Planning and Deploying Long Distance Wireless Sensor Networks: The Integration of Simulation and Experimentation

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Abstract. Wireless sensor networks allow unprecedented abilities to observe and understand large-scale, real-world phenomena at a fine spatial-temporal resolution. Their application in Developing Countries is even more interesting: they can help solve problems that affect communities. One of the limitations of current wireless sensors is the communication range, with most devices having 100 meters as maximum range. In contrast, many applications require long-range wireless sensor network where nodes are separated by large distances, giving the advantage of being able to monitor a large geographic area. In this paper we will present the results of an integrated approach combining a planning step using simulations and an experimental step carried out using off-the-shelf equipment over distances ranging from 600m to 12km. The results reveal that the simulation results agree with experimentation and show that long distance wireless sensor networks (LDWSN) are possible and that the quality of these links is high. Finally, we discuss the relative efficiency of our solution in terms of range compared to other wireless sensor networks.

Keywords: Waspmote, Long Distance WSN, WSN, Frequency, ICT4D.

1 Introduction to LDWSN

Wireless Sensor Networks (WSNs) are a branch of ICT technologies which have been widely deployed in industrialized regions in many applications to achieve environment observation, healthcare and medical monitoring, home security, machine failure diagnosis, chemical/biological detection and plant monitoring. WSNs are deployed in large numbers of tiny sensor nodes, each node being regarded as a low power and cheap computer that can perform sensing, computation and communication. The sensor nodes communicate wirelessly and are

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deployed in three forms : (1) Sensor node used to sense the environment, (2) Relay node used as relay for the information sensed by other nodes and (3) Sink node acting as base station with higher energy to transmit the sensed information to a local or remote processing place.

Traditional sensor technology allows the deployment of wireless sensor networks in a 1-to-m fashion where all the nodes, excepted the sink node, sense their environment and send the collected information to the base station for further processing. As currently deployed, WSNs are based on a multi-hop model allowing these networks to 1) span distances much larger than the transmission range of a single node 2) adapt to network changes, for example, by routing around a failed node using a different path in order to improve performance and 3) use less transmitter power as a result of the shorter distance transmission mode enabled by the potential to achieve local communication between neigbhor nodes.

In many practical applications that require sensor monitoring over long distances such as farming or water quality monitoring in developing regions where environmental conditions such as temperature, soil moisture and other levels of water troughs need to be measured at widely separated locations, the short wireless range provided by WSNs may be become a limiting factor in terms of both cost since multi-hop routing over long distances may require many sensors and coverage as the short range sensors can cover only a few hundred of meters. However, while being resolved for Wi-FI technology [1], the problem of range limitation has been only poorly addressed by the research community. The work presented in [2] proposes a sensor network in Australia where the range of a mote has been extended to 300 m, a distance that does not meet long distance application requirements. Motivated by the fact that the directional antenna is an established technology that has been proven effective in improving the radio link quality, the work presented in [3] proposes the integration of radio communication technology to not only compensate for the higher path loss intrinsic of shorter wavelengths but also to ensure higher link quality and to implement a form of antenna diversity. A switched beam directional antenna operating in the 2.4GHz ISM band (e.g. using the IEEE 802.15.4 standard) with dimensions, cost and complexity constraints comparable to those of commercially available sensor nodes is presented in [3]. Used outdoors, the antenna extends the communication range from 140m to more than 350m, while indoors it suppresses the interference due to multipath fading by reducing the signal variability of more than 70%. The antenna also reveals interference suppression from IEEE 802.11g systems and can be used as a form of angular diversity useful to cope with the variability of the radio signal. Similarly, the work presented in [4] considers the use of switched beam directional antennas in wireless sensor networks. Using comparison with an existing solution based on S-MAC, the paper shows that the introduction of directional antennas reduces interference, transmission delay and flooding and consequently improves throughput and energy consumption. As presented by [5], a long-range ad-hoc wireless sensor network is proposed where a radio propagation model is used to enhance the range of wireless nodes. Using this model, distances of up to 10 kilometers are reached using non-directional antennae by having the radio transceiver of the Berkeley Mote replaced with a lower frequency, higher power unit operating in the 40.66-41.00 MHz frequency band with a maximum power of 1 W EIRP.

