EE625 – Wireless Communications

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Assignment 3

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Exercise 1: Cellular network planning

This section aims to break down different variations of access point placement and returns the raw data collected before selecting and justifying which model is best suited for the hospital

The hospital has 9 floors with a surface of 25 meters by 30 meters each. The layout of each floor of the hospital is the same, as shown in the figure below. In addition, the ceiling height is equal to 3 meters in all floors. There are two beds in every room, however, the patients are allowed to walk freely around the hospital.

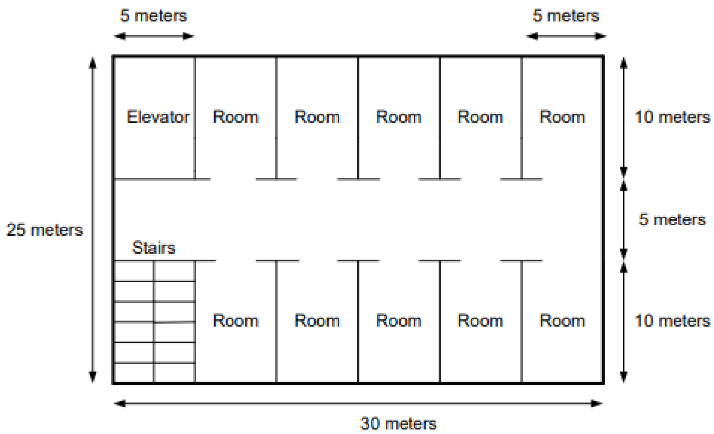


Figure 1. Plan of hospital floor

In this section, 3 variables will be changed, and their results will be calculated and shown in the following tables

Variable 1

Floors per Cell – this describes the number of floors each cell will moderate and thus describe (a) the number of patients it monitors, (b) its worst case path loss, (c) total number of cells, (d) distance between cells

Variable 2

Reuse Factor – this dictates the amount frequency bands used total in the hospital, i.e RF = 1 results in every cell using the same band and thus reducing (a) total carriers but also reducing (b) SIR.

Variable 3

Location of Cell – 2 types of location of the cell will be examined, (a) is the cell located in the centre of the room, (b) has on the far side of the wall which will alternate on sides between floors, this variation, will change mainly path loss and SIR. All cells will be placed on the ceiling of their respective floor, below illustrates the cells located in the centre of the room and the side of the room and their respective furthest away point in the room which will experience the most path loss

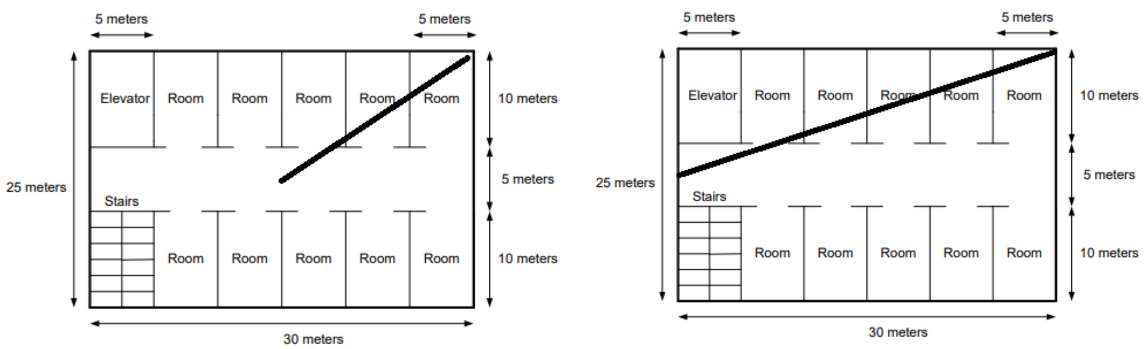


Figure 2. Plan of worst coverage for (a) V1 and (b) V2 cell placement

The goal is to collect the raw data by changing the variables and deduce which combination is best for a hospital application

The data collected in the tables are as:

Total Channels – Regardless of Reuse Factor, the total channels used in the hospital which comprises of number of cells used, its required trunks per cell and 4 control factors

Carriers per cell – which takes the number of channels per cell and divided by the given TDMA of 4

Path Loss – path loss is calculated with the path loss equation in which the inputs depend on the location of the cell and its reach, the input into the equation depend on FAF, PAF and distance to worst point in cell coverage.

SIR – continuation of Path Loss where the nearest interfere which depends on the reuse factor and their path loss to the worst location of the examined cell and SIR is them taken away from one another.

Total Carriers – uses the carriers per cell and reuse factor to calculate the total amount of carriers of frequency used.

V1

Floors per Cell	Reuse Factor	Total Channels	Carrier per Cell	Path Loss	SIR	Total Carriers
1	1	94	3.5	80.3202	9.9088	3.5
1	2	94	3.5	80.3202	20	7
1	3	94	3.5	80.3202	30.2615	10.5
1	4	94	3.5	80.3202	40.6618	14
2	1	72	4.75	90.3202	0	4.75
2	2	72	4.75	90.3202	20.6618	9.5
2	3	72	4.75	90.3202	41.7218	14.25
2	4	72	4.75	90.3202	62.9129	19
3	1	64	6	90.5848	10	6
3	2	64	6	90.5848	41.4603	12
3	3	64	6	90.5848	----	18
3	4	64	6	90.5848	----	24
4	1	61	7.25	100.5848	0	7.25
4	2	61	7.25	100.5848	31.4603	14.5
4	3	61	7.25	100.5848	----	21.75
4	4	61	7.25	100.5848	----	29

V2

Floors per Cell	Reuse Factor	Total Channels	Carrier per Cell	Path Loss	SIR	Total Carriers
1	1	94	3.5	88.2471	-17.502	3.5
1	2	94	3.5	88.2471	3.3077	7
1	3	94	3.5	88.2471	3.3077	10.5
1	4	94	3.5	88.2471	40.2556	14
2	1	72	4.75	98.2471	-27.6005	4.75
2	2	72	4.75	98.2471	14.9524	9.5
2	3	72	4.75	98.2471	14.9524	14.25
2	4	72	4.75	98.2471	60.9147	19
3	1	64	6	98.3449	-17.3816	6

3	2	64	6	98.3449	40.3685	12
3	3	64	6	98.3449	------	18
3	4	64	6	98.3449	------	24
4	1	61	7.25	108.3449	-26.7901	7.25
4	2	61	7.25	108.3449	30.6238	14.5
4	3	61	7.25	108.3449	------	21.75
4	4	61	7.25	108.3449	------	29

Notes:

When measuring Path Loss the following equations were used:

$$P_R\ (\text{dBm}) = P_T\ (\text{dBm}) - L\ (\text{dB}) - \sum_{i=1}^{N_f} \text{FAF}_i\ (\text{dB}) - \sum_{i=1}^{N_p} \text{PAF}_i\ (\text{dB})$$

$$L\ (\text{dB}) = K\ (\text{dB}) + 10\gamma \log_{10}\left(\frac{d}{d_0}\right)$$

Where:

d0 = 1

FAF = 10

PAF = 4

K = 45

The path loss had the Pt(dBm) removed to calculate the path loss not the received power.

