Using the Electromagnetic Spectrum

The electromagnetic spectrum is something we all use every day – for example for mobile communications, Wi-Fi, smart devices, navigation, the list is endless. However, the spectrum is a limited resource and access is very valuable. For instance in 2018 the UK's mobile phone operators spent more than £1.4 billion to purchase access to the spectrum for use with 5G. The traditional partitioning of the spectrum (e.g. the US Frequency Allocations 2016) works. However, in future we are likely to need to be more dynamic and use the spectrum that we can see is available as we may not be able to have our own dedicated band.

In order for us to operate in the Electromagnetic Environment (EME), we need to understand how it is being used. We can use sensors to measure the EME to try to help us to deduce this. However, the propagation of electromagnetic waves is very complicated. A large number of different factors such as reflection, diffraction, temperature etc. can affect it. What we measure at our sensor will not be what is happening elsewhere in the environment, for example at the transmitter. To model the system exactly is not feasible, so we have channel models, which can give us acceptable approximations.

For example, a very simple model:

$$P_r \propto P_t - 10n \log_{10} d$$

Where:

- P_r is the power received at the receiver
- P_t is the power emitted by the transmitter
- d is the distance between the transmitter and receiver
- n is the propagation exponent depending on the environment. Typically $2 \leq n \leq 4$

However, this model is not normally good enough. An example of a more complex model is the D1 NLOS that comes from the EU WINNER project[1]:

$$P_r = P_t - 25.1 \log_{10} d + 55.4 - 0.13(h_{BS} - 25) \log_{10}\left(\frac{d}{100}\right) - 0.9(h_{MS} - 1.5) + 21.3 \log_{10}\left(\frac{f_c}{5}\right)$$

Where, in addition to the definitions above:

- h_{BS} is the height of the base station
- h_{MS} is the height of the mobile station
- f_c is the operating frequency

The output of this follows a Log-Normal distribution, but this can be considered as a normal distribution as the scales are logarithmic (i.e. P is measured in dB). This distribution has a standard deviation of 8 dB.

Another example is the Longley-Rice Irregular Terrain Model, which produces statistical outputs, but is very complex.

[1] http://www.ero.dk/93F2FC5C-0C4B-4E44-8931-00A5B05A331B?frames=no& Accessed 16/06/2021 (page 45)

We have a series of key challenges, where each builds on the previous ones:

1. Modelling Uncertainty

The propagation models are very useful, but we need to understand the uncertainty when we do not know the true values of the parameters to put into them. For example, we may know the location of a transmitter, but have a probability distribution for its height. We may have a situation where several of the variables in the model are in terms of distributions and we need to understand how to combine them.

2. Finding Transmitters

If we have a set of measurements from our sensors, can we produce estimates of where the transmitters might be? The sensors may only record the power that they have received and not directionality making the challenge harder.

3. Placing Sensors

Can we work out the density of sensors needed to determine the spectrum usage within acceptable bounds? How will our uncertainty about the environment vary as we change the sensor density? If we know something about the topology, can we work out the best locations for the sensors?

4. Find Spectrum Occupancy

Given a sparse set of sensor readings, can we work out what parts of the spectrum are being used and the power density across an area?

5. Safe to Transmit

Building on the questions above, can we take the set of sensor readings and deduce how safe it is to transmit if we know the susceptibilities of the equipment? For example, if a piece of equipment is operating at a particular frequency we may not be able to transmit at frequencies close to that or risk causing interference. What is the best way to present this to people (or machines!) tasked with making decisions?