Simulations have been used in many research works to shorten development time by having all of the variables of a real system under the control of the designer, allowing better testing and debugging for example. However, it often happen that by making simplicative assumptions on the system requirements, the designers unintentionally introduce biases into the model wich affect the validity of the simulation such as leading to unrealistic behaviours or behaviours that do not map to real world behaviour. This paper revisits the problem of long distance wireless sensor network deployment in developing regions by (1) assessing the relevance of using simulation in planning long distance links and (2) proposing a long distance wireless sensor network (LDWSN) deployment as case study. The main contributions of our paper are twofold. First, using the radio mobile simulation software, we evaluate the accuracy of using a simulation package that builds around real maps to preplan long distance wireless sensor links. Secondly, we present a case study of a long distance wireless sensor network deployment using the Waspmote [6] technology with experiments conducted in harsh conditions.

The remainder of this paper is organized as follows. Section 2 describes the Radio Mobile simultaion software and present the simulation results obtained when planning long distance WSN (LDWSN) links. Section 3 describes the experiments conducted in harsh conditions in the Los Monegros Desert near Huesca in Spain and compare the experimental results with the simulative results. Section 4 discusses the relevance of LDWSN in developing countries and compare some of the features of the Waspmote to other WSN technologies in terms of long distance deployment. Our conclusions are presented in section 5.

2 Simulation of the Links

To check if radio links were feasible, we decided to use Radio Mobile [7], a free tool for the design and simulation of wireless systems. It predicts the performance of a radio link by using information about the equipment and a digital map of the area. Radio Mobile uses a digital terrain elevation model for the calculation of coverage, indicating received signal strength at various points along the path. It automatically builds a profile between two points in the digital map showing the coverage area and first Fresnel zone. During the simulation, it checks for line of sight and calculates the Path Loss, including losses due to obstacles. The software calculates the coverage area from the base station in a point-to-multipoint system. It works for systems having frequencies from 100 kHz to 200 GHz. It is based on the ITS (Longley-Rice) propagation model. Digital elevation maps (DEM) are available for free from several sources, and are available for most of the world. DEMs do not show coastlines or other readily identifiable landmarks, but they can easily be combined with other kinds of data (such as aerial photos or topographical charts) in several layers to obtain a more useful and readily recognizable representation. The digital elevation maps can be merged with scanned maps, satellite photos and Internet map services (such as Google Maps) to produce accurate prediction plots.

2.1 Candidate Locations

To test the feasibility of long wireless sensor links, it is necessary to find a location with an unobstructed line-of-sight between two sites. As the distance between sites increases, higher elevation is required at both ends.

For our experiments we selected 10 sites in the Los Monegros Desert near Huesca, Spain. Los Monegros is located within the provinces of Zaragoza and Huesca. The area is prone to chronic droughts, and much of the area is semi-desert. The climate is semiarid, with scare rainfall and high temperatures in the fall. Its maximum elevation is 822 meters, which can be found on the mountain called Oscuro. The lack of human activity ensured an interference-free environment. We did not carry out a site survey when selecting the candidate locations. The localization of the testbed is depicted by Figure 1. We selected ten spots in the area, which allowed us to establish six links. We considered both links with line of sight (LOS) and those with non line of sight (NLOS) as sensor networks are meant to be deployed in different environments as such trees, buildings, forests, etc. Table 1 shows the positions of the sites, the names of the 6 links and their types.

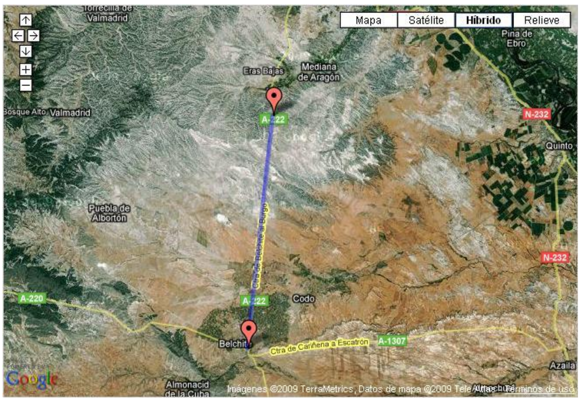


Fig. 1. Experimental setup in Los Monegros

2.2 Simulation Data

In addition to the locations, more data is required to run a simulation in Radio Mobile. The characteristics of the equipment, type of antennas and elevation above the ground need to be given as inputs to the software. For the experiments, we used Waspmote devices produced by Libelium, equipped with seven different 802.15.4/ZigBee transceivers. Waspmotes are built around XBee transceivers