When measuring SIR, the worst case of path loss was taken as per above, and the interferences path loss was then calculated to that point, which access point to be determined as the interferer depended on the Reuse Factor.

Detailed below is an example of the SIR analysis in which variation 2 is used with the top left access point is being our control node, the worst-case scenario for path loss in the bottom left corner of the room just above another access point. The potential interferers depend on the reuse factor, if 1 frequency band is used then the access point below will act as the interferer. If a reuse factor of 2 is used then the one access point just below can no longer act as an interferer and thus the interfere must either be one of the two closest, whichever has the largest interference. Due to the staggered approach to this design, the lower point on the left-hand side acts as the interfere for the 2 and 3 reuse factors due to it having no wall attenuation on its signal.

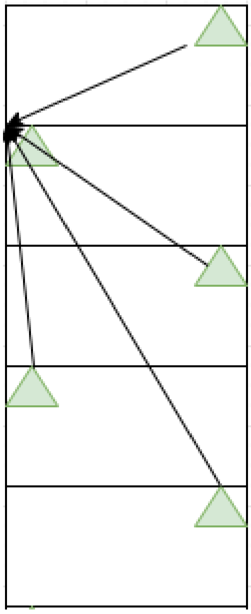


Figure 3. Variation 2 Cell interference with Reuse Factor of 1

Proposal

The proposed solution utilises variation 1 where the **cell is centred in the middle of the room** as this is the most ideal solution when each patient is connected to an access point depending only on level and not overall location. If overall location had an effect, a hybrid could be proposed, But I don't have the time to do all that. There will be 3 cells total spaced around that hospital as shown in **Figure 5**. indicated by the 3 triangles. The reuse factor will be 2 which will allow the upper and lower sections to use the same frequency range, worst case scenario their SIR to one another will be 41dBm which is above the standard of 20dBm.

This design will result in a total of 12 carriers across the whole hospital with a total bandwidth of 1.2MHz. This will have the one frequency band operating at 2.403GHz with its bandwidth ranging from 2.4GHz to 2.406GHz, and the other band operating at 2.397GHz with its bandwidth operating from 2.394 to 2.4GHz.

Floors per Cell	Reuse Factor	Total Channels	Carrier per Cell	Path Loss	SIR	Total Carriers
3	2	64	6	90.5848	41.4603	12

Comparing with the other candidates such as the ones below

Floors per Cell	Reuse Factor	Total Channels	Carrier per Cell	Path Loss	SIR	Total Carriers
1	2	94	3.5	80.3202	20	7
2	2	72	4.75	90.3202	20.6618	9.5

Both other candidates are centred in the middle of each floor, and both have less total carries and a sufficient SIR, with 1 floor per cell having a better path loss. But note that all meet the required sensitivity of the receiver which can withstand a loss of up to 103dBm.

Both alternatives though require more total cells, 2 floors per cell requires 2 more cells which is a 66% increase in cells which I believe does not justify the reduction of 3.5 total carriers. And the same goes for 2 floor per cell which has 3 times the amount of 3 floors per cell with not even half the total carriers.

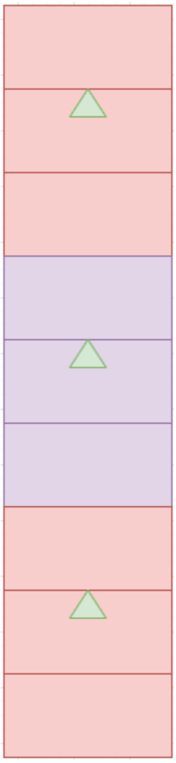
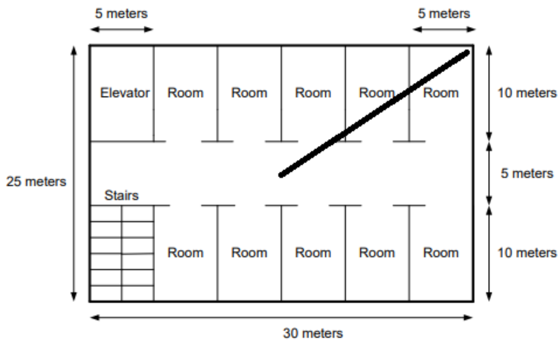


Figure 4. Model of Hospital cell layout and Frequency Usage



Exercise 2: Wireless channel characterisation

1. A graphical representation of the path-loss attenuation suffered by a signal from its transmission by a coordinator node to the closest access point as a function of the distance. Take into account the maximum distance that the sensor could be away from the access point.

The proposed solution will be used for the path loss measurement. The worst case scenario for path loss occurs at the bottom right corner of the sensor area

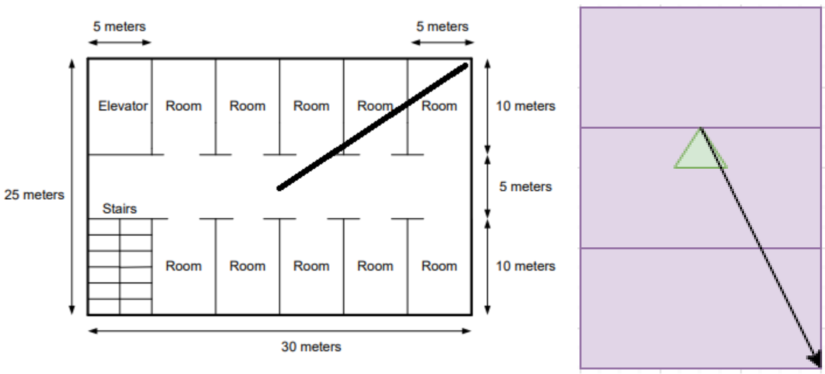


Figure 5. (a) Plan of cell coverage and (b) side view

This result passes through 3 walls at 6.29m, 13.2m, 14.14m and passes through a singular floor at 10.21 metres away from the antenna, for a total distance of 20.43m

