Radio Engineering: First Lab Session

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1 Preface

- The attendance to the lab sessions is compulsory. If you cannot attend a lab session, you have to inform me by email beforehand providing a proof that you cannot attend (e.g. flight reservation).
- Additionally, you may work on the assignments also at home.
- Final report due one week after final lab session
- The Matlab code and the measurement data can be downloaded from the course webpage.

2 Introduction

In 2012, Eurecom carried out a measurement campaign to study wireless broadband communications between boats on the sea. Because of the wide availability, reasonable prices, and high peak throughput, the IEEE 802.11n standard was chosen.

IEEE 802.11n is an amendment to the IEEE 802.11 wireless networking standard. Its purpose is to improve network throughput over the two previous standards—802.11a and 802.11g—with a significant increase in the maximum net data rate from 54 Mbit/s to 600 Mbit/s.

The questions that will be answered in this lab session is which data rates can be supported as a function of the distance of the boats.

2.1 Hardware

The hardware used for the measurements is the Javelin system from Wittelcom. This box can be used both as a master (access point) and as a slave (user terminal). It comes either packed together with a directional antenna (JL-55-23) or in an individual box that can be connected to an external antenna, such as the omi-directional antennas (ANT4958Q12VH) from Foshan Lanbowan Communications.

2.2 Measurement Description

For the measurements we used the JL-55-23 as an access point and the omni-directional antenna as a slave. The access point was mounted on land at a height of approximately 25m (above sea level) and the omni-directional antenna was mounted on the boat at about 3m above sea level. We used a carrier frequency of 5.6GHz, a bandwidth of 40MHz, and the maximum transmit power of 23dBm. During the measurements we recorded amongst others the received signal strength for both polarizations.