Table 1. Position of candidate sites

Position 1	Position 2	Distance	Link Number	Link Type
41.377708N 0.732896W	41.380916N 0.732873W	356m	Link 1	LOS
41.375178N 0.733515W	41.380916N 0.732873W	639m	Link 2	LOS
41.324061N 0.740585W	41.380916N 0.732873W	6363m	Link 3	LOS
41.316091N 0.742146W	41.424445N 0.725913W	12136m	Link 4	LOS
41.390453N 0.731088W	41.401531N 0.729388W	1238m	Link 5	NLOS
41.394053N 0.731088W	41.424445N 0.725913W	3810m	Link 6	NLOS

which provide flexibility in terms of multiplicity of operating power, protocols, and operating frequencies as depicted by the XBee features in Table 2. Other Waspmote characteristics include (1) minimum power consumption of the order of 0.7 μA in the Hibernate mode (2) flexible architecture allowing extra sensors to be easily installed in a modular way, and (3) the provision of GPS, GPRS and SD card on board. Furthermore, Waspmotes are powered with a lithium battery which can be recharged through a specially dedicated socket for the solar panel; this option is specially interesting for deployments in Developing Countries where power supply is not stable.

Table 2. Characteristics of XBee Transceivers

Model	Protocol	Frequency	TX power	Sensitivity	Label
XBee-802.15.4	802.15.4	2.4 GHz	1 mW	-92 dB	Dev1
XBee-802.15.4-Pro	802.15.4	2.4 GHz	63 mW	-100 dB	Dev2
XBee-ZB	ZigBee-Pro	2.4 GHz	2 mW	-96 dB	Dev3
XBee-ZB-Pro	Zigbee-Pro	2.4 GHz	50 mW	-102 dB	Dev4
XBee-868	RF	868 MHz	315 mW	-112 dB	Dev5
XBee-900	RF	900 MHz	50 mW	-100 dB	Dev6
XBee-XSC	RF	900 MHz	100 mW	-106 dB	Dev7

Table 2 describes the characteristics of the XBee transceivers. As described by the table, these transceivers will be referred to in the rest of the paper as Dev1,. . .,Dev7. The XBee transceivers are equipped with SMA antenna connectors so an external antenna can be used. For the simulation we considered omnidirectional antennas, with a gain of 2dBi and 5dBi in 2.4GHz and in 868/900MHz. Antennas with such gain can be commonly found on the market and do not require special alignments. The links used vertically polarized antennas.

The height from ground is assumed to be 2m, as this is the maximum height of a tripod.

2.3 Fresnel Zone and Link Budget Calculation

When simulating a wireless link, one has to check two important parameters to determine if the link is possible or not: Fresnel zone and link margin. The Fresnel zone is an ellipsoid area around the direct line between two communicating devices. It is widely known that the radius of the fresnel zone at its widest point is expressed by

$$r = 17.32\sqrt{zd/4f} \tag{1}$$

where z is the zone number with the value $z = 1$ referring to the first Fresnel Zone, f is the frequency used (expressed in MHz) and d is the exact distance (in meters) between the receiver and transmitter. If this area were partially blocked by an obstruction, e.g. a tree or a building, the signal arriving at the far end would be diminished. When building wireless links, we therefore need to be sure that these zones be kept free of obstructions. Of course, nothing is ever perfect, so usually in wireless networking we check that about 60 percent of the radius of the first Fresnel zone should be kept free.

For example, let's calculate the size of the first Fresnel zone in the middle of our longest, 12km link, transmitting at 2.4 GHz:

$$r = 17.32\sqrt{12000/4 * 2400} = 19.36m \tag{2}$$

We need to have at least one elevated point to be able to have a 12km link using the 2.4 GHz frequency. Radio Mobile takes care of calculating the Fresnel zone, once the positions and the equipment characteristics have been entered in the software.

