| | Travaux pratiques de conception de réseau<br>**TP05 – 5G NR planning** | **Classe**<br>**ISC-3RS** |
|---|---|---|
| HEIA-FR | S. Stijve | 19.01.2026 |

# Conception & Planning of a 5G Radio Access Network

## 1. Context and objective

As a member of the Engineering & Strategy Team at Frihesso SA, you participate to the pre-planning of the 5G New Radio (NR) network extension for a Swiss city. Each of you will be assigned a different city from this list: ZH (Zürich), GE (Geneva), BS (Basel), LS (Lausanne), BE (Bern), LU (Luzern) and LU-TI (Lugano). Each of you will also be assigned different network characteristics.

More details on the exact area to cover, as well as some technical information, are to be found in the following Excel sheet: TP-5GPlanning_ASSIGNEMENT_2526.xlsx

All the examples here below are for the city of Fribourg.

The objective is to produce a report detailing the work and the results to plan a RAN for your city. Please document what you're going, how you did it, and of course the results. Put your report on Moodle today before you leave the laboratory, but latest at 17h20.

## 2. Rough site count estimation

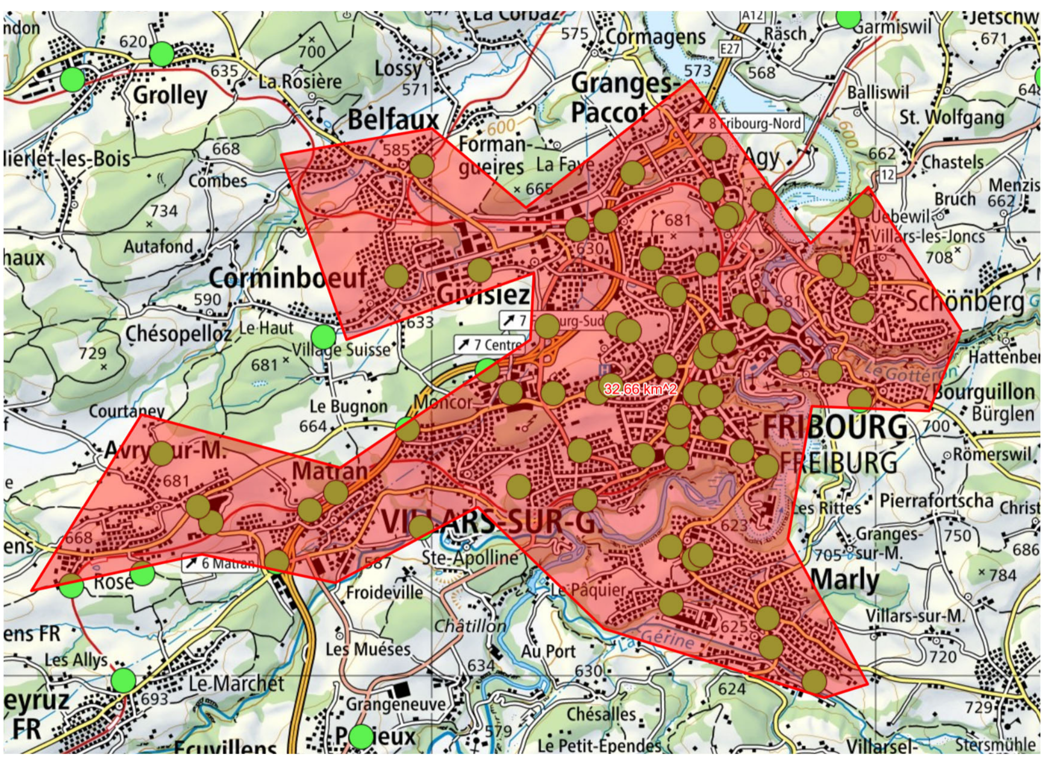



Fig 1: Example of a region to be covered. The urban area, marked in red, is approx. 33 km$^2$. (source: https://s.geo.admin.ch/5t3erj1v5jg7 ) You choose your city among the ones proposed.

The Frihesso SA top management wants a site count estimate for budgeting purposes, and they want it really quick! They just tell you that they want to cover the urban area of your city with three-sector sites, which frequency band the network should operate on, and a couple of network assumptions. You can find these inputs in the above-mentioned Excel sheet.

In order to come up with a rough site count estimation, you need to first get an estimate of the size of your cells. For this, some assumptions on the base station output power, the antenna type, the antenna gain, the antenna height, the UE position, the various losses induced by e.g. buildings, etc. have been made. These assumptions are also listed in the above-mentioned Excel sheet.

In order to calculate the cell size based on this, you will use the well-known COST231-Hata radio propagation model, which is described in chapter 5 of this document.

**Task 1:**

> Calculate the cell size based on the assumptions you have received using the COST231-Hata radio propagation model.
>
> Once your calculations are done, please reflect on whether the COST231-Hata radio propagation model was actually the right model to use. Has a limitation of this model been reached, for example?

Now you can calculate a rough site count estimation.

**Task 2:**

> Under time pressure, you consider that the quickest way to come up with the number of needed sites is to suppose that all cells will look like hexagons in a honeycomb, and that the city you have to cover is an ideal flat surface.
>
> For this, document in your report your hypotheses and calculations to obtain the total number of cells to cover the surface of the city assigned to you (don’t forget that you are building a network with 3-sector sites, not with omni antennas).

