Cantenna - Building a very low budget circular waveguide

Vasileios Dimitrakis and Niclas Scheuing

November 19, 2015

Figure 1: Cantenna in the typical Dimitrakis-Scheuing design emphasizing the mediterranean influences.

1 Introduction

The objective of this exercise is the creation and the performance evaluation of a high gain and directional Wi-Fi antenna. The effectiveness of the antenna will be evaluated in comparison with an omnidirectional and a professional Wi-Fi antenna. The design that we chose to build is a cantenna. Cantenna is a homemade directional waveguide antenna, made out of an open-ended metal can.

2 Theoretical background of the cantenna

The cantenna we built is a cylindrical directional waveguide antenna. This kind of waveguide supports both traverse electric (TE) and traverse magnetic (TM) modes. The traverse modes are a particular electromagnetic field pattern of radiation measured in a plane perpendicular (i.e., transverse) to the propagation direction of the beam. They have a cutoff frequency, below which electromagnetic energy is severely attenuated and above this, the certain mode is excited. An ideal cantenna has only one mode, the dominant one, which is the TE_{11}, because our cantenna is a cylindrical waveguide. If the cantenna excites more than one modes, the effectiveness of the antenna will decrease, because the energy of the electromagnetic wave will be spread within different modes. The mode that we do not want to trigger is the TM_{10}.

2.1 Cantenna design parameters

For our cantenna to work properly, some geometric properties need to be calculated first. The cantenna used in this exercise will use the Wi-Fi channel 6 with central frequency 2.437GHz and wavelength 12.31cm.

2.1.1 Can diameter

The cantenna should trigger the dominant mode TE_{11} only. This happens at any frequency higher then the cutoff frequency $f_{c,TE_{11}}$. No other mode is triggered for frequencies below $f_{c,TE_{11}}$, because waves are attenuated exponentially. The second mode is the TM_{10} and if the frequency is greater than the cutoff frequency $f_{c,TM_{10}}$, both the two first modes will be excited. We thus deduce that the Wi-Fi frequency f_{Wi-Fi} has to fulfill the following inequality:

$$f_{c,TE_{11}} < f_{Wi-Fi} < f_{c,TM_{10}} \tag{1}$$

.

The formulas for the above two frequencies for the cylindrical waveguide are the following[1]:

$$\frac{p_{11}c}{\pi f_{WiFi}} < D < \frac{p'_{01}c}{\pi f_{WiFi}} \tag{2}$$

where $p'_{11} = 1.841$ and $p_{01} = 2.405$ are parameters related to the Bessel function and c the speed of light. This yields in

$$72.18mm < D < 94mm \tag{3}$$

Therefore the diameter of our cantenna has to be between these limits.

2.1.2 Position of the copper element: Acts as the monopole

Not only that certain modes are triggered, when the electro magnetic wave of the Wi-Fi signal reaches the cantenna. The wave inside the can is also reflected by its bottom. This results in the creation of a static wave. The wavelength λ_g of the static wave inside of the can is equal to the wavelength of the mode that is triggered. In our case we want to trigger only the dominant mode TE_{11}. Placing the monopole, we must take into consideration the frequency of this static wave. The static wave is a sinusoid, so we know its highest amplitude can be found at a distance of $\frac{\lambda_g}{4}$ from the can bottom. Since we know $\lambda_g = 176.56mm$ as a property of the TE_{11} mode[2], we placed the monopole at a distance of $\frac{\lambda_g}{4} = 44.14mm$ from the can bottom. The monopole is a piece of copper wire placed orthogonally to the can surface pointing inwards.

2.1.3 Monopole length

The monopole antenna is a class of radio antenna consisting of a straight rod-shaped conductor, often mounted perpendicularly over some type of conductive surface, called a plane ground. In our case, we decided to built the most common type of the monopole, which is the quarter-wave monopole. It is also called *Marconi antenna*. This monopole is ideal for our configuration, because it is simple and it has the right dimensions, in order to fit inside the cantenna. The length of the monopole is equal to $\frac{1}{\lambda_{Wi-Fi}}$. Where λ_{Wi-Fi} is the wavelength of the Wi-Fi signal. In the current setup $\lambda_{Wi-Fi} = 123mm$, so the length of the monopole is $30.75mm$.

