From table if $SF = 8$, $100 \times ToA = 19.5$ sec is the duration of transmission cycle
- Since NbTrans = 3, we can have up to three transmissions, hence, the latest arrival of ACK can be at

$$t = 2 \times 100 \times \text{ToA} + (0.195 + 2 + 1) = 42.195 \text{ sec}$$

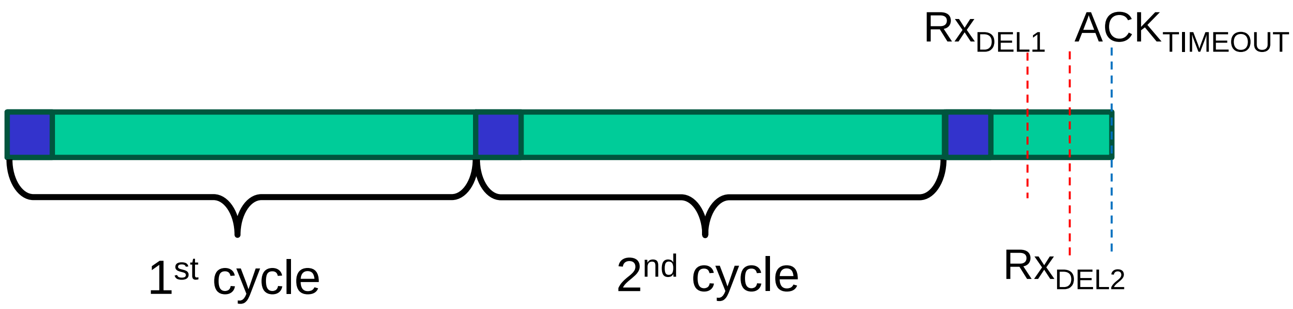

Figure not to scale!

Problem 5 – LoRaWAN lifetime

- An IoT node utilizes LoRa-based communication Class A module and microcontroller (MCU) for processing
- MCU with two power states, active and sleep,
- $P_{MCUon} = 20\ mW$ and $P_{MCUoff} = 200\ \mu W$
- The LoRa module consumes $P_{Rtx} = 400\ mW$, on average, in transmission mode and $P_{Roff} = 100\ \mu W$ in sleep mode
- Radio duty cycle is 1%, the average payload size is S_{pl} = 10 symbols, the preamble length is S_{pre} = 4 symbols, and the utilized bandwidth is BW = 250 kHz.
- Battery capacity is 5 Ah at 3.3 V
- If SF = 12, what is the lifetime of this IoT node for a single battery charge

Problem 5 – LoRaWAN lifetime answer

- We need to determine the duration of each cycle and the energy spend per cycle, then the lifecycle will be

$$L_t = T_{cycle} \times \frac{E_{batt}}{E_{cycle}}$$

- $T_{sym} = \frac{2^{SF}}{BW} = \frac{2^{12}}{250kHz} = 16.384\, msec$
- $T_{pkt} = T_{sym}\left(S_{pre} + 2 + 2.25 + S_{pl}\right) = T_{sym}(4 + 2 + 2.25 + 10) = 16.384 * 18.25 = 299.008\, ms \cong 299\, ms$, remember that $T_{cycle} = \frac{T_{pkt}}{d.c.}$
- $E_{batt} = 3600 \cdot C_{batt} \cdot V_{batt} = 3600 * 5 * 3.3 = 59.4kJ$
- $E_{cycle} = \left[\left(T_{cycle} - T_{pkt}\right)\left(P_{AU_{OFF}} + P_{R_{OFF}}\right)\right] + \left[T_{pkt}\left(P_{R_{tx}} + P_{AU_{ON}}\right)\right] = 0.99T_{cycle}(200 + 100) * 10^{-6} + 0.01T_{cycle}(400 + 20) * 10^{-3} = (0.297 + 4.2) * 10^{-3} * T_{cycle} = 134.4\, mJ\ per\ cycle$
- $L_t = T_{cycle} \times \frac{E_{batt}}{E_{cycle}} = \frac{299}{0.01} * \ 10^{-3} * \frac{59.4kJ}{134.4mJ} = 1.321 * 10^7 \sec or \sim 153\ days$
- or $L_t = T_{cycle} \times \frac{E_{batt}}{E_{cycle}} = \frac{299}{0.01} * 10^{-3} * \frac{(5*3.3)Wh}{134.4mJ} = 3{,}670.76h\ or \sim 153\ days$