ELEC-E7120 - Wireless Systems (Fall 2023)

Weekly Exercise Session #6

Unit VI. Project Workshop

Dr. Alexis Dowhuszko and Prof. Jyri Hämäläinen

Teaching Assistants:

- Cesar Olvera Espinosa (cesar.olveraespinosa@aalto.fi)
- Nida Arshad (nida.arshad@aalto.fi)
- Xinyu Zhang (xinyu.1.zhang@aalto.fi)

Aalto University

Solutions for Homework 5

Unit V. Wireless systems

Homework 5

Aalto University

5.1. Wi-Fi vs Bluetooth (1 point)

We need to download a file of one recorded lecture whose size is 100 MB (Megabytes) through two different wireless technologies, namely: Wi-Fi (IEEE 802.11g) and Bluetooth.

a) Assume that the raw bit data for the Wi-Fi (IEEE 802.11g) access point is 54 Mbps (Megabits-per-second) and transmit power is 20 dBm. Let us neglect for the moment any antenna gains and cable losses. For simplicity, we assume a transmission efficiency of 100%: That is, we consider that there is no signalling overhead, and that delays introduced by the contention-based multiple access protocol (i.e., CSMA-CA) do not exist. How long would it take, in this ideal situation, to download this file? How much energy would it be consumed in this process?

b) Let us now consider that we use a pair of Bluetooth (class 3) devices for the wireless link, which can provide a (raw) data rate at 1 Mbps (Megabit-per-second) with a transmission power of 0 dBm. How much time do we now need download the same file? And how much energy would be now consumed? For simplicity, we neglect again the PHY- and MAC-layer overhead and assume that the download speed is equal to the raw data rate that is transmitted.

c) Compare the spectral efficiency (in bps/Hz) and the energy efficiency (in bits/joules) for both technologies. For this, consider that the bandwidth of the Wi-Fi (IEEE 802.11n) transmission is 20 MHz and the bandwidth of the Bluetooth transmission is 1 MHz. What is the effect that you observe when comparing these two Key Performance Indicators Parameters (KPIs) for both wireless technologies? Are they aligned with your expectations, keeping in mind their target key applications?

Problem 5.1

a) Wi-Fi (IEEE 802.11g): $\boldsymbol{Data\ rate\ =\ 54\ Mbps,\ P\ =20\ dBm}$

$$Time = \frac{Data\ size}{Data\ rate} = \frac{100\ MBytes \times 8}{54\ Mbps} = \mathbf{14.8148\ sec}$$

$$E = P \cdot t = \left(10^{\frac{20\ dBm}{10}} \times 10^{-3}\right) \cdot 14.815 sec = \mathbf{1.48148\ Joules}$$

b) Bluetooth class 3: $\boldsymbol{Data\ rate = 1\ Mbps,\ P = 0\ dBm}$

$$Time = \frac{Data\ size}{Data\ rate} = \frac{100\ MBytes \times 8}{1\ Mbps} = \mathbf{800\ sec}$$

$$E = P \cdot t = \left(10^{\frac{0\ dBm}{10}} \times 10^{-3}\right) \cdot 800\ sec = \mathbf{0.8\ Joules}$$

c)

- **Wi-Fi (IEEE 802.11g):** $\boldsymbol{B = 20MHz}$

$$S.E. = \frac{Data\ rate}{Bandwidth} = \frac{54\ Mbps}{20\ MHz} = \mathbf{2.7\ {}^{bps}/_{Hz}}$$

$$E.E. = \frac{Data\ size}{Energy\ Consumed} = \frac{100\ MBytes\ \times 8}{1.48148\ Joules} = \mathbf{540 \times 10^6\ {}^{bits}/_{Joule}}$$

- **Bluetooth class 3:** $\boldsymbol{B = 1MHz}$

$$S.E. = \frac{Data\ rate}{Bandwidth} = \frac{1\ Mbps}{1\ MHz} = \mathbf{1\ {}^{bps}/_{Hz}}$$

$$E.E. = \frac{Data\ size}{Energy\ Consumed} = \frac{100\ MBytes \times 8}{0.8\ Joules} = \mathbf{1000 \times 10^6\ {}^{bits}/_{Joule}}$$