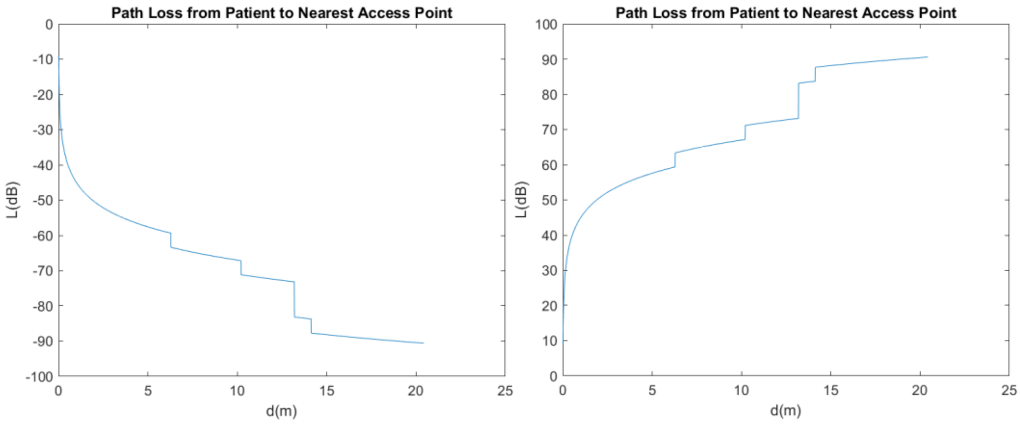


Figure 6. Path Loss of (a) Patient to AP and (b) AP to Patient worst case scenario

This path loss remains within the sensitivity from the receiver of the access point which can receive as low as 100dBm

2. Graphically represent and analyse the scattering function.

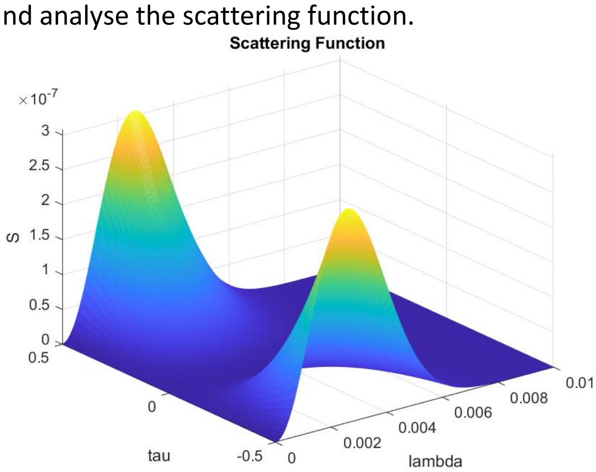


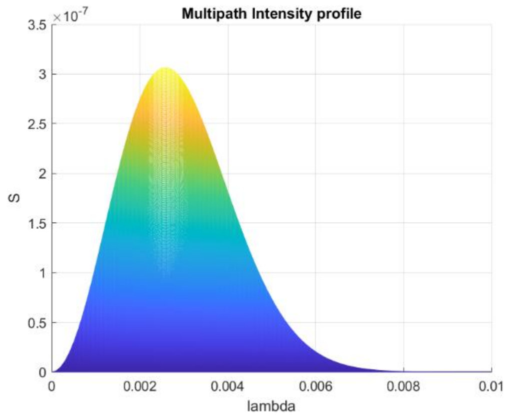
Figure 7. Scattering Function of wireless signal

- From the scattering function, calculate the expression for the multipath intensity profile function and the Doppler power spread function and represent them graphically. From those functions calculate the average multipath delay spread, Doppler spread, coherence bandwidth, and coherence time of the channel both mathematically and visually (from the graphs).

Multipath Intensity profile

The multipath intensity profile was calculated using the following function which produced the corresponding figure.

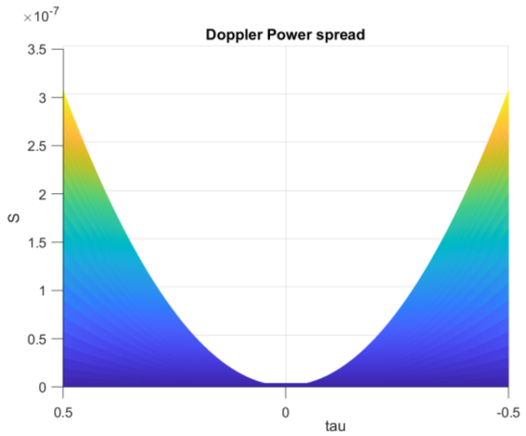
$$A_C(\tau) = \int_{-\infty}^{\infty} S(\tau;\rho)d\rho$$



Doppler Power spread

The Doppler spread profile was calculated using the following function which produced the corresponding figure

$$S_C(\rho) = \int_{-\infty}^{\infty} S(\tau;\rho)d\tau$$



Multipath delay spread

Multipath delay spread of the system is calculated when Ac(τ) is approximately 0.

Ac(τ) is approximately 0 when τ > 3σTm

Therefore, setting τ to 4σTm sufficies this

τ = .0048s = Tm

Doppler Spread

The doppler spread of the function can be found by applying the following equation to the Doppler Power Spread calculated before:

$$W_D = \sqrt{\frac{\int_{-\infty}^{\infty} \rho^2 S_C(\rho)d\rho}{\int_{-\infty}^{\infty} S_C(\rho)d\rho}} \text{ Hz}$$

This to compute this the following code was used:

```
Sc = int(S,y,0,+inf)% Doppler power spread function
Wd = double(sqrt(int(x^2*Sc,x,-pmax,pmax)/int(Sc,x,-pmax,pmax))) % Doppler
spread
```

This produced the result of: 13.943Hz

Coherence bandwidth

The Coherence Bandwidth can be calculated by applying the following equations to the Multipath delay spread calculated earlier:

$$\mu_{Tm} = \frac{\int_0^\infty \tau A_c(\tau) d\tau}{\int_0^\infty A_c(\tau) d\tau} \quad \sigma_{Tm} = \sqrt{\frac{\int_0^\infty (\tau - \mu_{Tm})^2 A_c(\tau) d\tau}{\int_0^\infty A_c(\tau) d\tau}}$$

Firstly, the average (Utm) delay spread is calculated then the RMS (σTm), Then by inverting σTm the coherence bandwidth can be discovered.