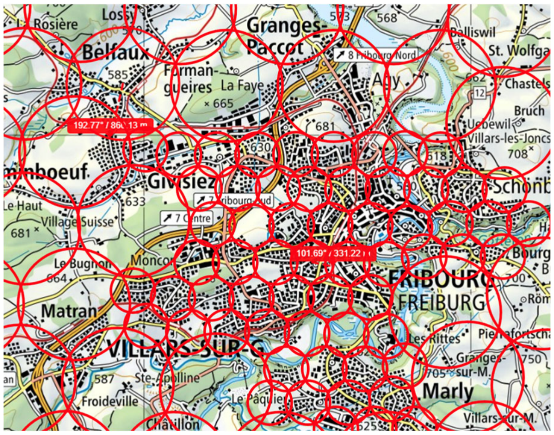
## 3. Pre-planning

The Frihesso SA top management seems happy with your site count. But you want more certainty!

**Task 3:**

> Perform a very simple pre-plan by distributing the theoretical coverage of sites/cells over the urban area. Try as much as possible to stick to the number of sites you estimated in the previous chapter: is it possible to cover the entire urban area? If not, do you need more or fewer sites?
>
> For doing this, you can use the tips presented in the chapter 6 “*Help to achieve the deliverables*” and chapter 7 “*Theoretical Pre-Planning*”.

Your pre-plan results will look like this:



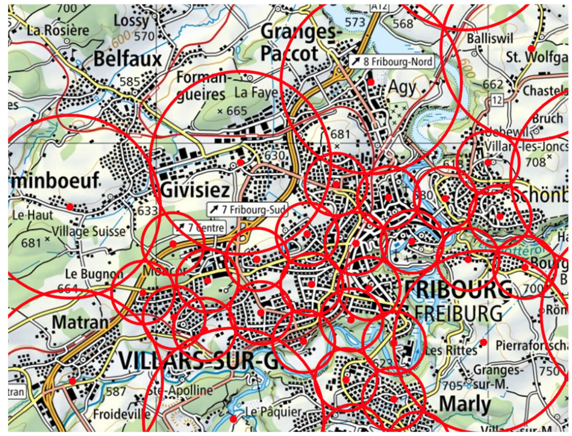




Fig [Bays, 2022]: 330 m (2022) [ZAHN, 2022]: 470 m (2022)
(Please ignore the circles in the rural areas surrounding the urban area)

The Frihesso SA top management heard a rumor that another mobile operator, Tele-UniFr, is also wanting to deploy its 5G network in the same cities! And you might have to share the sites! Given that you have calculated the output power of your sites using the maximum values the *Ordinance on Protection against Non-Ionizing Radiation* allows you, you might be forced to share the output power budget with Tele-UniFr in a 50% - 50% ratio.

**Task 4:**

> Calculate the new cell radiuses that you have to take into account. For this, use the *Log-distance Path Loss Model* as described under chapter 8 “*Recalculating the cell radiuses*”.
>
> Estimate the new site count using the same method as under Task 2.
>
> Write your assumptions, calculations and results in your report.

Now you want to compare your result with the already deployed sites from the commercial Swiss operators.

**Task 5:**

> Using the map.geo.admin.ch website, display the existing 5G sites installed by the Swiss MNOs for your city. To find this in the menu, go under Geocatalog > Population and Economy > Communication. Count the number of (5G) sites that are located within the urban area of your city and compare it with your evaluation. <u>Comment the difference</u>; give possible reasons why your site count is different than the actual number of sites installed by the Swiss MNOs.

## 4. Cell planning

Given a region to plan, the radio planner uses a radio propagation planning tool, or cell planning tool. But you need training to use these tools, so here a couple of basics:

A typical radio propagation planning tool provides:

1) **Coverage map**
2) **best (strongest) server map**
3) **SINR (or C/I) maps** (Signal to Interference+Noise Ratio = Carrier/Interference ratio when considering the noise as interferences or negligeable).

Given:

a) The location of the base station antennas (base station map)
b) The radio characteristics of the Tx and Rx of both the base station installation and the UE
c) The terrain and built environement (terrain map)
d) A propagation model

See https://www.wireless-planning.com/radioplanner and below for example (note: the pictures below are NOT for the same city ☹).

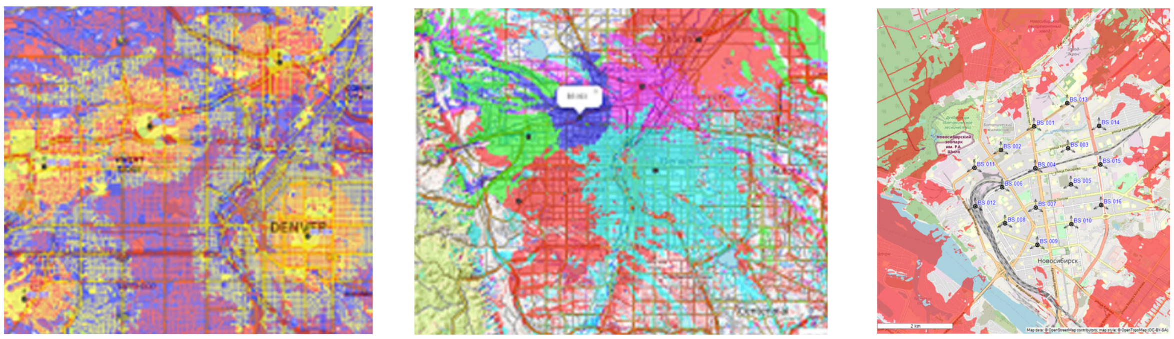



Fig (1) Coverage_dBm (left), (2) best server_color per site (middle), (3) SINR_dB (right).