	Theoretical value in mm	Actual Values in mm
Can diameter	72.18 to 94	100.5
Monopole position	44.14	44.1
Monopole length	30.75	30.75
Length of the can	¿132.42	162.5

Table 1: Cantenna geometry. Theoretical and actual values.

2.1.4 Length of the can

The length of the can has to be more than $\frac{3}{4}\lambda_g = 132.42mm$. The longer the cantenna is the more directional and effective becomes. In our case, the length of the cantenna is $160mm$, so we expect to be directional.

2.2 Cantenna theoretical and experimental device dimensions

In Table 1, we present the theoretical design parameters of the cantenna and the actual ones of our setup. Our cantenna satisfies all the design prerequisites and thus, we expect it to work fairly well regarding antenna gain and directivity.

3 Setup

In the following section we describe the experiment's setup.

3.1 Terminology

The machine serving as stationary receiver connected to the cantenna is denoted by `Receiver`. It is the one performing all measurements. The machine used as access point is called `AP`. It is moved around and sending traffic to the `Receiver`.

3.2 Materials

The materials and the equipment that were used for the creation and the setup of the antenna are the following:

- 2 Notebooks

- 1 *USB Alfa wireless adapter:* Is the wireless adapter connected to `Receiver`. The antennas are connected to this interface.
- 1 *TP-Link wireless adapter:* Is used by the `AP`.
- 1 *Pigtail cable:* Is used to connect the cantenna with the USB Alfa wireless adapter.
- 1 *female N-connector*
- 1 *piece of copper wire:* Is used as the active element, the monopole, that radiates the waves
- 1 *cylindrical can:* Plays the role of the Wi-fi antenna.
- *ifconfig*: Is used to configure the network interfaces.
- *iwconfig*: Is used to configure the *wireless* network interfaces.
- *iperf*: Network testing tool for creating data streams and measuring throughput.
- *iptraf*: Monitoring network interface throughput.
- *hostapd*: Is a user space deamon for Access Point and authentication servers.
- *netcat*: Used as a chat channel to communicate over larger distances.

3.3 Setting up the experiment

Wi-Fi channel : We used Wi-Fi channel 6.

Distance meassurement We placed markers on the ground (see Figure 3) at the distances of 1m, 10m, 20m, 40m, 60m, 80m, 100m. To measure the distance we used GPS and counting steps, which resulted in a maximum difference of less than 2m.

Cantenna mounting To keep the antennas stable in position and angle, we mounted them on a microphone stand. See Figure 4

Access Point The access point run on the `AP`machine using *hostapd*

Figure 2: Conducting the experiment in the field.1

Figure 3: Markers placed on the side of the road for the distance measurements.

Figure 4: All three antennas are stable in position and direction.

Figure 5: title

3.4 Gain measurements

We observed the way the signal strength changes when increasing the distance between the `AP`and the `Receiver`. This experiment was executed for three different antennas: an omnidirectional antenna, a professional cantenna and our cantenna. In order to be the measurements accurate, they were taken in an open area field. We chose the place seen in Figure 5 in order to avoid environmental effects, such as reflections by buildings, scattering by moving objects.

3.5 Directionality measurements

In the second phase of the experiment measured the directionality of each of the above antennas. All the measurements for the three antennas were taken in 20m distance from the Access Point. The starting point of the measurements was considered the one with 0°. Every next measurement was taken every 20°.

3.6 Maximum distance measurements

To see how far we can transmit using our cantenna, we increased the distance in steps of 20m starting at 100m. To check the connection, we used *netcat* to send messages and *ping*.

4 Results

All results of the measurements can be found in the Appendix in section 7.

4.1 Gain measurements

Signal Strength The results of the measurements can be found in the Appendix as Tables Table 2, Table 3, Table 4 and as plots Figure 7, Figure 8, Figure 9.

In Figure 6 we observe that all antennas mostly behave according to the *Free space loss* model. We observe some anomalies though. We assume that these are due to reflections and scattering on moving objects like cars and static objects as a fence and the road.

The antennas behave comparable regarding the measured signal strength. The directional antennas did not clearly outperform the onmi-directional, which is rather surprising. Opposed to the omni-directional antenna, the cantennas were connected to the adapter using a cable which could result in some performance loss.