This was done with the following code:

```
Ac = int(S,x,-pmax,pmax) % Multipath intensity profile function
muTm = double(int(y*Ac,y,0,+inf)/int(Ac,y,0,+inf))% mean delay spread
sigmaTm = double(sqrt(int((y-muTm)^2*Ac,y,0,+inf)/int(Ac,y,0,+inf)))% rms
Wc = 1/sigmaTm % coherence bandwidth
```

This produced the result of: 813.32Hz

Coherence Time

Lastly coherence time was calculated using the doppler spread calculated before which was 13.943Hz. coherence time is calculated using:

$$Coherence\ Time = \frac{1}{Wd} = \frac{1}{13.943}$$

Coherence Time: 0.071722s

Exercise 3: Communication system design and link budget

Using the information from Exercises 2 and 3, you are required to complete the calculations in relation to the link budget and data capacity between the coordinators and the access points.

For the link budget consider a gain of 3 dBi for the access point's antenna and 0 dBi for the coordinator's antenna. On the other hand, for the data capacity, consider that every patient can wear a maximum of 4 sensors on his/her body simultaneously. The nominal data rates for some type of sensors used in healthcare are given in Table below.

Signal	Sample Rate (kb/s)
Body temperature	0.1
Respiration	0.2
Blood oxygen sat.	1
Blood pressure	1
ECG	9
EEG	153.6

Using the information from above the following stats are presented:

Minimum transmit power for the access points.

Relevant stats:

Worst case path loss using 3 cell system: -90.5848 dBm

Access Point antenna gain: +3dBm

Coordinator antenna gain: +0dBm

Sensitivity of coordinator receiver antenna: -100dBm

Using the above stats, it is possible to plan the whole transmission from access point to coordinator in its worst-case scenario. Which is illustrated below

Therefore, the minimum transmit power required needs to be >= -12.4512dBm

Transmitting with a power of -12.4512dBm results in a 100dBm signal reaching the coordinator receiver

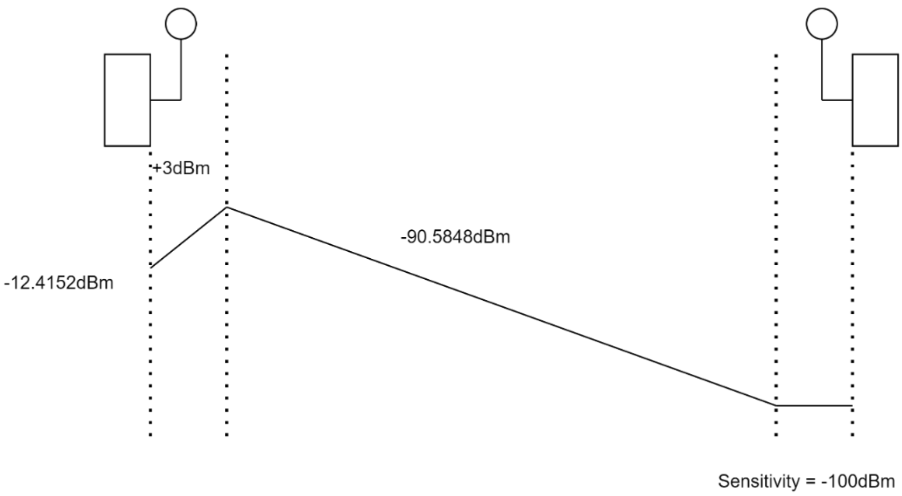


Figure 8. Worst Case transmission from Access Point to coordinator

Minimum transmit power for the coordinators.

Relevant stats:

Worst case path loss using 3 cell system: -90.5848 dBm

Coordinator antenna gain: +0dBm

Access Point antenna gain: +3dBm

Sensitivity of Access point receiver antenna: -100dBm

Using the above stats, it is possible to plan the whole transmission from access point to coordinator in its worst-case scenario. Which is illustrated below. The transmission of the coordinator has the same path loss and the access point has the same sensitivity rating from before. Only difference is the coordinator antenna gain is 0dBm but the Access point will increase the power received and thus the transmission power of the coordinator remains the same as the Access point.

Therefore, the minimum transmit power required needs to be >= -12.4512dBm

Transmitting with a power of -12.4512dBm results in a 100dBm signal reaching the access point receiver

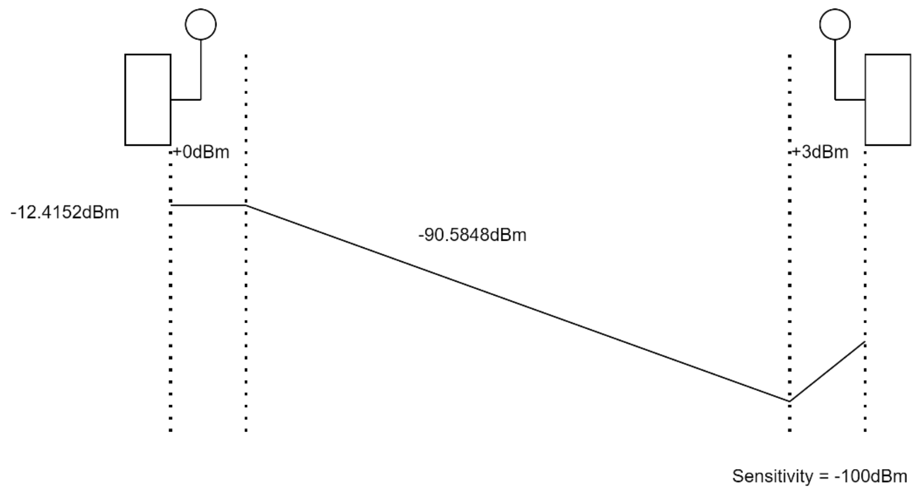


Figure 9. Worst Case transmission from coordinator to Access Point

Co-channel Signal-to-Interferers Ratio (SIR) at the cell border.