Given the time constraints, you are asked to come up with a very rudimentary layout of the urban 5G cells.

This cell planning exercise will use MATLAB to get an idea of the complexity of planning a RAN. With MATLAB you will be able to apply a hexagonal layout over your city, which will look something like this:

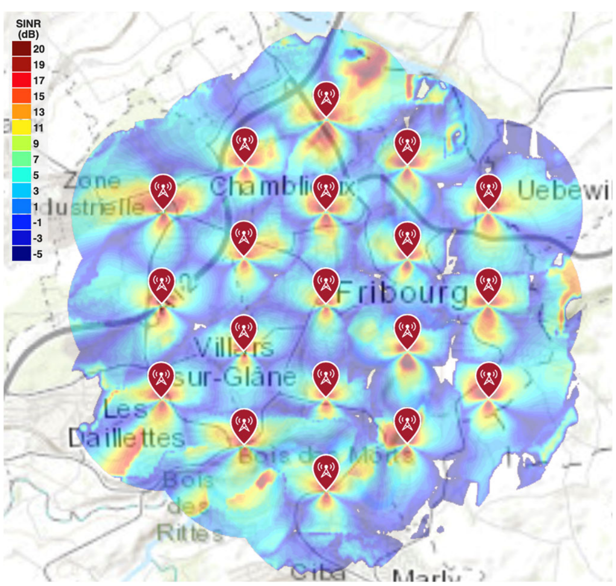



Fig Sample SINR maps

Explanations about the 19 sites with 3 sectors each that is to be put as an “hexagonal layout” over your city are given here: [https://ch.mathworks.com/help/phased/ug/sinr-map-for-a-5g-urban-micro-cell-test-environment.html](https://ch.mathworks.com/help/phased/ug/sinr-map-for-a-5g-urban-micro-cell-test-environment.html).

**Task 6:**

> First, get more information about the MATLAB code to be used. Visit first:
> https://ch.mathworks.com/help/antenna/examples.html?category=rf-propagation&s_tid=CRUX_topnav
>
> And then: https://ch.mathworks.com/help/antenna/ug/sinr-map-for-a-5G-urban-macro-cell-test-environment-1.html . Ensure the necessary MATLAB ‘toolboxes’ are installed.
>
> In an attempt to ease the work that you have to do, a modified version of this MATLAB code has been put at your disposal:
> SINRMapForA5GUrbanMacroCellTestEnvironment_TP_05_Planning.mlx
>
> Save it in your local folder under the name:
> CoverageAndSINRMapFor5G-NR_YourCity_YourName.mlx
>
> This code contains additional information on how to modify certain parameters, such as e.g. location, inter-site distance, frequency and antenna height, to get the wanted results. Also, the execution of this code stops at two places: the first time after showing the coverage of the site which is at the centre of the hexagonal layout, the second time after showing the combined coverage of all 19 sites, and then it finishes with a SINR map.
>
> On the map of your city, choose a very central location and adapt the code so that the “hexagonal layout” is centred on exactly that spot.
>
> Note that you should use the 'PropagationModel','longley-rice', which is described here: https://ch.mathworks.com/help/antenna/ref/rfprop.longleyrice.html.
>
> In your report, add the resulting coverage plot of the central site, the combined coverage plot and the SINR plot.

Your result should look like this:

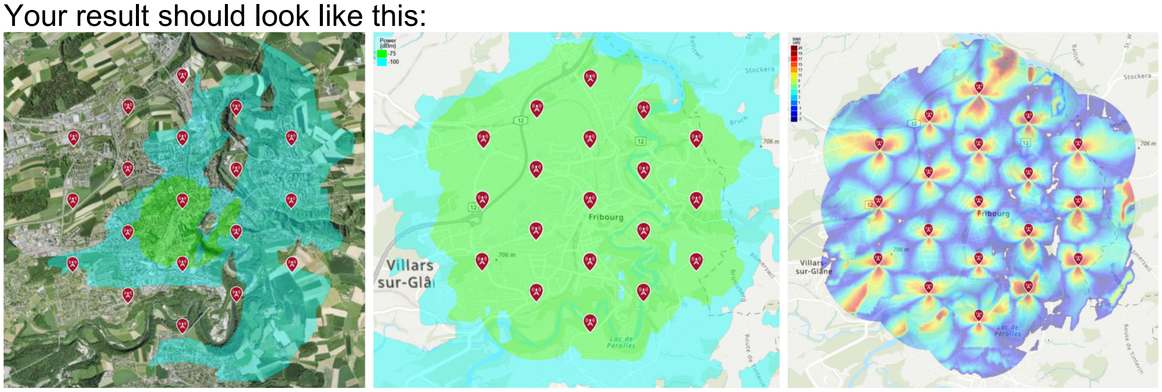



Fig Sample results for the city of Fribourg.

**Task 7:**

> - Observe the <u>coverage plot of the central site</u>. There are certainly areas close to it with bad coverage, and areas where the coverage is good. Put explanations about these good and bad coverage areas in your report.

- Observe the combined coverage plot. Are there any spots with bad coverage within the hexagonal layout or in the immediate vicinity? Put explanations about these bad coverage areas in your report.
- Observe where the SINR is "good" and where it is "bad". Again, put comments about this is your report.