The measurement data is stored in the file (Linux/Windows)[1]

```
/datas/teaching/courses/RADIO/lab2015/rssi_distance_omni_boat.mat
\\datas\teaching\courses\RADIO\lab2015\rssi_distance_omni_boat.mat
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The file contains two data pairs (rssi1,d1) for horizontal polarization and (rssi2,d2) for vertical polarization. The RSSI is measured in dBm and the distance in kilometers.

3 Tasks

1. The data-sheet fo the JL-55-23 specifies different RX sensitivity levels for different data rates. Additionally, assume that for the correct decoding of the lowest modulation and coding scheme (MCS) a SNR of 0dB is required. What is the maximum allowed receiver noise figure at room temperature ($T = 300$K) for the given system?

2. Plot the measurement data (RSSI vs distance) for both polarizations. Try to explain where the difference between the two polarizations comes from!

3. Implement the two-path model (4.55) from the Appendix and plot it on top of the measurement data. Use $E(1) = \frac{\lambda}{4\pi}$. Does the model fit the data? Try to explain why or why not!

4. Using the path loss approximation for large distances (4.59) from the Appendix, and assuming a fading margin of $M = 10$ dB, determine the maximum range of one cell for the lowest and the highest MCS.

[1] The file can also be downloaded from the course webpage

4.6.1 Appendix 4.A: Derivation of the d^{-4} Law

In this appendix, we derive the d^{-4} law for the received power. Consider the geometry in Fig. 4.15. The transmit antenna is placed at height $h_{\rm TX}$ over ground, where the ground is assumed to be at least partially conducting. The receive antenna is at height $h_{\rm RX}$ above ground. The distance to the transmit antenna is d. Two rays reach the receiver: the direct (line-of-sight) path, and the ground reflection. The angle of incidence for the ground-reflected ray is usually close to 90° (grazing angle of incidence), as the antenna heights (1.5m for the MS, 10 – 100m for the BS), are much smaller than the distance between MS and BS. We saw in Sec. 4.2.1 that in this case, the reflection coefficient is approximately -1, irrespective of the actual conductivity of the ground

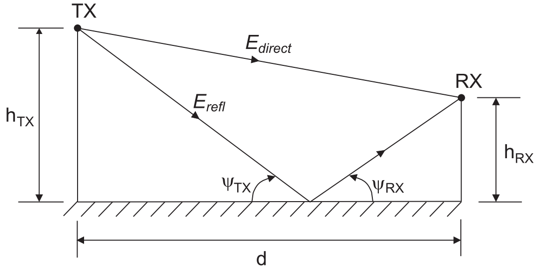

Figure 4.15 Geometry for the derivation of the d^{-4} law.

The field strength for the direct path is thus

$$E_{\rm direct}(d_{\rm direct}) = E(1{\rm m}) \left(\frac{1}{d_{\rm direct}|_{\rm m}}\right) \exp\left[j\left(2\pi f_{\rm c}t - 2\pi f_{\rm c}\frac{d_{\rm direct}}{c_0}\right)\right] \tag{4.50}$$

which follows from Eq. 4.9 (though note the phase term, as we are considering field strength now). Here, c_0 is the speed of light. The field strength of the reflected path is

$$E_{\rm refl}(d_{\rm refl}) = (-1)\cdot E(1{\rm m}) \left(\frac{1}{d_{\rm refl}|_{\rm m}}\right) \exp\left[j\left(2\pi f_{\rm c}t - 2\pi f_{\rm c}\frac{d_{\rm refl}}{c_0}\right)\right] \tag{4.51}$$

where the factor -1 is due to the reflection coefficient of the ground. The pathlengths $d_{\rm direct}$ and $d_{\rm refl}$ can be computed from simple geometric considerations as

$$d_{\rm direct} = \sqrt{(h_{\rm TX}-h_{\rm RX})^2 + d^2} \qquad d_{\rm refl} = \sqrt{(h_{\rm TX}+h_{\rm RX})^2 + d^2} \tag{4.52}$$

The total fieldstrength is obtained by coherent addition of the direct and the reflected ray.

Additional simplifications can be made due to the fact that the height of the antennas is much smaller than the distance between them. The impact of the longer distance for the ground reflected path on the amplitudes of the field strengths is negligible; only the resulting phase shift plays a role. This allows to write the total field as