In order to have a communication between two wireless devices, the radios require a certain minimum signal to be collected by the antennas and presented to their input socket. Determining if the link is feasible is a process called link budget calculation. Whether or not signals can be passed between the radios depends on the quality of the equipment being used and on the diminishment of the signal due to distance, called path loss.

As suggested by [9], to perform the link budget calculation, one must know the characteristics of the equipment being used and evaluate the path loss. Adding up all the gains and subtracting all the losses gives:

$$\begin{aligned}
TransmitPower \\
+TransmittingAntennaGain \\
+ReceivingAntennaGain \\
= \\
TotalGain \\
-FreeSpaceLoss \\
= \\
ExpectedReceivedSignalLevel \\
-ReceiverSensitivity \\
-AntennaCableLoss \\
= \\
LinkMargin
\end{aligned}$$

The Transmitting Antenna Gain, Receiving Antenna Gain and Receiver Sensitivity are dependent on the hardware used. The Free Space Loss depends on the frequency used and on the distance. The longer the distance, the higher the Free Space Loss.

On a given path, the variation in path loss over a period of time can be large, so a certain margin (difference between the signal level and the minimum received signal level) should be considered.This margin is the amount of signal above the sensitivity of radio that should be received in order to ensure a stable, high quality radio link during bad weather and other atmospheric disturbances. A margin of 10 to 15 dB is fine.

Radio Mobile is able to calculate the link margin for a specific link, given the positions and the characteristics of the equipment used.

2.4 Simulation Results

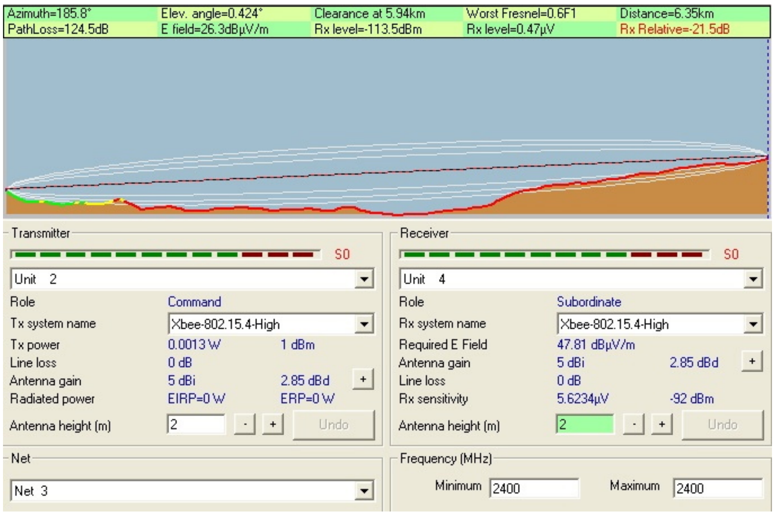
The equipment we wanted to use for the experiment consisted of seven different XBee cards, each one with two possible antennas. We thus had fourteen different