(Sidenote: fortunately, not all cells are fully loaded with users. The system should schedule the use of the frequency spectrum to avoid interference and thus obtain good SINR in more places than indicated.)

**Task 8:**

- Assign a different but similar frequency (e.g., 2.0 GHz) to a least one cell and explain the results (see lines 178 to 187 in the provided code as well as the explanation just above to not lose too much computing time). Did this/those cell(s) shrink or enlarge? Why?
- Assign a much lower frequency (e.g., 0.8 GHz; 800 MHz) to a least one cell and explain the results. Did this/those cell(s) shrink or enlarge? Why?
- Assign a much higher frequency (e.g., 4.1GHz) to a least one cell and explain the results. Did this/those cell(s) shrink or enlarge? Why?
- In case the cell size is shrinking, what technical solution can you propose to enlarge the cell size?

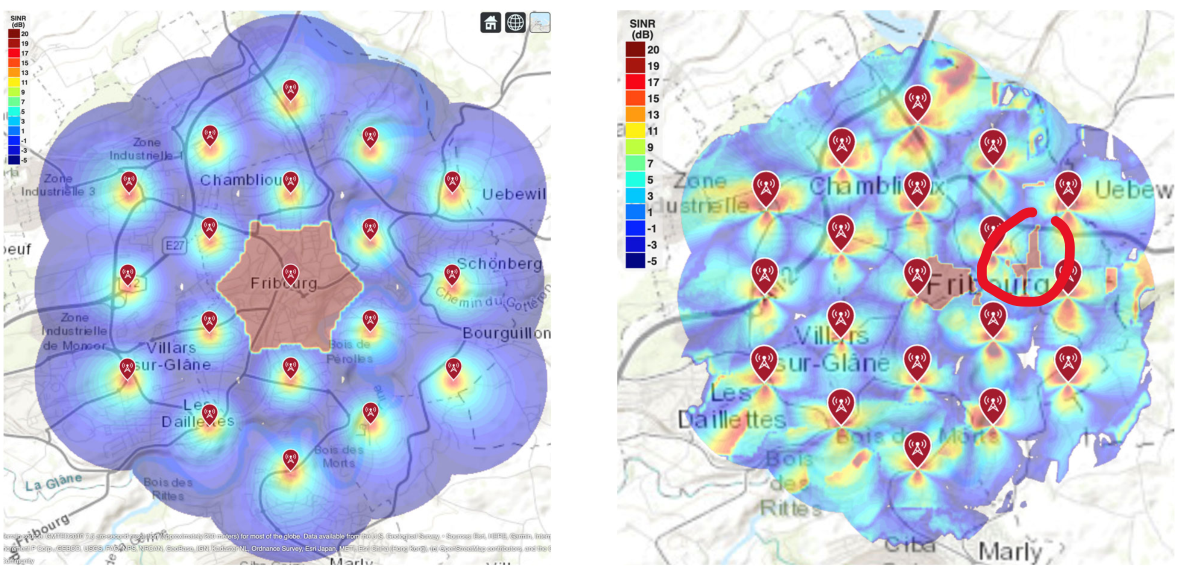



Fig SINR with dipole and close in model (left) and, less wrong with sector antenna and Longley-Rice propagation model (right).
Note: the buildings are NOT taken into account, so the reality is even more complex. Note also the "interesting" region covered by the central cell. which could help (or not !) the handover between the site near the covered zone.

**Task 9:**

Each and every cell in your network uses the same frequency band. This is referred to as "1/1 re-use". This generates interference. Discuss the resulting throughput if, instead of a 1/1 re-use, the frequency band were split in 7 sub-bands and assigned in clusters

> of 7 cells (that would be a 1/7 frequency re-use pattern). Assume a 10 MHz bandwidth and 100 Mbps.
>
> If you can, use the Shannon theorem to support your arguments. A brief reminder of Shannon's theorem is given in Chapter 10 “Shannon’s Channel capacity”.

**Task 10:**

> Verification: Verify your “circle-cell” planning of at least 1 urban cell using MATLAB. You have to tune the Tx Power to fit to your cell radius.
>
> See last Chapter of this document “Fitting Tx Power”. Note to help: Using -90dBm sensitivity for 30dBm Tx are “good” values to obtain a cell radius of about 500m … but this could depend on your city.
>
> Report your comments on the effect of changing the cell size, i.e., of changing the power budget by a few dB, try 3 (2, and 1) dB with MATLAB if you have time.

**Bonus Task:**

> Now that you’ve done this TP and that you know better what MATLAB can do in terms of wave propagation simulations and cell planning, what other task/exercises would you suggest?
>
> Is there a way to show more than two signal levels in coverage plots?
>
> Is there a way to take a more realistic antenna?

**Final Task:**

> Finalise your report and upload it on Moodle. Please also upload the MATLAB *.mlx file you created, used and modified.

## 5. COST231-HATA RADIO PROPAGATION MODEL

Accurate attenuation estimations play a crucial role in wireless network planning. Empirical propagation models are widely used in determining network coverage. The prediction accuracy of a propagation model also depends on its suitability for the environment under consideration. Attenuation of radio signals between transmitter and receiver is not only dependent on the distance but also on terrain characteristics.

