Channel model for ranging in a real world indoor communcation channels

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I. Goal

Create training data for transfer functions squared of a real indoor communcation channel in order to provide a training set for a neural net to determine distance between two 2.4 GHz device.

II. Why

Today there are ranging libraries for 2.4 GHz radios, like nrf_dm that measure the transfer function squared over an 80 MHz bandwidth. To compute distance a common method is to first try and resolve the transfer function (step 1), then compute the inverse fourier transform (step 2) to get the impulse response, and do a peak search of the impulse response (step 3) for the shortest delay, which is assumed to be the shortest path between devices.

The distance estimation in these libraries have limited accuracy, as there are error sources in each of the three steps. Maybe it's possible to train a neural net to do the estimation?

In order to train a neural net one needs a large sample set of realistic data. In the physical world it is non-trival to measure such a dataset, as the two devices must move, and one must at all times have a known distance. The measurement would be time consuming if one were to include transmission through walls.

As such, a realistic physical communication channel model, with sufficient accuracy, is needed.

III. How

Create a physical model that correctly enough models an indoor space with walls, and thus reflections.

As a first step, a 2D model should be developed, which is possible to expand into 3D.

The generation of data should be fast, so generation should be in a compiled language. Maybe it's good to prototype in high level language.

At the transmitter the signal can be described as

$$y_{tx,f} = A_{tx} e^{j2\pi f t + \phi_\Delta}$$

where ϕ_Δ is the initial phase offset of the transmitter, f is the carrier frequency, A_{tx} is the amplitude of the transmission.

For a single ray, the reciever would see

$$y_{rx,f,d} = A_{ch,f,d,\vec{A_r}} e^{j\phi_{ch,f,d,\vec{\phi_r}}} y_{tx,f}$$

where $A_{ch,f,d,\vec{r},\vec{p}}$ is the amplitude response of the channel as a function of frequency f and distance d, and a vector of reflections or re-transmissions $\vec{A_r}$ and $\vec{\phi_r}$

As such, assuming Friis path loss, the amplitude would be

$$A_{ch,f,d} = \frac{c}{4\pi f d^2} \prod \vec{A_r}$$

Assume that reflected and re-transmitted waves undergo a phase change, then phase would be

$$\phi_{ch,f,d} = 2\pi \frac{fd}{c} + \sum \vec{\phi_r}$$

If we expand to multiple rays, for a fixed distance between devices, the reciever signal will be

$$y_{rx,f} = H(f) y_{tx,f}$$

And the transfer function

$$H(f) = \sum_{k=0}^{N} A_{ch,f,d[k]} e^{j\phi_{ch,f,d[k]}}$$

where d is the distance each ray has traveled, k is the index of the ray, and N is the total number of rays.

The shortest path between two devices must correspond to a direct ray, however, the direct ray can undergo re-transmission through walls. All other rays must have a distance longer than direct rays, and can be a series of reflections and re-transmissions.

IV. Channel model

The code for the channel model can be found at model.py.

Assume a direct ray. Assume that other rays, $\vec{R}$ have uniformly distributed distance from the direct ray up to 100 meters. Assume that all reflected rays undergo a $-\pi$ phase shift. Assume that the $\prod \vec{A_r}$ is a normal distribution with a mean of 0.15 and a standard deviation of 0.05.

Assuming a 80 MHz bandwidth in the 2.4 GHz ISM band, the transfer function could be as shown in Figures 1, 2, 3.