Table 3. Link Margin and Fresnel Zone Clearance at 2dBi

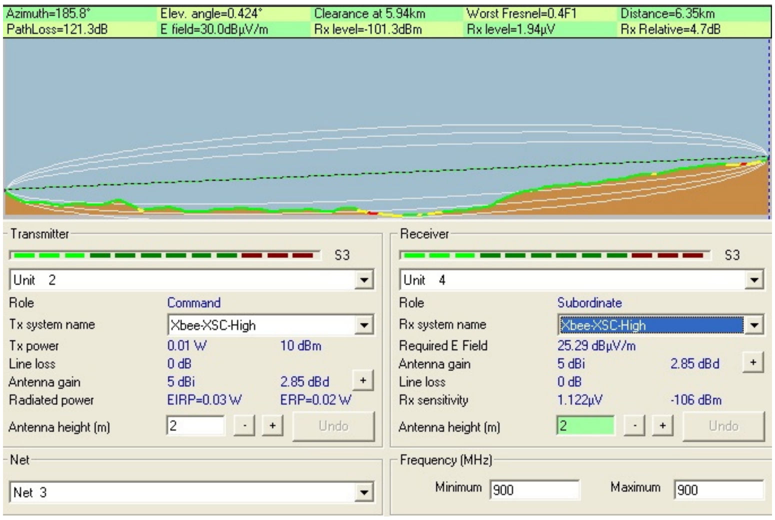
Xbee card at 2dBi	Antenna	Link 1	Link 2	Link 3
XBee-802.15.4	2dBi	2.6,1.0F1	-4.7,0.7F1	-28.5,0.6F1
XBee-802.15.4-Pro	2dBi	18.6,1.0F1	11.3,0.7F1	-12.5,0.6F1
XBee-ZB	2dBi	9.6,1.0F1	2.3,0.7F1	-21.5,0.6F1
XBee-ZB-Pro	2dBi	19.6,1.0F1	12.3,0.7F1	-11.5,0.6F1
XBee-868	2dBi	37.9,0.6F1	31.0,0.4F1	9.8,0.4F1
XBee-900	2dBi	17.6,0.6F1	10.8,0.4F1	-10.3,0.4F1
XBee-XSC	2dBi	26.6,0.6F1	19.8,0.4F1	-1.3,0.4F1
Xbee card at 2dBi	Antenna	Link 4	Link 5	Link 6
XBee-802.15.4	2dBi	-28.3,0.8F1	-24.3,0.1F1	-46.8,-0.5F1
XBee-802.15.4-Pro	2dBi	-12.3,0.8F1	-8.3,0.1F1	-30.8,-0.5F1
XBee-ZB	2dBi	-21.3,0.8F1	-17.3,0.1F1	-39.8,-0.5F1
XBee-ZB-Pro	2dBi	-11.3,0.8F1	-7.3,0.1F1	-29.8,-0.5F1
XBee-868	2dBi	8.5,0.5F1	15.4.3,0.1F1	-1.7,-0.3F1
XBee-900	2dBi	-11.6,0.5F1	-4.7,0.1F1	-22.1,-0.3F1
XBee-XSC	2dBi	-2.6,0.5F1	4.3,0.1F1	-13.0,-0.3F1

Table 4. Link Margin and Fresnel Zone Clearance at 5dBi

Xbee card at 5dBi	Antenna	Link 1	Link 2	Link 3
XBee-802.15.4	5dBi	9.5,1.0F1	2.3,0.7F1	-21.5,0.6F1
XBee-802.15.4-Pro	5dBi	24.6,1.0F1	17.3,0.7F1	-6.5,0.6F1
XBee-ZB	5dBi	15.6,1.0F1	8.3,0.7F1	-15.5,0.6F1
XBee-ZB-Pro	5dBi	25.6,1.0F1	18.3,0.7F1	-5.5,0.6F1
XBee-868	5dBi	43.9,0.6F1	37.0,0.4F1	15.8,0.4F1
XBee-900	5dBi	23.6,0.6F1	16.8,0.4F1	-4.3,0.4F1
XBee-XSC	5dBi	32.6,0.6F1	25.8,0.4F1	4.7,0.4F1
Xbee card at 5dBi	Antenna	Link 4	Link 5	Link 6
XBee-802.15.4	5dBi	-21.3,0.8F1	-17.3,0.1F1	-39.8,-0.5F1
XBee-802.15.4-Pro	5dBi	-6.3,0.8F1	-2.3,0.1F1	-24.8,-0.5F1
XBee-ZB	5dBi	-15.3,0.8F1	-11.3,0.1F1	-33.8,-0.5F1
XBee-ZB-Pro	5dBi	-5.3,0.8F1	-1.3,0.1F1	-23.8,-0.5F1
XBee-868	5dBi	14.5,0.5F1	21.4,0.1F1	4.3,-0.3F1
XBee-900	5dBi	-5.6,0.5F1	1.3,0.1F1	-16.1,-0.3F1
XBee-XSC	5dBi	3.4,0.5F1	10.3,0.1F1	-7.0,-0.3F1



