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Abstract: This research report contains range measurement results from two low-power wireless modules: the Analog Devices SmartMesh LTP5902 module and the Analog Devices SmartMesh LTP5902+SE2438T "extended range" module. Range measurements are done over 5 scenarios (line of sight, smart agriculture, urban canyon, forest canyon, advanced metering infrastructure), and for 2 node heights. This document is targeted at SmartMesh users, and contains sufficient information to replicate the measurements. It is meant to be used as a reference but does not attempt to fully introduce SmartMesh, nor low-power wireless in general.

Key-words: Range measurements, SmartMesh.

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Contents

1 Hardware **4**
1.1 LTC5800 4
1.2 LTP5902 Module 4
1.3 LTP5902+SE2438T "Extended Range" Module 4
1.4 DC9025 mote 4
1.5 Box 4
1.6 Pole 4
1.7 Hand-held GPS 4

2 Software **7**
2.1 Preliminary Mote Configuration 7
2.2 TX Mote 7
2.3 RX Mote 8
2.4 Procedure 10

3 Results **10**
3.1 Line of Sight 10
3.2 Smart Agriculture 12
3.3 Urban Canyon 12
3.4 Forest Canyon 12
3.5 Advanced Metering Infrastructure 12
3.6 Summary 12

4 Acknowledgments **18**

1 Hardware

1.1 LTC5800

The LTC5800[1] is a system-on-chip containing an ARM Cortex-M3 micro-controller and an IEEE802.15.4 compliant radio. It is at the heart of all SmartMesh products, both the SmartMesh IP and SmartMesh WirelessHART product lines.

SmartMesh[2] is a complete low-power wireless mesh networking solution by Analog Devices.

1.2 LTP5902 Module

The LTP5902 is a pre-certified castellated module which contains an LTC5800 chip and all external components it needs to be functional (crystals, MMCX antenna connector, passives).

1.3 LTP5902+SE2438T "Extended Range" Module

The "Extended Range" module is similar to the LTP5902 Module, but adds a Skyworks SE2438T[3] external PA/LNA.

1.4 DC9025 mote

The DC9025 is a mote which accommodates a module, a 2×AA battery pack, an antenna, and a plastic enclosure. We use two versions of the DC9025 mote: one with the LTP5902 module (Fig. 1), one with the LTP5902+SE2438T "extended range" module (Fig. 2).

1.5 Box

A node, depicted in Fig. 3, is composed of a DC9025 Aude board (regular or extended-range) connected to a DC9010 interface, which is connected to a computer through USB. All this is housed in an IP55 plastic box for easy handling.

1.6 Pole

We create a 2 m high pole by fixing a PVC tube onto a tripod using zip ties, as illustrated in Fig. 4. We then attach one box to each pole, and configure one of the boxes as a transmitter (TX), one as a receiver (RX). We use the same two poles for measuring the range of the regular and extended range motes, by swapping the boxes.

1.7 Hand-held GPS

During the experiment, we use a Garmin GPSMAP64 hand-held GPS to record the position of the poles. This device datasheet indicates a location accuracy of 3 m, which is in practice what we observed. Given the ranges tested, the impact on the results of the inaccuracy of the hand-held GPS is negligible.

[1] `http://www.analog.com/en/products/ltc5800-ipm.html`
[2] `http://www.analog.com/en/products/rf-microwave/wireless-sensor-networks/smartmesh-ip.html`
[3] `https://www.rfmw.com/datasheets/skyworks/SE2438T.pdf`