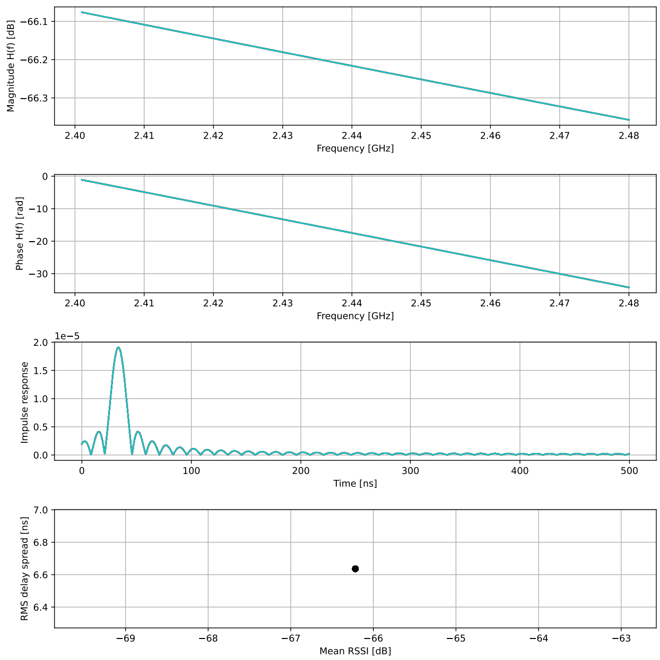

Fig. 1. 10 meter direct path, One ray, 100 runs

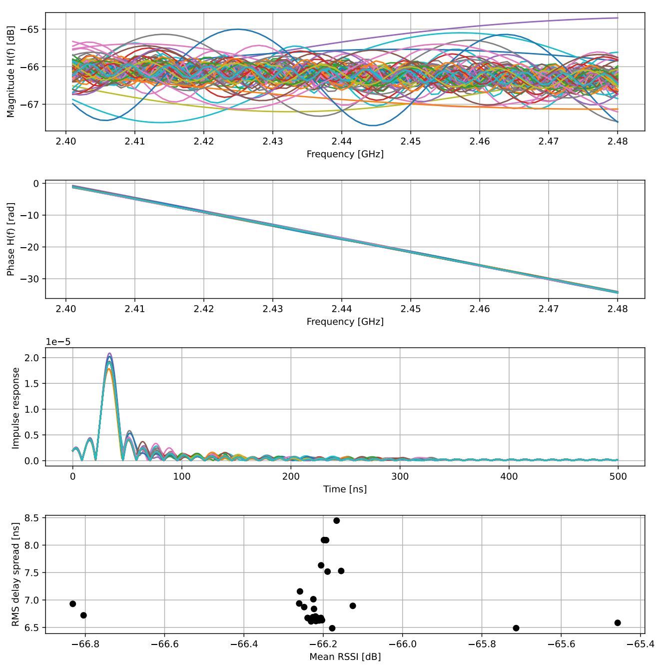

Fig. 2. 10 meter direct path, Two rays, 100 runs

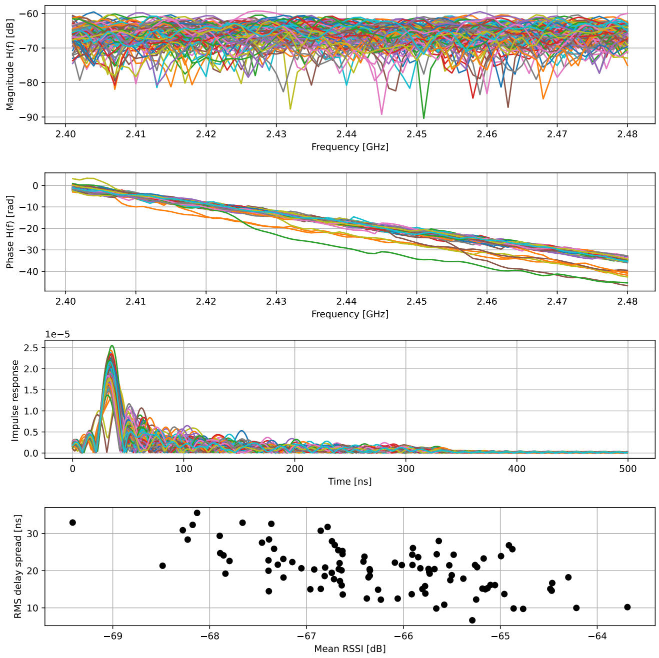

Fig. 3. 10 meter direct path, 100 rays, 100 runs

V. Distance model

It is possible to run the model over multiple distances, and as such, see how the RMS delay spread is as a function of distance. In Figures 4,6,6 simulation of 1 meter to 20 meters is shown for 10,100,1000 rays and 100 channel realization per distance.

The number of rays will natuarlly impact the RMS delay spread. How many rays are important in a real room would depend on the reflection coefficient matrix.

VI. Further work

The $\prod \vec{A_r}$ and $\sum \vec{\phi_r}$ should be updated more accurately reflect real world coefficients for example Reflection and Transmission Properties of Common Construction Materials at 2.4 GHz Frequency

The distance of rays should somehow be computed from a real scenario, like the floorplan of a home, and should include a model of the number of reflections or transmissions

There might already be ray based models, so literature should be checked.