The COST231-Hata model is a widely used radio propagation model. The model was built for coverage prediction across various European terrains. This model is an extension of the Hata model (Hata 1981), which in turn is based on the Okumura model (Neskovic et al. 2000, Okumura et al. 1968). The COST231-Hata model covers a wider range of frequencies. Moreover, its simplicity and availability of correction factors make it applicable to urban, suburban and rural areas. The COST231-Hata model has the following parameters:

- Frequency range: 500 MHz to 2000 MHz
- Transmitter height: 30 m to 100 m
- Link distance: up to 20 km
- Mobile Station (MS) height: 1 m to 10 m

The path loss equation for the COST231-Hata model is formulated as follows:

$$L = A + B \log_{10} R - C$$

With:

$$A = 46.3 + 33.9 \log_{10} f - 13.82 \log_{10} h_b$$

$$B = 44.9 - 6.55 \log_{10} h_b$$

$$\mathrm{C} = 3.2\,(\log_{10}(11.75\,\mathrm{h_m}))^2 - 4.97 - 3 \qquad \text{for urban areas}$$

$$\mathrm{C} = (1.1 \log_{10} f - 0.7)\,\mathrm{h_m} - (1.56 \log_{10} f - 0.8) \qquad \text{for rural areas}$$

$L$ = *median path loss in decibels* (dB)
$F$ = *frequency of transmission in Megahertz* (MHz)
$R$ = *link distance in kilometers* (km)
$h_b$ = *base station antenna effective height in meters* (m)
$h_b$ = *mobile station antenna effective height in meters* (m)

Note that if $L$ is known and we are looking for $R$, the formula is then expressed as follows:

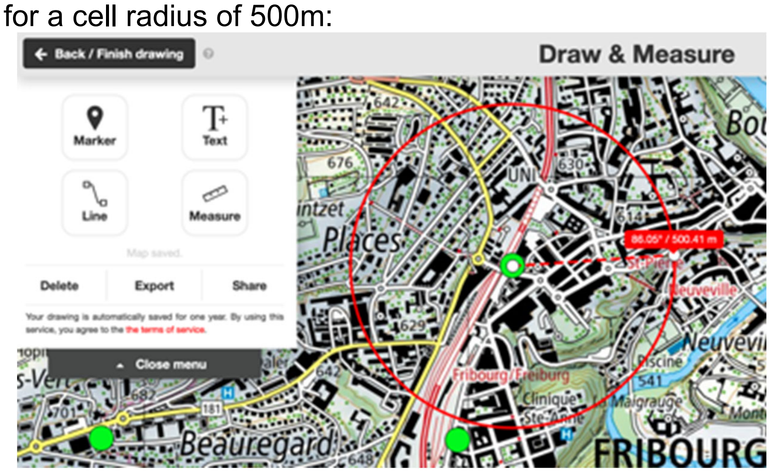
$$R = 10^{\left(\frac{L-A+C}{B}\right)}$$

Source: ISSN 2222-2863 Vol.4, No.9, 2013, p.39-48

## 6. Help to achieve the deliverables

To plan the location of **cells in the urban area of your city**. Place the cell center only on buildings. **Draw a circle** to represent the cell **according to your cell radius** using [https://s.geo.admin.ch/651695838013](https://s.geo.admin.ch/651695838013) (or [https://map.geo.admin.ch](https://map.geo.admin.ch)). Consider that it is only possible to put a small mast **on the top of a building** (not possible in the middle of a park or any open space).

Example for a cell radius of 500m:



**You can use map.geo.admin.ch to draw one cell** in the urban area to get your cell radius and then it is easier (unless you find some tricks in map.geo.admin.ch *) to continue the cell planning using e.g. PPTx and the definition of your city from the EXCEL shown above.

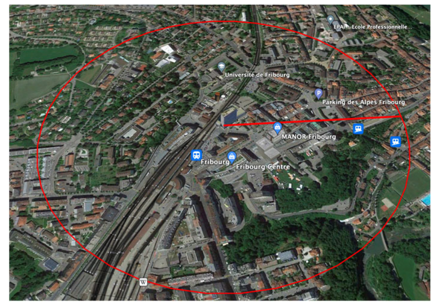
(*) Another way, using map.geo.admin.ch, is to "Draw&Measure on map & click export" a kml file, edit it using https://kml4earth.appspot.com/circlegen.html and then import it (under Advanced tools).
For example LON= 7.15224118548514, LAT=46.80431668393029

Circle radius: 500 meters ☐ Auto refresh

Center latitude: 46.804316 / longitude: 7.15224118 [decimal degs] (optional)

Circle color: Red Width: 2

Generate circle



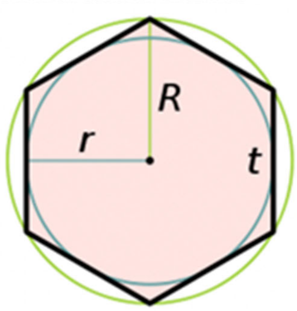
**If you find a "good way", please share it.**

**If you use use map.geo.admin.ch, please share your results** by copying link such as https://s.geo.admin.ch/651695838013 in your PPTx.


## 7. THEORETICAL PRE-PLANNING

To simplify the pre-planning, compute the approximate number of (hexagonal) cells (sites) to cover the total area. Show the details of the calculations.