(a) Link 3 (6.363 km) at 2.4 GHz

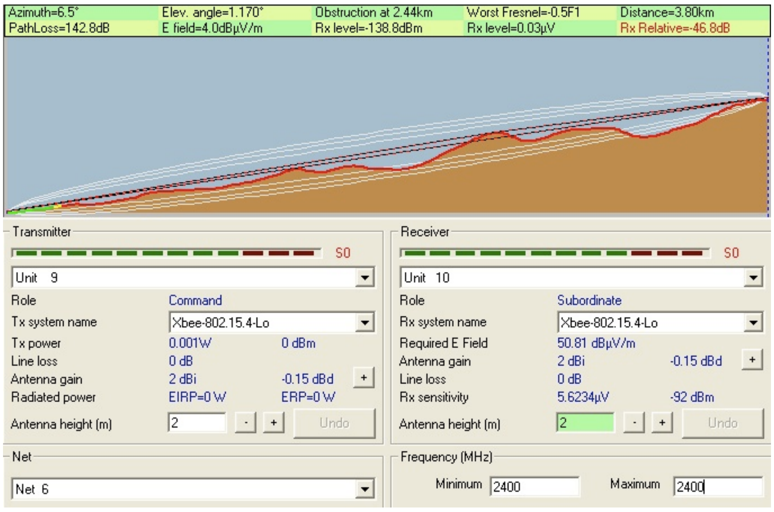


(b) Link 3 (6.363 km) at 900 MHz

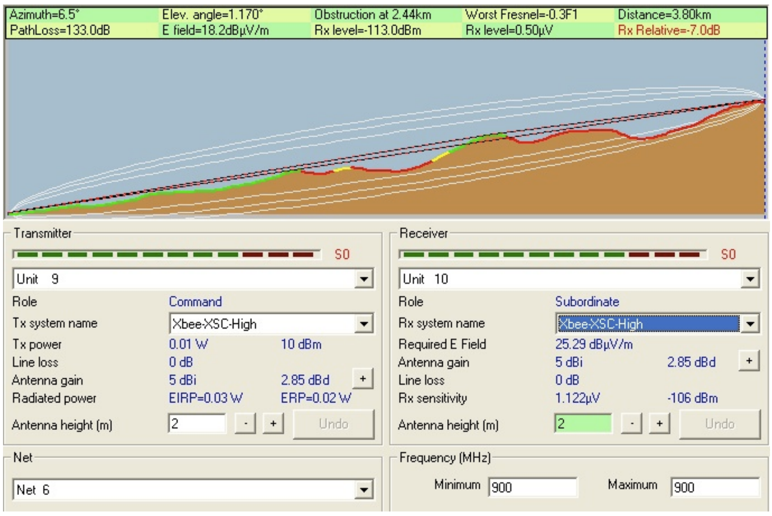
Fig. 2. Link 3 (6.363 km)

hardware solutions for each of the six links. It is not possible to report a graph of all the results, but Table 3 and 4 summarize the simulation results.

As can be seen from the simulation results, links behave differently according to the frequency used and to the output power. Longer links are only possible using lower frequencies (868 and 900 MHz), while 2.4 GHz is only usable for shorter links.



(a) Link 6 (3.810 km) at 2.4 GHz



(b) Link 6 (3.810 km) at 900 MHz

Fig. 3. Link 6 (3.810 km)

Figure 2 (a) and (b) show the Fresnel zone and link margin as presented by Radio Mobile for link number 3 at 2.4 GHz and 900 Mhz. The Fresnel zone is much larger at 900 MHz and the link margin is bigger.

Figure 3 (a) and (b) show the Fresnel zone and link margin as presented by Radio Mobile for link number 6 at 2.4 GHz and 900 Mhz. The two figures reveal a performance pattern similar to link 3 where the Fresnel zone is much larger and the link margin is bigger at 900 MHz.

3 Experiments

In October 2009 we performed the experiments in the Los Monegros Desert near Huesca, Spain, over a period of 3 days. We wanted to check if the experimental results were consistent with the simulation ones, and wanted to measure power consumption in a real-world environment. To test the link quality, we sent 100 packets of 90 Bytes each and counted how many packets were received to measure throughput. We also measured the RSSI level.