Spectral Efficiency

$$\boxed{S.E. = \frac{Data\ rate\ [bps]}{Bandwidth\ [Hz]}}$$

Energy Consumed

$$\boxed{E = Power \cdot Time}$$

Energy Efficiency

$$\boxed{E.E. = \frac{Data\ size\ [bits]}{Energy\ Consumed\ [Joule]}}$$

	Wi-Fi (IEEE 802.11g)	Bluetooth class 3
Time	14.8148 sec	800 sec (**13 mins**)
Energy consumed	**1.48148 Joules**	0.8 Joules
Spectral efficiency	2.7 bps/Hz	1 bps/Hz
Energy efficiency	$540\ {}^{Mbits}/_{Joule}$	$1000\ {}^{Mbits}/_{Joule}$
Differences	**More spectral efficiency** High data rate More transmit power, so More energy consumed	**More energy efficiency** Less energy consumed Less transmit power, so Less energy consumed

Homework 5

5.2. Bluetooth throughput in scatternet

- Bluetooth devices frequency-hop in a pseudo-random sequence of 79 channels (1 MHz each) on the license-free 2.4 GHz ISM band. Each Bluetooth piconet is synchronized to a frequency hopping sequence defined by the master device, so that all the slave devices in the piconet are tuned at the correct channel at any transmission time instant.

- Let us assume that *'N'* independent Bluetooth piconets are coexisting in the same area. For sake of simplicity, the internal clocks of all master devices are synchronized, such that only full overlapping collisions may take place when two different piconets select the same frequency for the given hop. Moreover, let us assume that all piconets are using Data High-rate packets type-1 (DH1) in both directions (*i.e.*, master-to-slave and slave-to-master), alternating one DH1 packet from master-to-slave and one DH1 packet from slave-to-master sequentially. Note that each DH1 packet transport 27 bytes of useful data in every time slot of duration of 0.625 milliseconds.

- For sake of simplicity, we consider that the full packet is lost if a collision takes place (this is a reasonable assumption, since DH1 packets do not use Forward Error Correction). Note that for a successful transmission using DH1 packets, there should be no collision neither in the transmission slot (when the data is sent from source to the destination) and the following reception slot (where the ACK of correct reception issued from the destination).

- Find the throughput that each Bluetooth piconet can support in each direction of communication when *'N'* equals *'1'*, *'10'* and *'100'*. Express the result in kbps.

- What is the effect that you observe in the aggregate data rate of the *Scatternet* for $N = 1, 10, 100$? (Note: the aggregate data rate of the Bluetooth scatternet is the sum of the individual data rates of the piconets). Give a short but clear justification of this observation.

Homework 5

When there is N=1 piconet there is no collision so,

$$P_{\text{no collision 1 piconets}} = 1$$

When N=2 it means the second piconet has a 1 in 79 chance of colliding on the same frequency,

$$P_{\text{no collision 2 piconets}} = 1 - 1/79$$

Now if we have added a third piconet when N=3 there's a probability that neither the second nor third piconet will collide with the first piconet as,

$$P_{\text{no collision 3 piconets}} = (1-1/79)^2$$

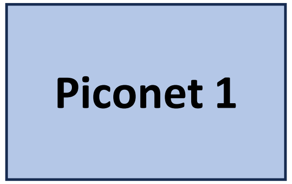
If we have *n* piconets transmitting at the same time, the probability of our first piconet not colliding on the same frequency as any of them is,

$$P_{\text{no collision n piconets}} = (1 - 1/79)^{n-1}$$

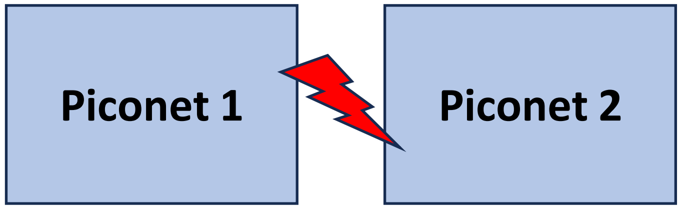
For a successful transmission, we need to both send and receive. The probability of our first piconet not colliding with any of the other piconets in both slots as

$$P_{\text{no collision n piconets in 2 slots}} = (1 - 1/79)^{2n-2}$$

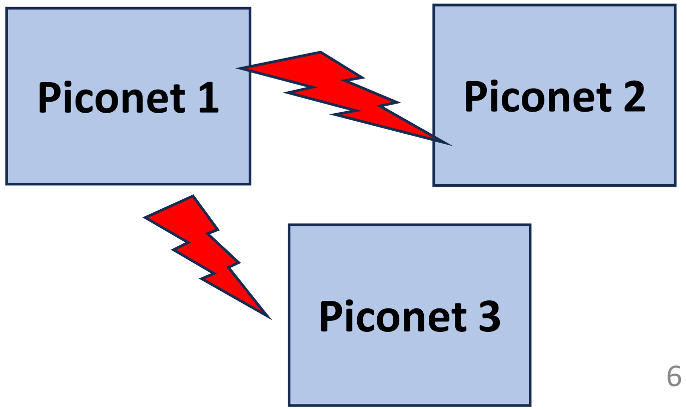
No collision as there is no other piconet



Piconet 1 had 1/79 collision probability with piconet 2 as both will select same frequency channel



Piconet 1 had 1/79 collision probability with piconet 2 and 1/79 probability with piconet 3 as three of them will select same frequency channel



Homework 5

- The probability that each piconet chooses the same channel is the same since they are independent.