Bandwidth Figure 10 to Figure 12 show the bandwidth measurement. We observe an average bandwidth of roughly 6 Mib/s for our cantenna, 8 Mib/s for the professional cantenna and 5.5 Mib/s for the omni-directional antenna. The cantennas outperform the omni-directional antenna by a factor of up to 1.45. This is not reflected in the signal strength measurements. We could not explicitly identify the cause of this phenomenon. The bandwidth does not decrease with increasing distance. The signal is still strong enough at a distance of 100m to not get a significant error-rate. This changes for higher distances, see subsection 4.3.

4.2 Directionality measurements

Signal strength The results can be found in Figure 13 Figure 15 and Table 5 to Table 7.

To measure the directionality we use two measures. The *half-power beam width*, the angle between the half-power pints of the main lobe. And the

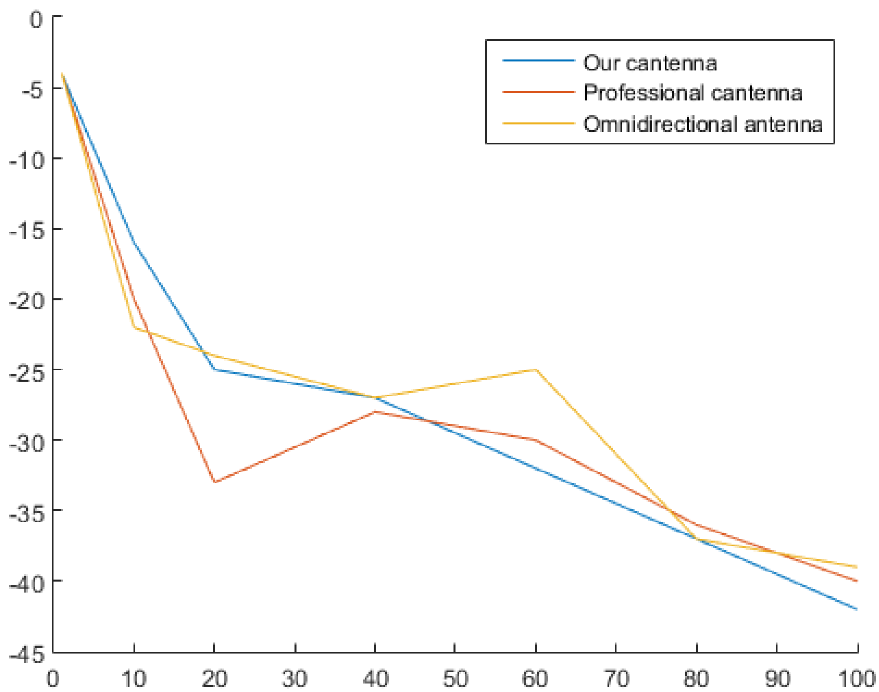

Figure 6: The decreasing signal power of all three antennas. Corresponds to *free space loss* model except for some values (e.g. at 20m for the professional cantenna)

front-to-back ratio, th ratio of power-gain between the front and the rear of the antenna.

For our cantenna the *half-power beam width* is 70° and the *front-to-back ratio* is 22dB. For the professional antenna we got a *half-power beam width* of approximately 80° and a *front-to-back ratio* of 11dB. The omni-directional has a maximum at 0° and a minimum at 180° but for the other angles the gain is almost constant, as expected for a omni-directional antenna.

Bandwidth The result of the bandwidth measurements can be seen in Figure 16 to Figure 18 and Table 5 to Table 7. The bandwidth and the signal strength do not correlate for the directional antennas. The maximum can be found at around 240° and not at 0° where we expected it. We assume this is due to our hasty measurement methodology because we can not come up with any other explanation.

4.3 Maximum distance measurements

Using our cantenna we could go up to 250m before losing the connection. The signal strength decreased drastically at a distance of 240m (-70dBm)while the bandwidth was stable up to 140m (4.5Mib/s) and decreased to 800Kib/s at 250m where we lost the connection.