3.1 Experimental Results

Table 5 show the results of our tests. To check if the simulations give similar results compared to the experiments, we graphed the simulated link margin and

Table 5. Experimental performance

XBee features	Feature	Dev1	Dev2	Dev3	Dev4	Dev5	Dev6	Dev7
	Protocol	802.15.4	802.15.4	Zigbee-Pro	ZigBee-Pro	RF	RF	RF
	Frequency (Hz)	2.4G	2.4G	2.4G	2.4G	868M	900M	900M
	TX power (mW)	1	63	2	50	315	50	100
	Sensivity(-dBm)	92	100	96	102	112	100	106
Throughput	Distance	Dev1	Dev2	Dev3	Dev4	Dev5	Dev6	Dev7
2dBi	356m (LOS)	85%	100%	100%	100%	100%	100%	100%
	639m (LOS)	0%	100%	0%	100%	100%	100%	100%
	6363m (LOS)	0%	18%	0%	25%	100%	0%	80%
	12136m (LOS)	0%	0%	0%	0%	100%	0%	0%
	1239m (NLOS)	0%	0%	0%	0%	100%	0%	100%
	3810m (NLOS)	0%	0%	0%	0%	0%	0%	0%
5dBi	356m (LOS)	100%	100%	100%	100%	100%	100%	100%
	639m (LOS)	19%	100%	100%	100%	100%	100%	100%
	6363m (LOS)	0%	100%	0%	100%	100%	0%	100%
	12136m (LOS)	0%	0%	0%	0%	100%	0%	100%
	1239m (NLOS)	0%	0%	0%	0%	100%	0%	100%
	3810m (NLOS)	0%	0%	0%	0%	50%	0%	10%
RSSI(dBm)	Distance	Dev1	Dev2	Dev3	Dev4	Dev5	Dev6	Dev7
2dBi	356m (LOS)	-94	-72	-84	-70	-70	-70	-70
	639m (LOS)		-91		-78	-70	-70	-70
	6363m (LOS)					-97		-94
	12136m (LOS)					-100		
	1239m (NLOS)							
	3810m (NLOS)					-77		
5dBi	356m (LOS)	-87	-70	-72	-70	-70	-70	-70
	639m (LOS)	-94	-70	-90	-70	-70	-70	-70
	6363m (LOS)					-80		-101
	12136m (LOS)					-97		-83
	1239m (NLOS)		-97		-83			-93
	3810m (NLOS)					-78		

Table 6. Power consumption

State	From OFF to ON	Time	From sleep to ON	Time
TX Unicast without encryption	890.82nAh	79.4ms	849.16nAh	76.4ms
TX Unicast with encryption	904.73nAh	79.36ms	863.07nAh	76.36ms
TX Broadcast without encryption	887.79nAh	78,7ms	846.13nAh	75.7ms
RX Broadcast without encryption	889.45nAh	78,6ms	847.79nAh	75.6ms
RX Unicast without encryption	825.52nAh	74ms	783.86nAh	71ms
RX Unicast with encryption	826.11nAh	73.92ms	784.45nAh	70.92ms
RX Broadcast without encryption	818.55nAh	73.4ms	776.89nAh	70.4ms
RX Broadcast with encryption	818.63nAh	73.4ms	776.97nAh	70.4ms

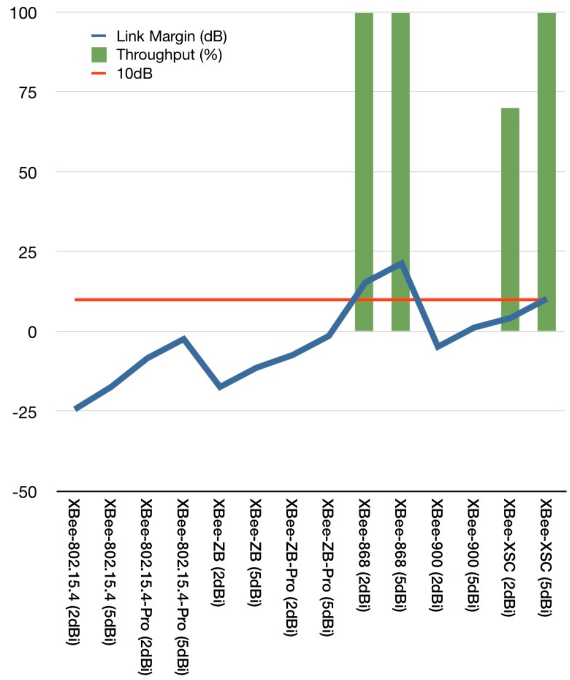


Fig. 4. Comparison between the simulated link margin and the measured throughput. Highlighted is the threshold value of 10 dB.