$$\begin{aligned} E_{\rm tot}(d) &= E(1m)\left(\frac{1}{d|_m}\right)\left\{\exp\left[j\left(2\pi f_{\rm c}t - 2\pi f_{\rm c}\frac{d_{\rm direct}}{c_0}\right)\right] - \exp\left[j\left(2\pi f_{\rm c}t - 2\pi f_{\rm c}\frac{d_{\rm refl}}{c_0}\right)\right]\right\} \\ &= E(1m)\left(\frac{1}{d|_m}\right)\exp\left[j\left(2\pi f_{\rm c}t - 2\pi f_{\rm c}\frac{d_{\rm direct}}{c_0}\right)\right]\left\{1 - \exp\left[-j\left(2\pi f_{\rm c}\frac{d_{\rm refl}-d_{\rm direct}}{c_0}\right)\right]\right\} \end{aligned} \tag{4.53}$$

Furthermore, the differences in the pathlength, d_{refl} - d_{direct}, can be expanded into a Taylor series, so that

$$d_{\mathrm{refl}} - d_{\mathrm{direct}} = 2\frac{h_{\mathrm{TX}}h_{\mathrm{RX}}}{d} \tag{4.54}$$

The magnitude of the field strength can thus be written as

$$|E_{\mathrm{tot}}(d)| = E(1m)\frac{1}{d|_m}\sqrt{(1-\cos(\Delta\varphi))^2 + \sin^2(\Delta\varphi)} \tag{4.55}$$

where

$$\Delta\varphi = 2\frac{h_{\mathrm{TX}}h_{\mathrm{RX}}}{d}\frac{2\pi f_{\mathrm{c}}}{c_0} \tag{4.56}$$

Assume now that $\Delta\varphi$ is much smaller than $\pi/2$ (an assumption that is consistent with our basic assumption that d is large and the antenna heights are small). This is fulfilled for

$$d_{\mathrm{limit}} \gg \frac{8h_{\mathrm{TX}}h_{\mathrm{RX}}}{\lambda} \tag{4.57}$$

In that case, $\sin(\Delta\varphi) \approx \Delta\varphi$, and $1 - \cos(\Delta\varphi)$ is on the order of $(\Delta\varphi)^2$, i.e., negligible. Inserting this into the equation for E_{tot} results in

$$|E_{\mathrm{tot}}(d)| = E(1m)\frac{1}{d}2\frac{h_{\mathrm{TX}}h_{\mathrm{RX}}}{d}\frac{2\pi}{\lambda} \tag{4.58}$$

According to this equation, the field strength decreases with the square of the distance, and the received power thus decreases with d^4. Friis' law is then replaced with

$$P_{\mathrm{RX}}(d) \approx P_{\mathrm{TX}}G_{\mathrm{TX}}G_{\mathrm{RX}}\left(\frac{h_{\mathrm{TX}}h_{\mathrm{RX}}}{d^2}\right)^2 \tag{4.59}$$

From Eq. (4.53), it follows that this behavior occurs when $\Delta\varphi \le \pi$, i.e., for a distance $d \ge d_{\mathrm{break}}$ where

$$d_{\mathrm{break}} = \frac{4h_{\mathrm{TX}}h_{\mathrm{RX}}}{\lambda} \tag{4.60}$$

WITELCOM – Javelin TDM LINK

Javelin – Radio Link System

High Speed and long range 2x2 MIMO Unit

The Witelcom Javelin links are specially developed for secure high capacity and low latency/jitter backhauling for everything from 2G to LTE/WiMAX networks, offering operators an attractive price/performance options. Javelin is available in both 100 Mbps and Gigabit versions. With its OFDM and Mimo technology the products have improved nLos capabilities and can operate in nLos environment.

Javelin offers a simple and intuitive user interfacing to allow the operator to easily deploy, monitor and operate the systems.

System Highlights

- Real aggregated throughput of up to 250 Mbps full duplex – 500 Mbps aggregated.
- Gigabit Ethernet interface
- Fiber optic and E1/T1 expansion option
- 2 x 2 MIMO 802.11a/n with 300 Mbps "over the air" data rates
- Ultra low latency and jitter performance
- Telco power – AC and 48V
- Available in 2.3 GHz, 2.4 GHz, 4.9 GHz, 5.2-5.8 GHz and 6 GHz
- Up to 23 dBm aggregated TX-power for long range capability
- Adaptive Link Rates, TPC & DFS support (iaw ETSII regulation)

The Javelin supports all the carrier grade requirements related to telecommunication deployments, and provides professional installation kits for mounting. The Javelin is developed for outdoor environment and includes an outdoor panel antenna unit with IEC529/IP67 water tightness
Vlan management and Vlan Switch functionality

Javelin System Description

The Javelin consists of an Indoor Unit (IDU) and Outdoor Unit (ODU), and a single RJ45 CAT5E outdoor cable connecting the units together at a distance of up to 100 meters. The IDU can be powered with 110-230V AC or directly from 48VDC (AF) Telco power. Javelin can be expanded with optional E1/T1 and fiber optic interfaces.

The 5GHz Javelin (JL-55) RF specifications

Standard Frequencies (UNII, UNII-2, 802.11a):
5.180 – 5.350 - 8 channels available in ETSI (& UNII)
5.470 - 5.725 – 11 channels available in ETSI