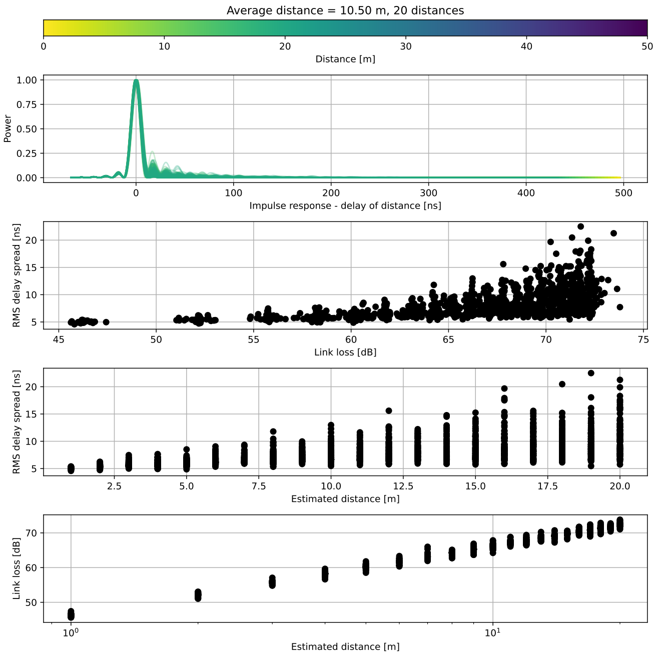

Fig. 4. Multiple distances 10 rays

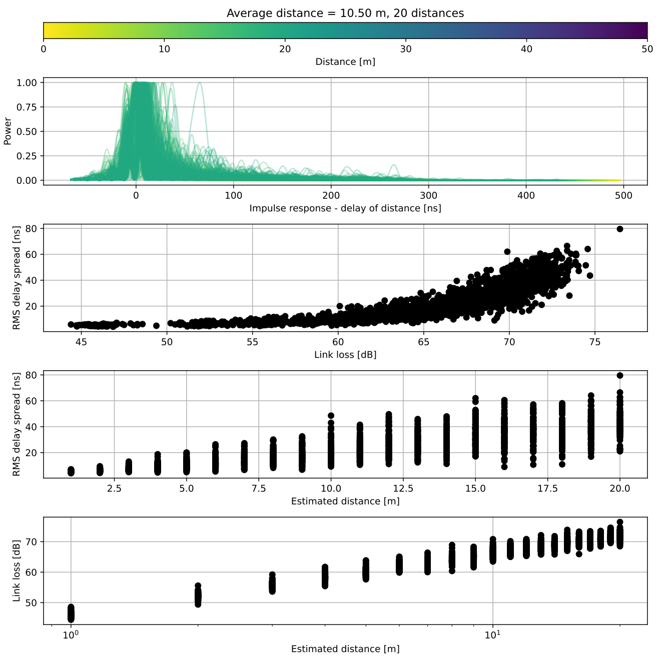

Fig. 5. Multiple distances 100 rays

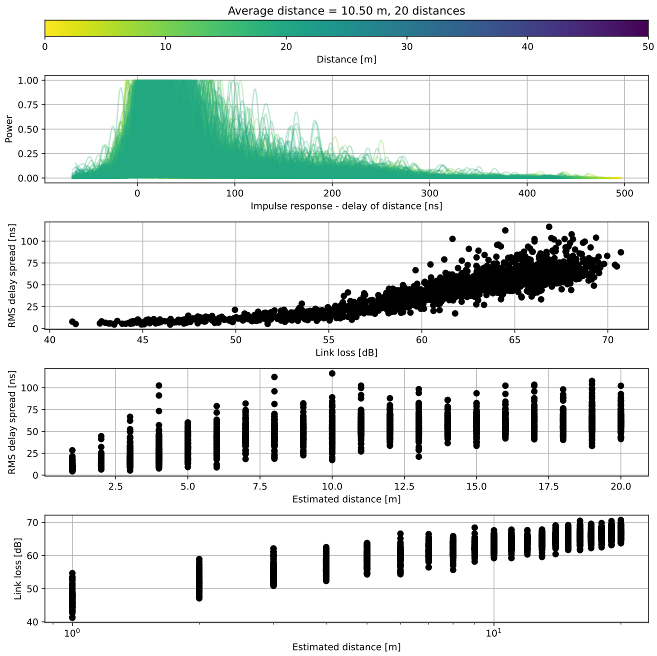

Fig. 6. Multiple distances 1000 rays