5 Conclusion

We achieved to build high-gain directional antenna that provides a *higher bandwidth* than the omni-directional antenna. Regarding their *signal strength* all three antennas perform similarly. This is rather Even though we measured outdoors, we observed some *anomalies* due to environmental effects and measurement errors. The maximum distance of 250m we could reach, implies a potential benefit for real life applications.

6 References

References

[1] RF Cafe. Rectangular & circular waveguide: Equations, fields, & fco calculator. `http://www.rfcafe.com/references/electrical/waveguide.htm`, 2015.

Distance in m	signal strength in dBm	transfer rate in Kib/s
1	-4	520
10	-16	5649
20	-25	5024
40	-27	5194
60	-32	6386
80	-37	5933
100	-42	6300

Table 2: Our cantenna. Measured signal strength and bandwidth depending on the distance

Distance in m	signal strength in dBm	transfer rate in Kib/s
1	-4	389
10	-20	8500
20	-33	8400
40	-28	9300
60	-30	8200
80	-36	7900
100	-40	7800

Table 3: Professional cantenna. Measured signal strength and bandwidth depending on the distance

[2] University of Oklahoma Department of Physics and Astronomy. Circular waveguide. `http://www.nhn.ou.edu/~johnson/Education/Juniorlab/Microwave/CylindricalWaveguide.pdf`, 2015.

7 Appendix

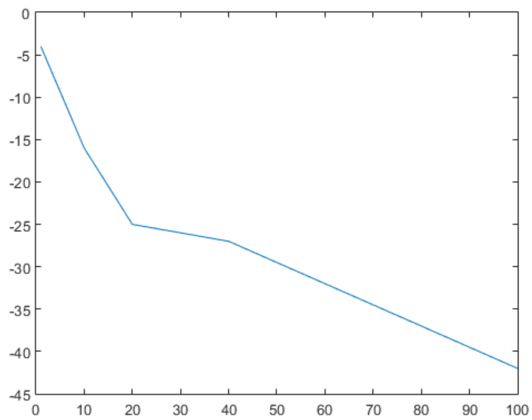

Figure 7: Our cantenna. Measured signal strength depending on the distance. Horizontal axis in meters, vertical axis in dBm.

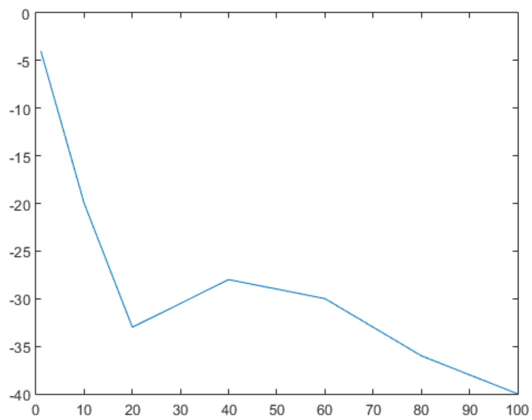

Figure 8: Professional cantenna. Measured signal strength depending on the distance. Horizontal axis in meters, vertical axis in dBm.

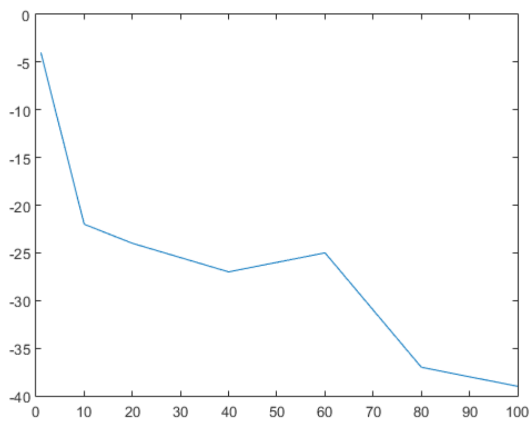

Figure 9: Omni-directional cantenna. Measured signal strength depending on the distance. Horizontal axis in meters, vertical axis in dBm.