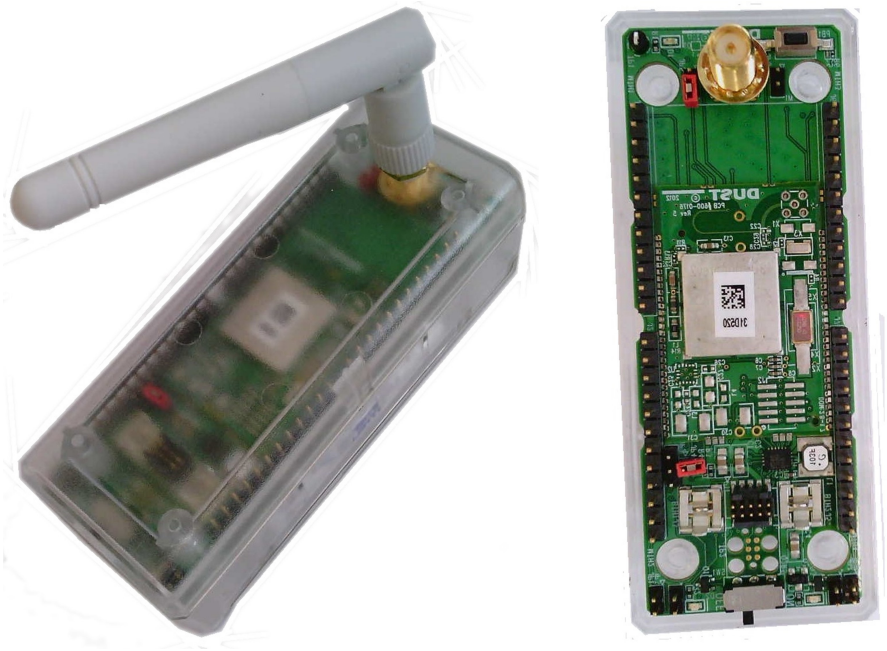


Figure 1: The DC9025 mote with the LTP5902 module.

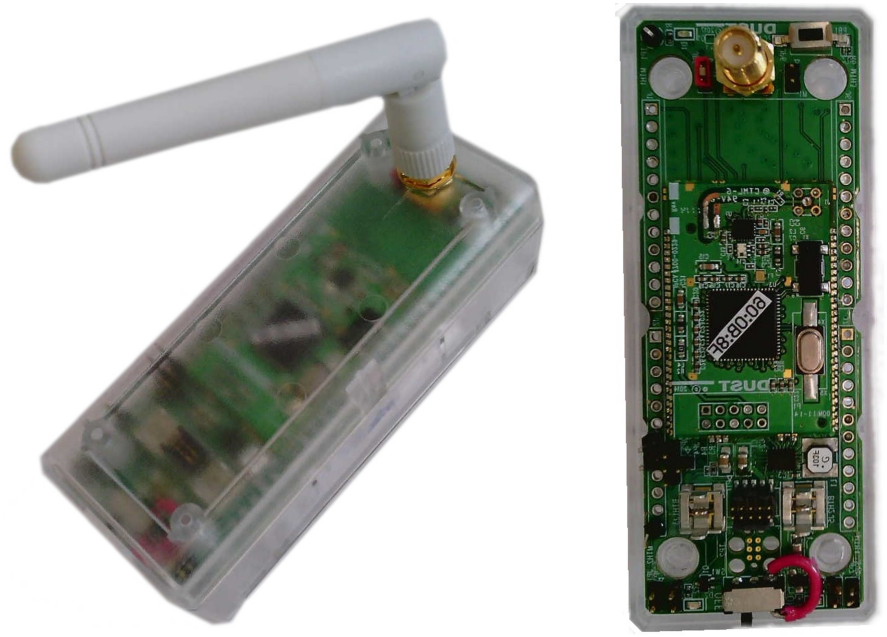


Figure 2: The DC9025 mote with the LTP5902+Skyworks SE2438T “extended range” module.

Figure 3: A box contains a mote and a DC9010, used to interface the mote to a computer.

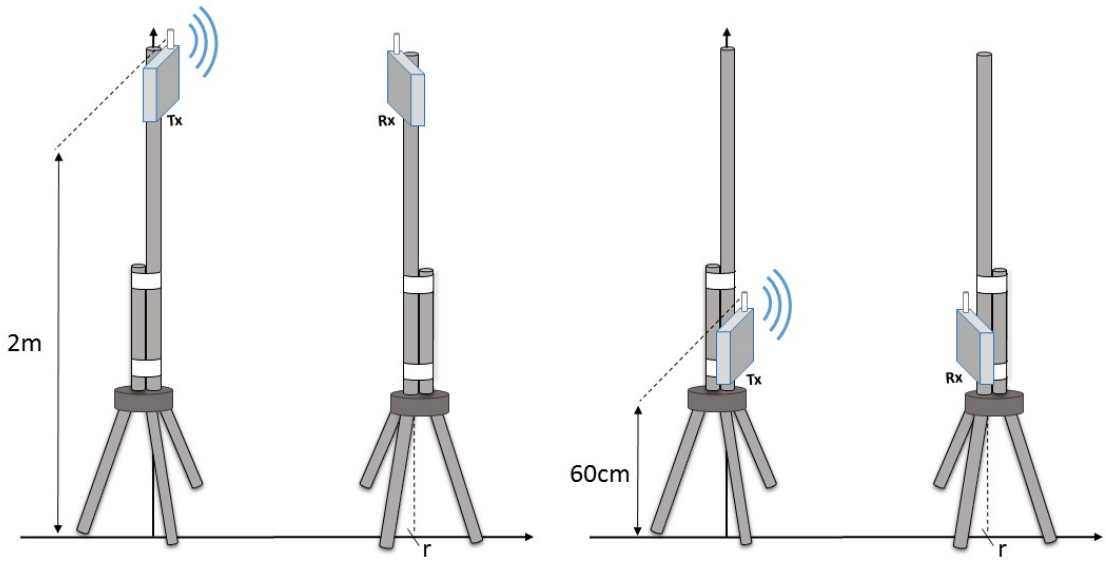


Figure 4: Setup used for range testing.