**Recall** (from geometry of hexagonal cells):




| | | | |
|---|---|---|---|
| **Cellular geometry** | | | |
| **Ominidirectional antennas** | | | |
| https://en.wikipedia.org/wiki/Hexagon | | | |
| Cell radius | R | (not r) | |
| inradius | r | =sqrt(3)/2 R | |
| side length | t | =6*R | |
| Area | A | =3sqrt(3)/2 *R^2 | =2.6 * R^2 |
| **Example:** | | | |
| Give Cell radius | R | 1 | km |
| Compute Area | A | 2.60 | km^2 |

**Plan using https://map.geo.admin.ch** the "Measure" tool to draw circles (cells) using the relevant radius and environment. As an alternative you might want to draw the two cell radius and **then use PowerPoint** (or any other drawing tool) to cover the desired area with the given cell.

Take screen shots to document your work. Show your trials in an Annex with a short explanation why that particular solution was not satisfying.

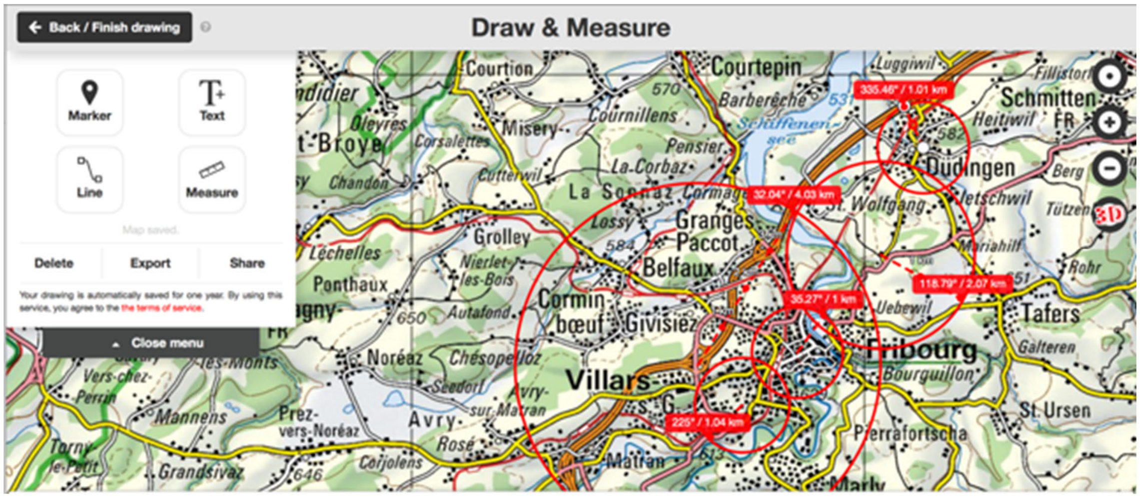



**Figure:** an example on how your approximate plan will look like (note that you will plan using only 1 cell radius).

## 8. RECALCULATING THE CELL RADIUSES

In order to recalculate a new cell radius from an existing one, the *Log-distance Path Loss Model* will be used. This radio propagation model takes a value at a reference point $d_0$ and calculate other points from there.

It has been established empirically, and also demonstrated scientifically, that the Received Power from a transmitter decreases logarithmically with distance, and that in all radio environments:

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$ (PL stands for Path Loss)

The same formula, but using dB:

$$\overline{PL_{dB}}(d) = PL_{dB}(d_o) + 10\, n \log\,(d\,/\,d_o\,)$$

Note that the reference distance $d_0$ must be in the far field region of the antenna.

The Path Loss Exponent $n$ depends on the propagation environment. $n$ has been determined empirically for several propagation environments:

Path Loss Exponents for Different Environments

| Environment | Path Loss Exponent, $n$ |
|---|---|
| Free space | 2 |
| Urban area cellular radio | 2.7 to 3.5 |
| Shadowed urban cellular radio | 3 to 5 |
| In building line-of-sight | 1.6 to 1.8 |
| Obstructed in building | 4 to 6 |
| Obstructed in factories | 2 to 3 |

Fig: Path Loss Exponent $n$ for several environments

Here below, for your information, one of the measurement results that led to the table here above. You will see that there are great variations in path loss (the factor $\sigma$ takes this variation into consideration).

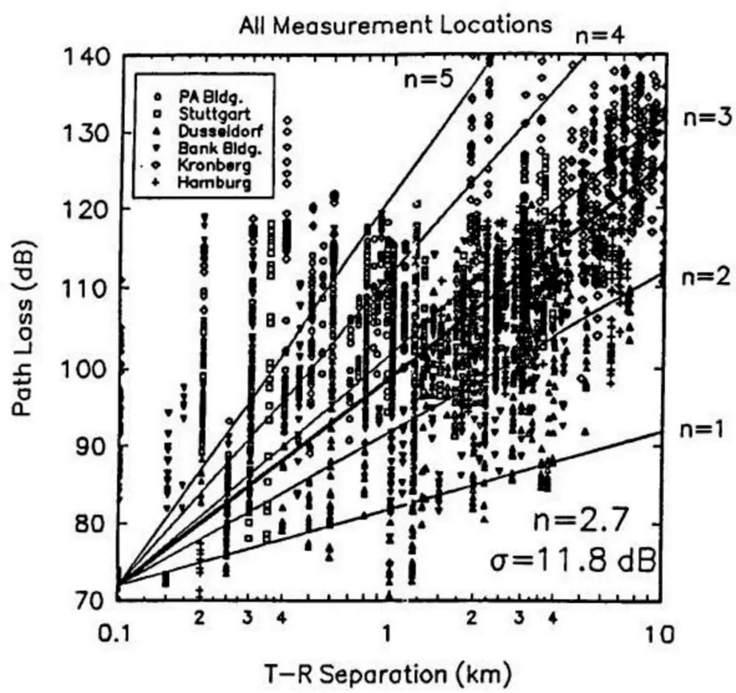



**Figure 4.17** Scatter plot of measured data and corresponding MMSE path loss model for many cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [from [Sei91] © IEEE].