  When N=1

$$1/(0.625\times10^{-3}\times2)=800 \text{ packets}$$

$$TP_1=800\times27\times8=172.8 \text{ kbps}$$

- Also, there should be no collision neither in the transmission slot (when the data is sent to the destination) and the following reception slot.

  When N = 10, the throughput

$$TP_{N=10}=p_{no-collision}(N=10)\times TP_1\approx137.39 \text{ kbps}$$

  When N = 100, the throughput

$$TP_{N=100}=p_{no-collision}(N=100)\times TP_1\approx13.87 \text{ kbps}$$

- This suggests that data rate increases as N increases but saturates asymptotically with the increase in number of piconets owing partly due to probability of collisions.

Homework 5

Aalto University

5.3. Optical Wireless Communication (1.5 points)

Make a table comparing Visible Light Communication (VLC) and Free-Space Optical (FSO) technologies for optical wireless communications, making emphasis on the following points:

- Highlight similarities and differences considering, e.g., the portion of the Electro-Magnetic spectrum that is used in each case, the kind of light sources that is utilized in each situation, the target data rate and coverage range that is expected, among other things that you consider relevant.
- Which of both technologies is more suitable for wireless access? And which one for wireless point-to-point connectivity? Why? Justify your answer properly.
- Propose two use cases (application scenarios) in which the use of VLC would have notable advantages with respect to FSO, and two use cases in which FSO would be more convenient to use when compared to VLC? Justify your answers.

Problem 5.3

	Visible Light Communication (VLC)	Free-Space Optical (FSO)
Bands (portion of electromagnetic spectrum)	Visible light bands (380nm – 700nm)	Infra-red bands (800nm - 1578nm)
Transmitter (Kind of light sources)	LEDs	Laser diodes (LD)
Target data rate (feasible today)	About 100-1000 Mbps (depends on LED)	About 1-10 Gbps (depends on LD and range)
Distance (coverage range)	Few meters (mainly 1-10 meters, sometimes up to hundred meters)	Few kilometres (from 100 meters up to thousands of kilometres)
Scenario	Indoor	Outdoor
Wireless access or point-to-point?	Wireless access (short-range)	Wireless point-to-point (large-range)
Advantage	Illumination (Safe for humans)	Invisible to the human eye
Challenges	Sun light and other led lights (street lights)	Weather Conditions: Smog and fog
Illumination	Yes	No
Case 1	Vehicle to vehicle communication	Last-mile access
Case 2	Underwater communication	Bridging WAN access
Case 3	Medical applications	Satellite communication (Point-to-point links)

Problem 5.3

VLC system

- **Vehicle to vehicle communication**
  - Vehicle lights and traffic lights infrastructure
  - Applications
    - Cooperative forward collision warning
    - Pre-crash sensing
    - Stop sign movement assistant
    - Traffic signal violation warning
    - Curve speed warning
  - Pros
    - Low latency
    - High-speed vehicle safety communication
    - High-speed VLC system (like Li-Fi)

- **Underwater communication networks**
  - Applications
    - Observatory maintenance of the oceans
    - Deployment opportunity from the ships
  - Pros
    - RF waves do not travel well in seawater

- **Medical applications**
  - Applications
    - Provide communication
    - Beneficial for robotic surgeries
  - Pros
    - RF signals cause interference with different monitoring equipment

Problem 5.3

FSO system

- **Last-mile access**
  - Implementing it in the last mile along with other networks
  - Reduce cost instead of laying cables/fiber (very costly)
  - High-speed link

- **Bridging WAN Access**
  - Supports high-speed data services
    - Mobile users
    - Small satellite terminals
  - High-speed trunking network
    - Acts as a backbone

- **Point-to-point links (for short and long-range)**
  - Communication between point-to-point links
    - Two buildings
    - Two ships
    - From aircraft to ground
    - Satellite to ground
  - Reduce cost
  - Provide high data rate