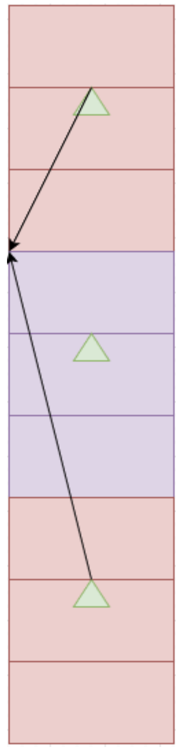
The SIR was calculated by calculating the path loss from the observed cell to its worst covered area. then the nearest cell using the same frequency had its path loss measured to the same point. The SIR was calculated by the observed taken away from the interferer.

the Analysis uses the proposed solution of 3 cells with a reuse factor of 2 so the top and bottom section can interfere with one another. the worst-case scenario is the bottom corner of the top section since it's the furthest away from the cell in the y axis at 6m and has to pass through a floor. The interferer on the bottom section must travel 5 floors and 12m in the y axis

Using the equations:

$$P_R\ (\text{dBm}) = P_T\ (\text{dBm}) - L\ (\text{dB}) - \sum_{i=1}^{N_f} \text{FAF}_i\ (\text{dB}) - \sum_{i=1}^{N_p} \text{PAF}_i\ (\text{dB})$$

$$L\ (\text{dB}) = K\ (\text{dB}) + 10\gamma \log_{10}\left(\frac{d}{d_0}\right)$$



The path loss for the observed cell is:

98.3449dBm

The path loss for the interferer is:

138.7134dBm

This results in the SIR being:

138.7134dBm - 98.3449dBm = **40.3685dBm**

An appropriate digital modulation scheme for the communication between coordinator and access point.

A common modulation scheme for 2.4GHz with FDMA utilises 802.11a which is an OFDM scheme multiplexing scheme where each carrier uses QAM modulation. The larger the QAM rate the higher BPS (bits per second) within the transmission but the signal also becomes more susceptible to errors depending on SIR

The plot below details error rate depending on the SNR/SIR rate for different QAM levels [1]. It illustrates that as the SIR rate decreases the bit error rate increases depending on the QAM level used

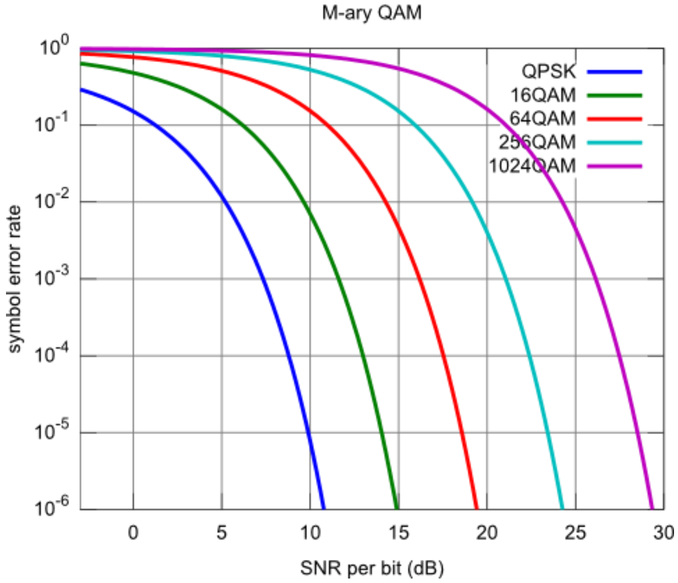
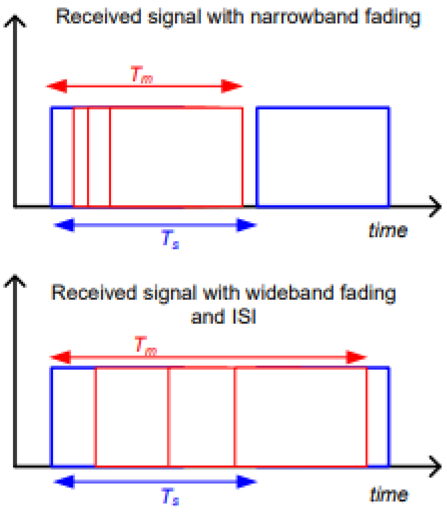


Figure 10. BER vs SNR for different QAM models

The proposed scheme has at worst case an SIR of 41.7218dB. Therefore, I recommend the use of 1024QAM which has a very high transmission rate and has a bit error rate of less than 10^{-6} at 41.7218dB.

The type of pulse shape employed.



As detailed in the multipath delay spread section. The multipath delay spread is approximately 0 when after .0048s.

Therefore, the pulse shape should be greater than this value to reduce interference.

By using the Flat-Fading effects which is specialised for and amplitude varying channel which patients located and moving around a hospital will introduce. As such the symbol time should be greater than 10σTm.

Therefore, symbol time should be 12ms.

This leads to the symbol time being 12ms and the delay spread approximately being 4.8ms. This will reduce most ISI (Inter Signal Interference) between each symbol.

If the use of an equalizer is required.

No, since the symbol time has been increased to be more than the delay spread of the signal, there should be little ISI once the symbol time is greater than 12ms.

Any other parameter you consider relevant.

Flat-Fading effects of the channel should be considered, also if that the channel is slow-fading or fast-fading in its transmission.

Exercise 4: Considerations for body-centric communications

As it was explained before, all the sensors allocated over a patient body will communicate with another sensor which will work as a coordinator. All these devices form an on-body communication network. As an expert, you know that the correct election and allocation of the sensors in the human body are crucial for reliable wireless communications in on-body networks. Therefore, in no more than 500 words, you should give the hospital personnel guidelines and recommendations about what type of sensors to use (type of antenna, etc,) and how to allocate them in the human body to maximise their communication reliability. Support your answer with references.

The sensor chosen will utilises the IEEE.15.6 standard specifically designed for wireless communication in side or in the vicinity of a human body [2], [3]. The model uses the UWB PHY variant, which allows up to four sensors to be attached to the patient, select a channel unique to each patient sensor from 6.6-10.25 GHz each with a bandwidth of up to 500MHz [2]. This frequency range allows high bit rate transfer of 394.8kbps which encompasses all required transfer rates including EEG. So, one sensor is enough for any examination. It also has a short travel distance to reduce potential interference with other patients. But due to patients being allowed to roam freely it is suggested a unique channel is required for every patient. The sensors will share a channel on a patient using TDMA [4].