In this TP, we will use the *Log-distance Path Loss Model* to recalculate cell radiuses. The cell radiuses we already have corresponds to the reference distance $d_0$ :

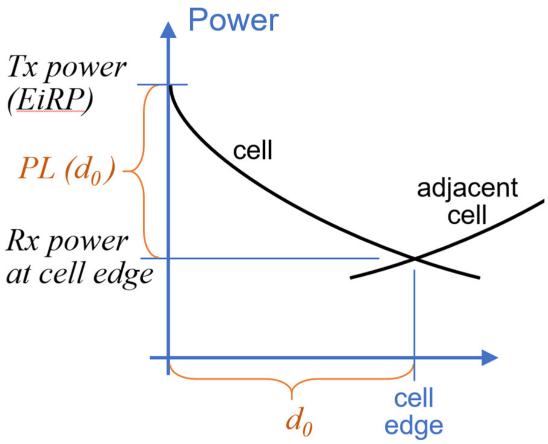



Fig: Rx Power of a cell as a function of the distance from the antenna

The new cell radiuses, coming from the variation of Tx power that has to be applied on all sites, are the distances $d$ in the equation. As the intention is to guarantee the same level of coverage, the Rx power at cell edge is kept identical:

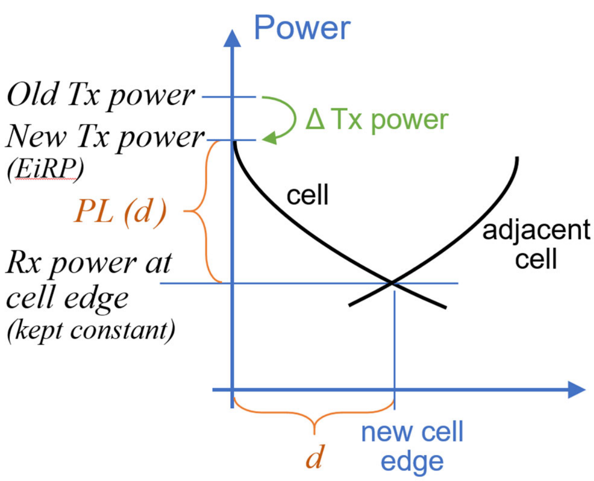



Fig: Rx Power of a cell as a function of the distance from the antenna, with a variation of Tx power

As it can be deduced from the two figures, PL($d$) = PL ($d_0$) - Δ Tx power. With this, and with the *Log-distance Path Loss Model*, the new cell radiuses can be calculated.
Take $n$ = 3.5 for urban area and $n$ = 2.5 for rural area.

## 9. For the somewhat more realistic plan

**Use MATLAB:**

**Using the coordinates of the locations of your base station antennas.**

**To get the lat-lon coordinates of a location in [https://map.geo.admin.ch](https://map.geo.admin.ch)**

Right-click and copy WGS 84 (lat/lon) coordinates: such 46.79201, 7.16053


## 10. Shannon's channel capacity

Source: https://www.semtech.com/uploads/documents/an1200.22.pdf

The theorem establishes Shannon's channel capacity for a communication link and defines the maximum data rate (information) that can be transmitted within a specified bandwidth in the presence of noise interference:

$$C = B * log_2\left(1 + \frac{S}{N}\right) \qquad \text{Equation 1}$$

Where:

C = channel capacity (bit/s)
B = channel bandwidth (Hz)
S = average received signal power (Watts)
N = average noise or interference power (Watts)
S/N = signal to noise ratio (SNR) expressed as a linear power ratio

By rearranging Equation 1 from log base 2 to the natural log, e, and by noting that $\ln = log_e$ we can manipulate the equation as follows:

$$\frac{C}{B} = 1.433 * \frac{S}{N} \qquad \text{Equation 2}$$

The following graphs demonstrate that C/B = y = 1.433*x (with x=S/N) is a good approximation of Equation 1 only up to small x=S/N = 0.06 (SNR = 10 log(0.06) = -12dB). For larger values, a much better fit, up to x=S/N < 0.4 (SNR=-4dB) is C/B ≅ 1.25* S/N.

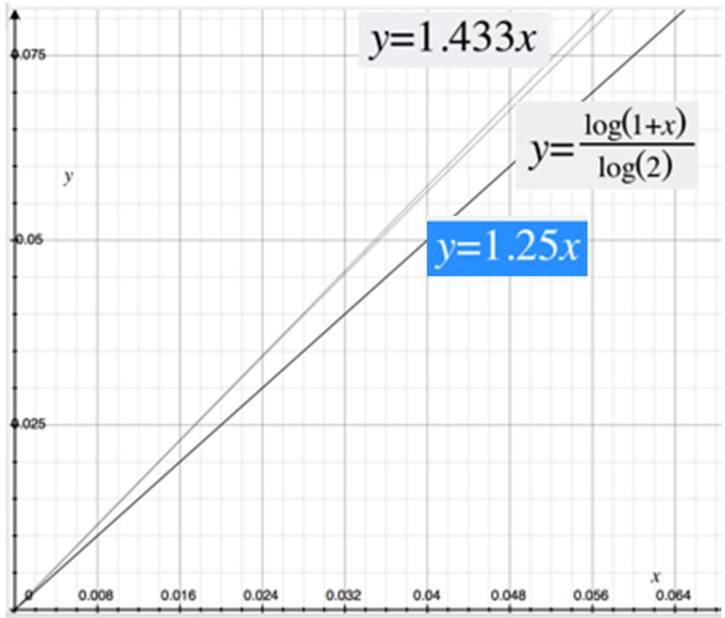



**Figure:** C/B = y = 1.433*x (with x=S/N) is a good approximation of Equation 1 up to small signal to noise ratio: x=S/N = 0.06 (SNR = 10 log(0.06) = -12 dB).