5.725 – 5.850 – Depending on Regulatory Domain
Modulation technique:
2 x 2 MIMO OFDM. Selectable channel width of 40MHz, 20MHz, 10MHz and 5MHz
RF Access Protocols:
Both TDMA and CSMA/CA options
OFDM: BPSK, QPSK, 16-QAM, 64-QAM
System Security: AES 128
RF Output Power:
Selectable for regulatory domain: up to 23 dBm aggregated TX power
IP Operation Mode: Transparent Bride mode
Transfer Data Rate (Link Speed): Up to 300 Mbps (link speed).

Supported Link rates:

MIMO Data Rates & RX-sensitivity			
MCS 15 – 300 Mbps	-74 dBm	MCS 7 - 150 Mbps	-77 dBm
MCS 14 – 270 Mbps	-76 dBm	MCS 6 - 135 Mbps	-79 dBm
MCS 13 – 240 Mbps	-78 dBm	MCS 5 - 120 Mbps	-80 dBm
MCS 12 - 180 Mbps	-82 dBm	MCS 4 - 90 Mbps	-84 dBm
MCS 11 - 120 Mbps	-84 dBm	MCS 3 - 60 Mbps	-87 dBm
MCS 10 - 90 Mbps	-87 dBm	MCS 2 - 45 Mbps	-92 dBm
MCS 9 - 60 Mbps	-90 dBm	MCS 1 - 30 Mbps	-94 dBm
MCS 8 - 30 Mbps	-92 dBm	MCS 0 - 15 Mbps	-97 dBm

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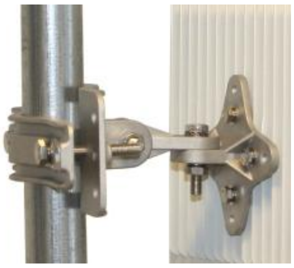
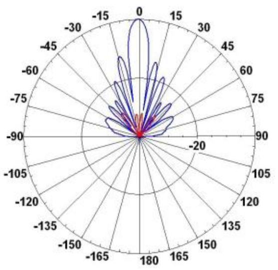
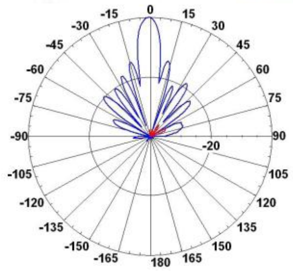
Norway

WITELCOM – Javelin TDM LINK

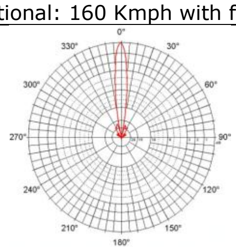


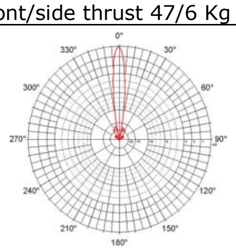




JL-55-23 & JLG-55-23 Specifications

Unit Size	ODU: 370 x 370 x 70 mm (housing) IDU: 1U Rack Unit
Integrated Antenna	Flat panel 23dBi 5GHz Wide Band (5.1–5.9 GHz) - 370x370mm, Dual Linear (V&H) polarization, 8x8 degrees beam with (at -3dBm) – recommended up to 40 km
Ethernet	JL-55-23: 10/100 Mbps, JLG-55-23: 10/100/1000 Mbps & IDU fiber optic option
Mode	Bride mode, router mode, NAT mode with DHCP client, PPPoE and static WAN. Static or DHCP server for LAN. VLAN for management and VLAN Switch Web browser configuration
E1/T1 option	Unframed (transparent), ITU-T G.703, G.826. 1U rack mount unit
Power source	IEEE 803.af 48V dc (AF)
Weight	4Kg
External Connectors	Weather sealed RJ45
Enclosure Material	Aluminum
Fasteners	Stainless Steel & aluminum
Heat Dissipation	20W max
External Color	RAL 9002
Mounting	Both wall and pole mount
AZ/EL control	Both
Pole Size	1¾÷3" Ø (45-75mm Ø)
Temperature	-20°C to 75°C
Humidity	100%
Water Tightness	IEC 529 / IP67
Wind Load (Survival)	Operational: 160 Kmph with front/side thrust 47/6 Kg (220 Kmph)





JL-55-29 & JLG-55-29 Specifications

Unit Size	ODU: 300 x 300 x 70 mm (housing) IDU: 1U Rack Unit
Antenna	Parabolic 29dBi 5GHz Wide Band (5.1–5.9 GHz) - 900x900mm, Dual Linear (V&H) polarization, 5x5 degrees beam with (at -3dBm)
Ethernet	JL-55-23: 10/100 Mbps, JLG-55-23: 10/100/1000 Mbps & IDU fiber optic option
Mode	Bride mode, router mode, NAT mode with DHCP client, PPPoE and static WAN. Static or DHCP server for LAN. VLAN for management and VLAN Switch Web browser configuration
E1/T1 option	Unframed (transparent), ITU-T G.703, G.826. 1U rack mount unit
Weight	10Kg (total)
External Connectors	Weather sealed RJ45
Enclosure Material	Aluminum
Fasteners	Stainless Steel & aluminum
Heat Dissipation	20W max
External Color	RAL 9002
Mounting	Both wall and pole mount
AZ/EL control	Both
Pole Size	1¾÷3" Ø (45-75mm Ø)
Temperature	-20°C to 75°C
Humidity	100%
Water Tightness	IEC 529 / IP67
Wind Load (Survival)	Operational: 120 Kmph with front/side thrust 113 lbs (@100 mph)

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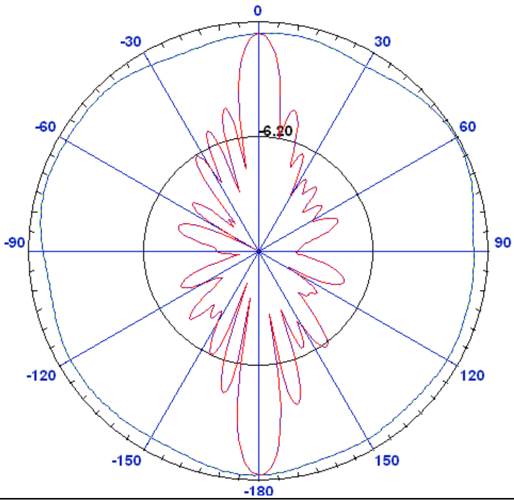
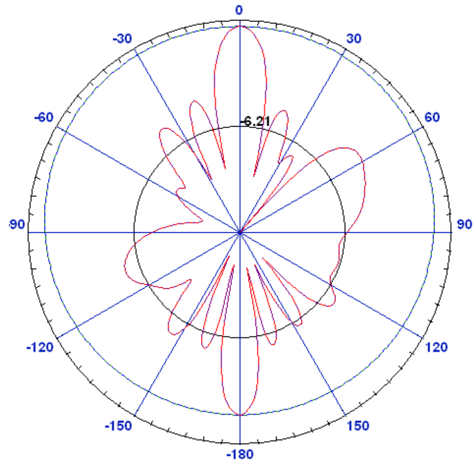
4.9-5.8GHz Dual Pol Omni Antenna

Specifications

Model	ANT4958Q12VH
Freq. Range	4900-5850MHz
Bandwidth	950MHz
Gain	2x12dBi
Horizontal Beamwidth	360 º
Vertical Beamwidth	13º
V.S.W.R	< 1.5Type;Max 2.0
Isolation	>27dB
Nominal Impedance	50 ohm
Polarization	Horizontal and Vertical
Max Power	50W
Connector	2-RPSMA
Dimensions	Φ60x370mm
Weight	1.5kg
Rated Wind Velocity	60 m/s



Vertical



Horizontal

VSWR/ Isolation

Pic

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The Lanbowan policy of continuing development may result in improvement or change to this product.