TABLE III
IEEE 802.15.6 SUPPORTED BIT RATES

PHY	Frequency band (MHz), center frequency (MHz), or moulation	Bit rate 0 (kbps)	Bit rate 1 (kbps)	Bit rate 2 (kbps)	Bit rate 3 (kbps)	Bit rate 4 (kbps)	Bit rate 5 (kbps)	Bit rate 6 (kbps)	Bit rate 7 (kbps)
NB	402 - 405	75.9	151.8	303.6	455.4	-	-	-	-
	420 - 450	75.9	151.8	187.5	-	-	-	-	-
	863 - 870	101.2	202.4	404.8	607.2	-	-	-	-
	902 - 928	101.2	202.4	404.8	607.1	-	-	-	-
	950 - 958	101.2	202.4	404.8	607.1	-	-	-	-
	2360 - 2400	121.4	242.9	485.7	971.4	-	-	-	-
	2400 - 2483.5	121.4	242.9	485.7	971.4	-	-	-	-
UWB	Non-coherent	394.8	789.7	1579	3159	6318	12636	-	-
	Differentially-coherent	487	975	1950	3900	7800	15600	557	1114
	FM	202.2	-	-	-	-	-	-	-
HBC	21	164	328	656	1312.5	-	-	-	-

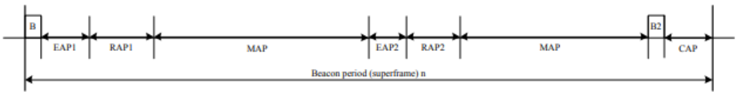
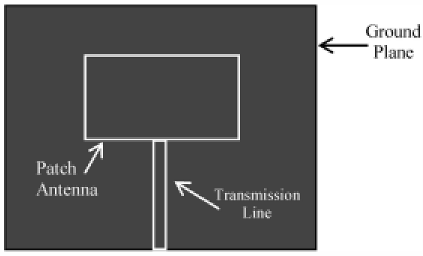
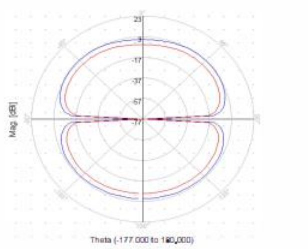
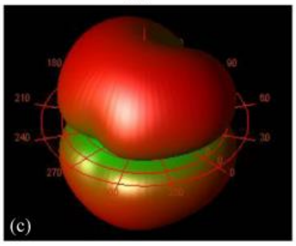


Fig. 3. IEEE 802.15.6 SF structure for beacon mode with beacon periods access technique, including EAP, RAP, MAP and CAP periods.





(a)



Once a unique channel has been selected for all the patients they need to be placed on the body, firstly is the antenna orientation. The sensor will be a pad that radiates on both directions as designed in the figure below [5]. It can be placed on or in the body, the sensor is strong enough to be placed anywhere so on or in body is strictly a medical decision. The pad is 12.33mm by 15.5mm [5] enough to be placed on a fingertip as requested for sensor A. As stated, the sensor only wirelessly transmits in along its planes with a dead zone across its perimeter. So, when placing the sensor be sure to have one of the planes facing the coordinator in the centre of the body, to do this avoid the stomach area where possible and move the senor to the patient’s sides, the antennas power is powerful enough to pass through-body.

Lastly the overall placement of the cells will use the cluster protocol. This scheme is used to reduce power usage of system which extends lifetime [6] and reduces path-loss and end-to-end delay due to mobility and structure of human body [4]. The cluster design allows the sensors to communicate with one another and the coordinator [4]. This design requires the cells to be placed around the body of the patient and not too focused in one location, with the sensors communicating with one another and the coordinator using the same channel due to TDMA.

In all the to setup the patient and connect the sensors to the node the doctor/nurse must (a) select a unique channel for each patient that does no other patient has and no other external communications use. The bandwidth of UWB should receive no significant external interferers and it does not match the Access point bandwidth either which will allow most of the bandwidth to be available, (b) place the sensor on/in the patient with either side orientated towards the coordinator to make sure the coordinator is within the radiated area and (c) place the sensors around the patient's body to build a working cluster design which increases lifetime and reduces path-loss.

Exercise 5: Security considerations

Finally, security is a crucial aspect in wireless communications applied to healthcare. The wireless system should be made as robust as possible to ensure the data integrity and confidentiality. Despite that the implementation of the security in the system is not part of your tasks you should be aware of the risks involved and possible solutions to avoid them. For this reason, in no more than 500 words, you should provide some guidelines and recommendations about possible security techniques and solutions to be implemented in the system. In order to do this, you should study the information in Section 9 of the class notes on security in wireless communications. Support your answer with references.

The hospital patient wireless sensor network (WSN) consists of two systems that transmit wirelessly in the physical layer that are susceptible to being intercepted. Firstly, are the sensors across the human body transmitting to each other (due to the clustered standard proposed) and to the coordinator. The second system communicates the coordinator to the closet Access point and vice versa.

For the first system I recommend physical layer encryption for the sensors to transmit to one another and to the coordinator due to physical layer encryptions prominence in IoT [7]. This is recommended due to the vast number of sensors across patients which if using a traditional cryptography scheme would require a unique key for every sensor. To accommodate all the sensors on patients, up to 3,960 public and private keys would need to be generated.

Other reasons to utilise physical layer encryption, are the short range of the patient's wireless communication and thus for it to be intercepted the interceptor would need to be in proximity. As mentioned prior the sensors use the same channel with TDMA which the interceptor wouldn't know which sensors uses what TD.

By utilising physical layer encryption such as key generation or beamforming there will be enough encryption in my opinion for the short-range system. Beamforming can focus each sensor towards the coordinator so the only way an interceptor can obtain the transmission is to be within the path [8] which is not possible as it is passing through the human body. Key generation from the channel uses the randomness of each human body which changes depending on stored fat, organ seizes and muscle sizes or bone density to generate a key for encoding the data [9]. The physical layer encryption is best placed on not moving parts so that the beamforming doesn't need to reconfigure a lot and the wireless channel is consistent for the key generation.

For connecting the coordinators to the Access points, I recommend using cryptography methods such as RSA or AES. Both encryption methods use keys to encrypt and decrypt the data. In RSA every receiver has a public and private key, where the private key is two prime number only know to them and the public is a product of the two prime number [10] which is made known only to the coordinators. While AES uses the same key for transmission and receiving [11], I recommend RSA due to the only 3 Access points placed in the whole hospital which will only require 3 key generations. These RSA key generations need to be complex enough to be avoided being cracked over a long period of time. It is recommended to encrypt with above 2048 bits length for the public key for the security of the system to last around 100 years [12]. And to generate new keys once every couple of years as a safety precaution.