the measured throughput for link number 3 (1239 m). The results are shown in Figure 4. When the link margin is above 10 dB, then the link is possible and the throughput is high (70% up to 100%). When it is lower than 10 dB, then the link is not possible. From the experimental results, only link that use 868 or 900 MHz were possible at 1239 m. This is in agreement with the simulation results which predicted that longer distance links were feasible in only the lower frequency bands of 868 MHz and 900 MHz.

3.2 Impact of Encryption of Power Consumption

During the experiments we also made some measurements to assess the impact of the encryption implemented by the waspmote platform on power consumption. We used four different type of transmissions:

1. Unicast without encryption
2. Unicast with encryption
3. Broadcast without encryption
4. Broadcast with encryption

Note that in these experiments, we measured the time and energy consumption from the sleep and OFF modes to the ON mode to evaluate what is the best energy saving mode for a possible synchronization algorithm. In case of a unicast transmission the protocols waits for an ACK signal, while in case of broadcast there is no ACK. However, in broadcast mode each packet is always sent three times. As depicted by Table 6, the results reveal that encryption (AES 128b) does not add any consumption due to the fact that it is performed using specific hardware circuits included in the XBee card and not in the software layer.

4 LDWSN in Developing Countries

Long distance wireless networks are a necessity for developing countries. Large scale deployments of long wireless networks has been revealed mostly for the WiFi technology with the Technology and Infrastructure for Emerging Regions (TIER) project at University of California at Berkeley [1] spearheading the first efforts in collaboration with Intel, by utilizing a modified Wi-Fi setup to create long-distance point-to-point links for several of its projects in the developing world. This initiative was followed by several others in the developing regions such as (1) an unamplified Wi-Fi link of 279 km link achieved by Fundacin Escuela Latinoamericana de Redes (Latin American Networking School) [8] (2) a chain multi-hop WiFi based longest network of the world spanning 445 km in the jungle region of Peru, Loreto, implemented by the Rural Telecommunications Research Group of the Pontificia Universidad Catlica del Per (GTR PUCP) [9] and (3) other networks such as the implemented by the APRL unit of the International Centre for Theoretical Physics in Malawi [10].

While most long distance deployments of WiFi have been focussed on fine-tuning the MAC protocol [[11]-[16]], long distance WSN deployment has been demonstrated in the Waspmote family of sensor networks. Waspmote achieves much longer range compared hundred meters range limitation of many of the existing sensor technologies. Waspmote achieves much longer range compared to hundred meters range limitation of many of the existing sensor technologies. The main differences between Waspmote and these technologies in order to get LDWSN are:

- Higher sensibility.
- Higher txpower.
- Waspmote uses an external connector for the antenna (SMA) allowing the connection of antennas with a higher gain and with the right polarity.

It should also be observed that the frequency plays a capital role in long range deployment. While for the 2.4GHz band, the links can be quite similar, WiFi can not compete with the 868 and 900MHz bands used by some of the Waspmote transceivers.

5 Conclusion

Building upon the Radio Mobile and Waspmote family of WSNs, this paper has assessed the relevance of using simulation in wireless sensor network preplanning and presented a long distance WSN deployment scenario in harsh conditions. The preliminary results presented reveal that simulation may be in agreement with the reality obtained through experimentation when planning long distance links. These results also reveal that by offering a diversity of transceivers running in different frequency bands, the Waspmote family of WSNs present a good platform for the deployment of long distance WSNs. Using a testbed in desert conditions, this paper has presented the preliminary steps towards the implementation of WSNs beyond their traditional ranges. A future step consist of building upon our study to compare different radio propagation models to assess how closely fit with real-life deployment they are. Comparing WiFi long distance efforts with LDWSN using the 802.15.4 modulation and/or protocol is another direction for future research work.

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