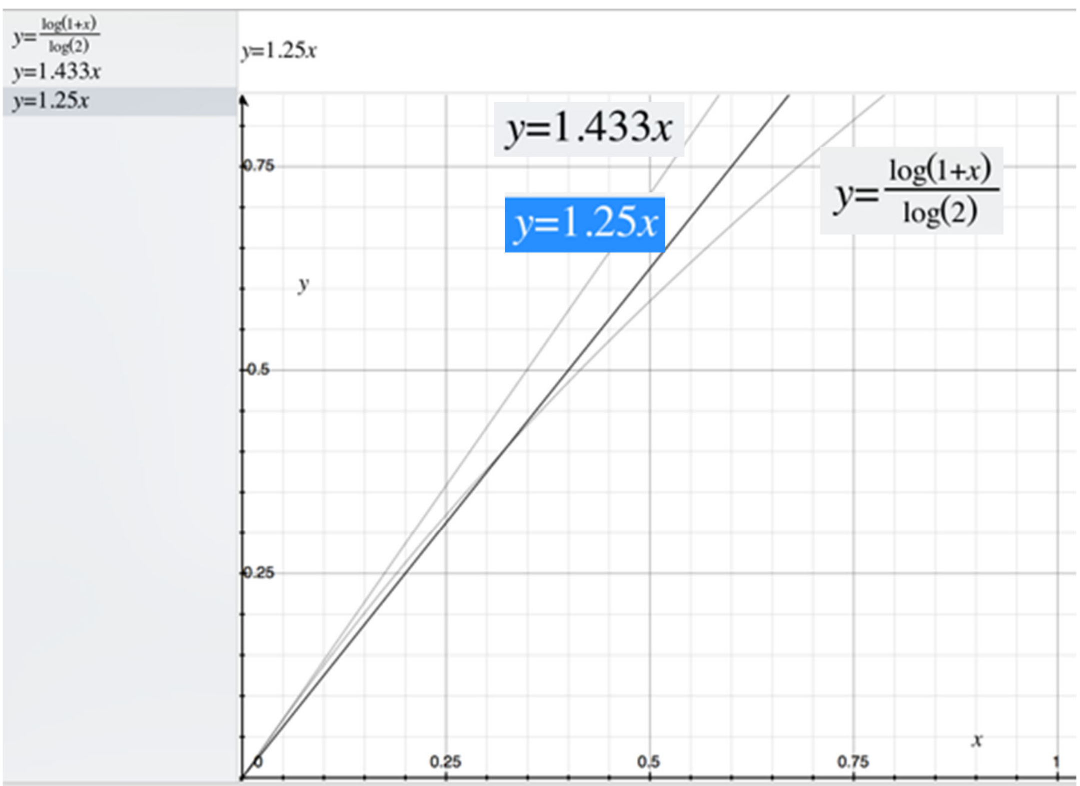
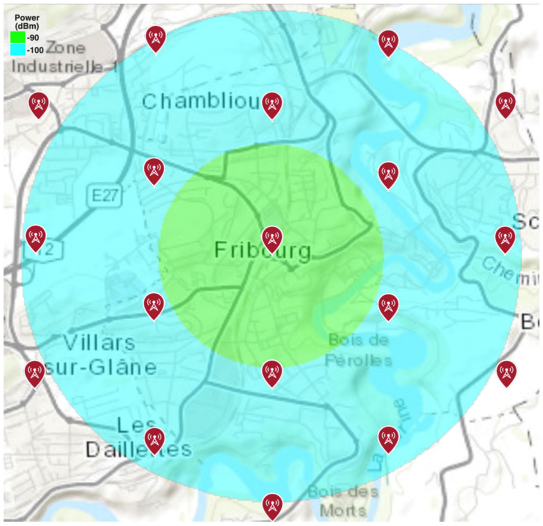



**Figure:** For x=S/N < 0.4 (SNR = -4 dB) the y=C/B ≅ 1.25* S/N is a better approximation of the Shannon's capacity C (with respect to bandwidth B).

## 11. Fitting Tx Power

```
coverage(txs(1,1),'PropagationModel','closein', 'SignalStrengths',[strongSignal_dBm,weakSignal_dBm], ...
```

```
    'Colors', [strongSignalColor,weakSignalColor], 'MaxRange', 3000)
```




**BE CAREFUL:** .TransmitterPower **in Watt: multiply by 10^(ΔL_dB) to increase power LTx_dBm by ΔL_dB.**

**Below, the original Tx power in Watt is divided by 10.**

```
newTx = txs;
newTx (1,1).TransmitterPower= txs(1,1).TransmitterPower/10 ;
coverage(newTx (1,1),'PropagationModel','closein',
'SignalStrengths',[strongSignal_dBm,weakSignal_dBm], ...
    'Colors', [strongSignalColor,weakSignalColor], 'MaxRange', 3000)
```