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Appendix

Exercise 1

V1_PathLoss_worstCase.m

```
% Path loss
clear all; clc;
d = 0:0.01:20;
K = 45;
gamma = 1.8;
d0 = 1;
L = K + 10*gamma*log10(d/d0);

PAF = 4;
FAF = 10;

OnefloorPerCell = K + 10*gamma*log10(19.75/d0) + 3*PAF + 0*FAF
TwofloorPerCell = K + 10*gamma*log10(19.75/d0) + 3*PAF + 1*FAF
ThreefloorPerCell = K + 10*gamma*log10(20.43/d0) + 3*PAF + 1*FAF
FourfloorPerCell = K + 10*gamma*log10(20.43/d0) + 3*PAF + 2*FAF
plot(d, L)
title('Path Loss')
xlabel('d(m)')
ylabel('L(dB)')
```

V2_PathLoss_worstCase.m

```
% Path loss
clear all; clc;
d = 0:0.01:20;
K = 45;
gamma = 1.8;
d0 = 1;
L = K + 10*gamma*log10(d/d0);

PAF = 4;
FAF = 10;

distanceHeightis3 = sqrt(30^2 + 12.5^2 + 3^2) %xzy
distanceHeightis6 = sqrt(30^2 + 12.5^2 + 6^2) %xzy


OnefloorPerCell = K + 10*gamma*log10(distanceHeightis3/d0) + 4*PAF + 0*FAF
TwofloorPerCell = K + 10*gamma*log10(distanceHeightis3/d0) + 4*PAF + 1*FAF
ThreefloorPerCell = K + 10*gamma*log10(distanceHeightis6/d0) + 4*PAF + 1*FAF
FourfloorPerCell = K + 10*gamma*log10(distanceHeightis6/d0) + 4*PAF + 2*FAF
plot(d, L)
title('Path Loss')
xlabel('d(m)')
ylabel('L(dB)')
```

V1_SIR.m

```
% Path loss
clear all; clc;
d = 0:0.01:20;
K = 45;
```

```
gamma = 1.8;
d0 = 1;
L = K + 10*gamma*log10(d/d0);

PAF = 4;
FAF = 10;



prompt = "Floors per Cell: ";
fpc = input(prompt)
prompt = "Reuse Factor: ";
ReuseFactor = input(prompt);


if fpc == 1
%%1 floor
%calculate distance between Access point and transmitter
distanceA = sqrt(15^2 + 12.5^2 + 3^2) %xzy
distanceB = sqrt(15^2 + 12.5^2 + ((ReuseFactor - 1)*3)^2) %xzy

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 3*PAF + 0*FAF
B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + ReuseFactor*FAF

SIRatio = B - A

elseif(fpc == 2)
%%2 floor

%calculate distance between Access point and transmitter
distanceA = sqrt(15^2 + 12.5^2 + 3^2) %xzy

    if ReuseFactor == 1
       distanceB = sqrt(15^2 + 12.5^2 + (1*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(15^2 + 12.5^2 + (3*3)^2) %xzy
    elseif ReuseFactor == 3
       distanceB = sqrt(15^2 + 12.5^2 + (5*3)^2) %xzy
    elseif ReuseFactor == 4
       distanceB = sqrt(15^2 + 12.5^2 + (7*3)^2) %xzy
    end

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 3*PAF + 1*FAF
    if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 1*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 3*FAF
    elseif ReuseFactor == 3
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 5*FAF
    elseif ReuseFactor == 4
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 7*FAF
    end

SIRatio = B - A

elseif(fpc == 3)
%%3 floor
```

```
distanceA = sqrt(15^2 + 12.5^2 + 6^2) %xzy
if ReuseFactor == 1
       distanceB = sqrt(15^2 + 12.5^2 + (2*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(15^2 + 12.5^2 + (5*3)^2) %xzy
    end

A = K + 10*gamma*log10(distanceA/d0) + 3*PAF + 1*FAF
    if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 2*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 5*FAF
    end

SIRatio = B - A


elseif(fpc == 4)
%%4 floor

distanceA = sqrt(15^2 + 12.5^2 + 6^2) %xzy
    if ReuseFactor == 1
       distanceB = sqrt(15^2 + 12.5^2 + (2*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(15^2 + 12.5^2 + (5*3)^2) %xzy
    end

A = K + 10*gamma*log10(distanceA/d0) + 3*PAF + 2*FAF
    if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 2*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 3*PAF + 5*FAF
    end

SIRatio = B - A

end
```