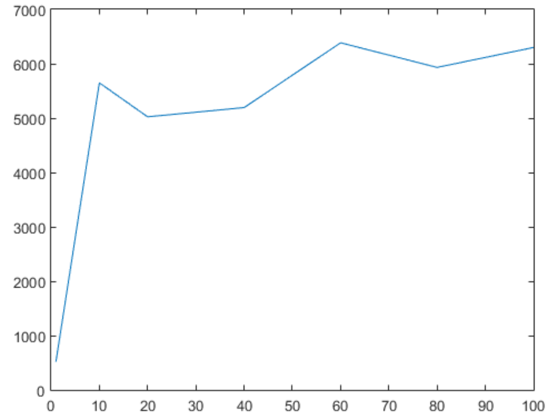

Figure 10: Our cantenna. Measured bandwidth depending on the distance. Horizontal axis in meters, vertical axis in Kib/s.

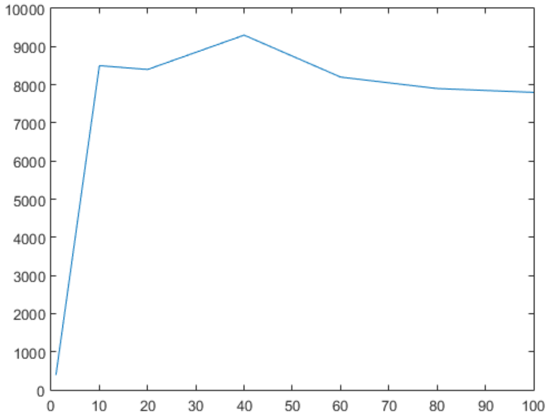

Figure 11: Professional cantenna. Measured bandwidth depending on the distance. Horizontal axis in meters, vertical axis in Kib/s.

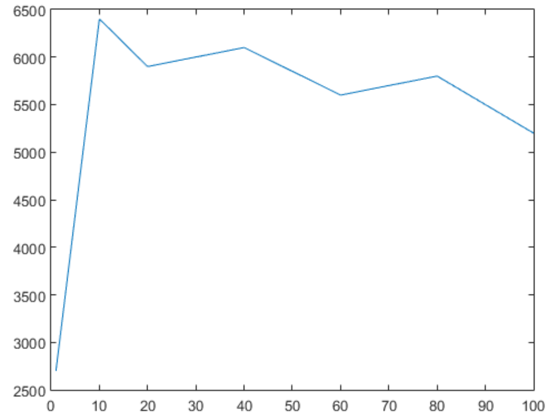

Figure 12: Omni-directional cantenna. Measured 1bandwidth depending on the distance. Horizontal axis in meters, vertical axis in Kib/s.

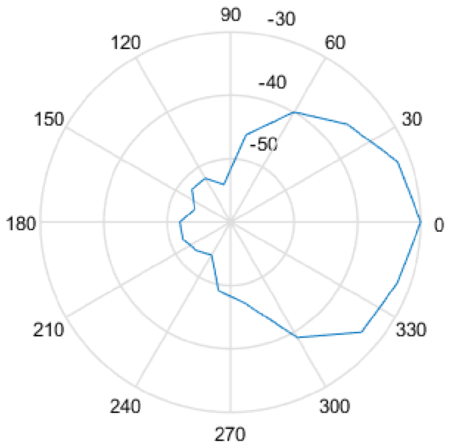

Figure 13: Our cantenna. Measured signal strength depending on the angle. Polar axis in degree, radius axis in dBm.

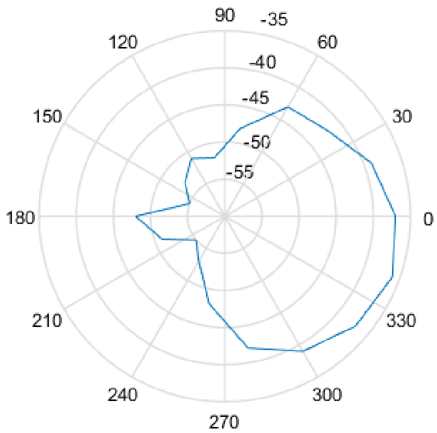

Figure 14: Professional cantenna. Measured signal strength depending on the angle. Polar axis in degree, radius axis in dBm.