V2_SIR.m

```
% Path loss
clear all; clc;
d = 0:0.01:20;
K = 45;
gamma = 1.8;
d0 = 1;
L = K + 10*gamma*log10(d/d0);

PAF = 4;
FAF = 10;



prompt = "Floors per Cell: ";
fpc = input(prompt)
prompt = "Reuse Factor: ";
```

```
ReuseFactor = input(prompt);


if fpc == 1
%%1 floor
%calculate distance between Access point and transmitter
distanceA = sqrt(30^2 + 12.5^2 + (1*3)^2) %xzy
if ReuseFactor == 1
       distanceB = sqrt(0^2 + 12.5^2 + (0*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(30^2 + 12.5^2 + (1*3)^2) %xzy
    elseif ReuseFactor == 3
       distanceB = sqrt(0^2 + 12.5^2 + (2*3)^2) %xzy
    elseif ReuseFactor == 4
       distanceB = sqrt(30^2 + 12.5^2 + (3*3)^2) %xzy
    elseif ReuseFactor == 5
       distanceB = sqrt(0^2 + 12.5^2 + (4*3)^2) %xzy
end

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 5*PAF + 0*FAF
if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 1*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 2*FAF
    elseif ReuseFactor == 3
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 3*FAF
    elseif ReuseFactor == 4
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 4*FAF
    elseif ReuseFactor == 5
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 5*FAF
end

SIRatio = B - A

elseif(fpc == 2)
%%2 floor

%calculate distance between Access point and transmitter
distanceA = sqrt(30^2 + 12.5^2 + (2*3)^2) %xzy
if ReuseFactor == 1
       distanceB = sqrt(0^2 + 12.5^2 + (0*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(30^2 + 12.5^2 + (2*3)^2) %xzy
    elseif ReuseFactor == 3
       distanceB = sqrt(0^2 + 12.5^2 + (4*3)^2) %xzy
    elseif ReuseFactor == 4
       distanceB = sqrt(30^2 + 12.5^2 + (6*3)^2) %xzy
    elseif ReuseFactor == 5
       distanceB = sqrt(0^2 + 12.5^2 + (8*3)^2) %xzy
end

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 5*PAF + 1*FAF
if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 1*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 3*FAF
    elseif ReuseFactor == 3
```

```
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 5*FAF
    elseif ReuseFactor == 4
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 7*FAF
    elseif ReuseFactor == 5
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 9*FAF
end
SIRatio = B - A

elseif(fpc == 3)
%%3 floor

distanceA = sqrt(30^2 + 12.5^2 + (2*3)^2) %xzy
if ReuseFactor == 1
       distanceB = sqrt(0^2 + 12.5^2 + (1*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(30^2 + 12.5^2 + (4*3)^2) %xzy
end

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 5*PAF + 1*FAF
if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 2*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 5*FAF
end
SIRatio = B - A


elseif(fpc == 4)
%%4 floor

distanceA = sqrt(30^2 + 12.5^2 + (2*3)^2) %xzy
if ReuseFactor == 1
       distanceB = sqrt(0^2 + 12.5^2 + (2*3)^2) %xzy
    elseif ReuseFactor == 2
       distanceB = sqrt(30^2 + 12.5^2 + (5*3)^2) %xzy
end

%calculate total path loss
A = K + 10*gamma*log10(distanceA/d0) + 5*PAF + 2*FAF
if ReuseFactor == 1
        B = K + 10*gamma*log10(distanceB/d0) + 0*PAF + 2*FAF
    elseif ReuseFactor == 2
        B = K + 10*gamma*log10(distanceB/d0) + 5*PAF + 5*FAF
end

SIRatio = B - A

end
```

Exercise 2

q2_1.m

```
% Path loss
d = 0:0.01:20.43;
K = 45;
gamma = 1.8;
d0 = 1;
```

```
L = K + 10*gamma*log10(d/d0);

PAF = 4;
FAF = 10;

wall1 = 6.29
floor1 = 10.21
wall2 = 13.2
wall3 = 14.14

L = +(K + 10*gamma*log10(d/d0)).*(d<wall1) ...
    + (PAF + K + 10*gamma*log10(d/d0)).*(d>=wall1 & d <floor1) ... wall
attentuation
    + (PAF + PAF + K + 10*gamma*log10(d/d0)).*(d>=floor1 & d <wall2) ... wall
attentuation
    + (PAF + PAF + FAF + K + 10*gamma*log10(d/d0)).*(d>=wall2 & d <wall3) ... wall
attentuation
    + (PAF + PAF + FAF + PAF + K + 10*gamma*log10(d/d0)).*(d>=wall3); % floor
attentuation


plot(d, L)
title('Path Loss from Patient to Nearest Access Point')
xlabel('d(m)')
ylabel('L(dB)')
```

q2_2.m

```
clear;
[x,y] = meshgrid(0:0.0001:.01, -0.5:0.001:0.5);
s = size(x);

for i=1:s(1)
    for j=1:s(2)
        S(i,j) = scattering(x(i,j),y(i,j));
    end
end

for i=1:s(1)
    for j=26
        S2(i,j) = scattering(x(i,j),y(i,j));
    end
end

mesh(x,y,S)
xlabel('lambda')
ylabel('tau')
zlabel('S')
title('Scattering Function')

% plot(S)
% plot(S2)
% xlabel('lambda')
% ylabel('tau')
% zlabel('S')
% title('Scattering2 Function')


display('Finished')
```

q2_3.m

```
clear all; clc;
alpha = 2;
beta = 150000;
pmax = 18;

syms x y
% S = 2*x^alpha*y*exp(-beta*y^2);
% S = .5*y^2*abs((x^alpha)*exp(-beta*x^2))
S = .5*x^2*abs((y^alpha)*exp(-beta*y^2))

Ac = int(S,x,-pmax,pmax) % Multipath intensity profile function
Sc = int(S,y,0,+inf)% Doppler power spread function

muTm = double(int(y*Ac,y,0,+inf)/int(Ac,y,0,+inf))% mean delay spread
sigmaTm = double(sqrt(int((y-muTm)^2*Ac,y,0,+inf)/int(Ac,y,0,+inf)))% rms delay
spread

Wd = double(sqrt(int(x^2*Sc,x,-pmax,pmax)/int(Sc,x,-pmax,pmax))) % Doppler spread
Tc = 1/Wd % coherence time
Wc = 1/sigmaTm % coherence bandwidth



sprintf('the Doppler spread is %0.5g',Wd)
disp('Key Results')
sprintf('the Doppler power spread function is: ')
disp(Sc)
sprintf('the Multipath intensity profile function is: ')
disp(Ac)
sprintf('the coherence time is %0.5g s',Tc)
sprintf('the coherence bandwidth is %0.5g Hz',Wc)
```

plot_Sc_Ac.m

```
close all
clear
x = -6:0.1:6;
y = 0:0.0001:0.01;

Ac = 72*y.*exp(-80000*y.^2); % multipath intensity profile function Ac = int(S,x,-
6,6)
Sc = x.^2/320000; % Doppler power spread function Sc = int(S,y,0,+inf)
plot(x,Sc)
xlabel('lambda')
ylabel('Sc')
title('Doppler')
figure
plot(y,Ac)
xlabel('tau')
ylabel('Ac')
title('Multipath delay')
```

doppler.m

```
function Sc = doppler(x,y)

Sc = -(x^2*exp(-80000*y^2))/320000.*(y>0 & abs(x)<=6)...
      +(0*x*y).*(y<=0 || abs(x)>6);
```

```
end
```

delay.m

```
function Ac = delay(x,y)

Ac = (x^3*y*exp(-80000*y^2))/6.*(y>0 & abs(x)<=6)+(0*x*y).*(y<=0 || abs(x)>6);

end
```

scattering.m

```
function S = scattering(x,y)
pmax = 20;
alpha = 2;
beta = 150000;
S = .5*y^2*abs(x^alpha*exp(-beta*x^2)).*(x>0 & abs(y)<=pmax)...
    + (0*y^2*x).*(x<=0 || abs(y)>pmax);

end
```