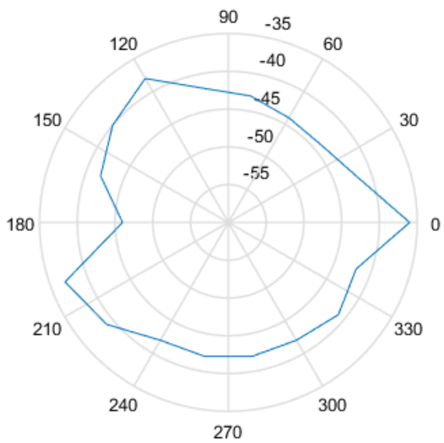

Figure 15: Omni-directional cantenna. Measured signal strength depending on the angle. Polar axis in degree, radius axis in dBm.

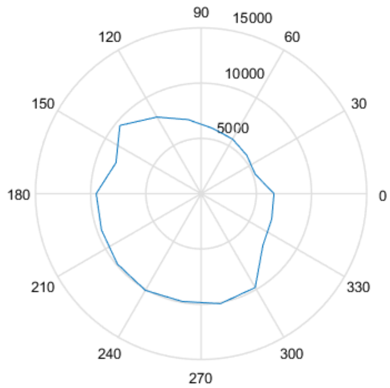

Figure 16: Our cantenna. Measured bandwidth depending on the angle. Polar axis in degree, radius axis in Kib/s.

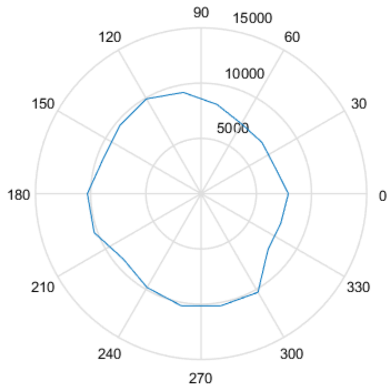

Figure 17: Professional cantenna. Measured bandwidth depending on the angle. Polar axis in degree, radius axis in Kib/s.

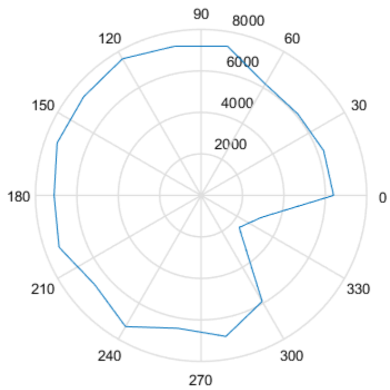

Figure 18: Omni-directional cantenna. Measured bandwidth depending on the angle. Polar axis in degree, radius axis in Kib/s.

Distance in m	signal strength in dBm	transfer rate in Kib/s
1	-4	2700
10	-22	6400
20	-24	5900
40	-27	6100
60	-25	5600
80	-37	5800
100	-39	5200

Table 4: Omni-directional antenna. Measured signal strength and bandwidth depending on the distance

Angle in degrees m	signal strength in dBm	transfer rate in Kib/s
0	-30	6600
20	-32	5200
40	-36	5400
60	-40	5700
80	-46	6000
100	-54	6800
120	-52	8000
140	-52	9600
160	-54	8200
180	-52	9500
200	-52	9600
220	-53	9900
240	-54	10100
260	-49	9900
280	-47	10100
300	-39	9800
320	-33	7300
340	-32	6800

Table 5: Our cantenna. Measured signal strength and bandwidth depending on the angle

Angle in degrees m	signal strength in dBm	transfer rate in Kib/s
0	-37	7900
20	-39	7100
40	-42	7200
60	-43	7300
80	-48	8200
100	-52	9300
120	-51	9900
140	-53	9600
160	-55	9400
180	-48	10300
200	-51	10300
220	-55	9200
240	-53	9800
260	-48	10300
280	-42	10300
300	-39	10300
320	-37	7900
340	-36	7700

Table 6: Pofessional cantenna. Measured signal strength and bandwidth depending on the angle

Angle in degrees m	signal strength in dBm	transfer rate in Kib/s
0	-36	6400
20	-42	6300
40	-44	6100
60	-44	6200
80	-43	7300
100	-42	7300
120	-38	7600
140	-40	7400
160	-42	7400
180	-46	7100
200	-37	7300
220	-39	6700
240	-42	7300
260	-42	6500
280	-42	6900
300	-42	5900
320	-41	2400
340	-42	3100

Table 7: Omni-directional antenna. Measured signal strength and bandwidth depending on the angle