2 Software

This section describes the software used to drive the TX and RX motes. We use Teraterm to enter commands into the Command Line Interface (CLI) of the motes. We use the "radiotest" mode of the motes. Besides ranging, radiotest is used for testing the hardware, for example at manufacturing.

2.1 Preliminary Mote Configuration

On the CLI interface, we enter "`set mode slave`" to enter the right mode for radiotest, then "`reset`".

2.2 TX Mote

The "`radiotest tx`" command allows the user to initiate a radio transmission test. The syntax of the command is:

```
radiotest tx <type> <chanMask> <pwr> <stationId> <repeatCnt> <pkLen> <delay>
```

where:

- `type` – Type of transmission test. Value "`pk`" means that packets are sent (as opposed to a continuous signal).
- `chanMask` – Hexadecimal bitmask of channels (0-15) for the test. Bit 0 corresponds to 2.405 GHz.
- `pwr` – Transmit power, in dB. Valid values are 0 and 8.
- `stationId` – Unique (0-255) station id of the sender. Must match station id value of the receiver.
- `repeatCnt` – Number of times to repeat the packet sequence (0=do not stop).
- `pkLen` – Length of packet (2-125 bytes)
- `dly` – Delay after transmission (0-65535 microseconds)

We use the following command:

```
radiotest tx pk 0x8421 8 255 0 20 800
```

After entering that command, the TX mote continuously sends 20 B packets, at +8 dBm, on the 4 frequencies depicted in Fig. 5 in a round-robin fashion. The frequencies are chosen so they cover the entire frequency band, and are equally spaced. The 20 B length corresponds to the settings recommended by the IEEE to measure sensivity. With this setting, the mote transmits 694 packets per second, 174 packets on each of the 4 frequencies.

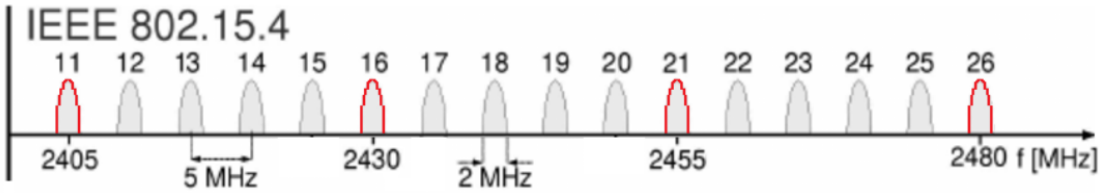


Figure 5: Measurements are done on the 4 frequencies highlighted red, then averaged.

2.3 RX Mote

The "`radiotest rx`" command turns the radio on in receive mode, on a particular frequency, for a specified amount of time. After that time, we enter the "`radiotest stat`" command to see the number of packets received. The syntax of the command is:

```
radiotest rx <chanMask> <time> <stationId>
```

where:

- `chanMask` – Hexadecimal bitmask of channels (0-15) for the test.
- `time` – Duration of receive test, in seconds.
- `stationId` – Unique (1-255) id of the receiver. Must match sender's station id.

We use the following command:

```
radiotest rx <chanMask> 15 255
```

We repeat this command once for each frequency:

- with `chanMask=0x0001`, the mote listens at 2.405 GHz.
- with `chanMask=0x0020`, the mote listens at 2.430 GHz.
- with `chanMask=0x0400`, the mote listens at 2.455 GHz.
- with `chanMask=0x8000`, the mote listens at 2.480 GHz.

For each frequency, the mote listens for 15 s. During that time, and given the rate at which the transmit mote sends, we expect the mote to receive at most 2604 packets. We define the Packet Delivery Ratio (PDR) at that frequency as the portion of those packets it actually receives.

We automate the process of entering the command for each frequency by using the following Teraterm script:

```
logautoclosemode 1

filename = 'C:\Users\marcelo ferreira\Desktop\Experiment\'

beep 2
messagebox 'Mark GPS position of Tx!' 'Attention !!!'
```

```
inputbox 'Environment identifier!' 'Place name: '
strconcat filename inputstr
gettime timeval "--%d_%m_%Y--%H_%M_%S"
strconcat filename timeval

logopen filename 0 0

do
    inputbox 'Position identifier!' 'GPS marker: '
    logwrite 'GPS marker:'
    logwrite inputstr

    logpause
    sendln 'Testing before beginning'
    :Testing
    beep 1
    sendln 'radiotest rx 0x8000 1 255'
    waitln 'Rx completed'
    sendln 'radiotest stat'
    waitln 'Radio Test Statistics:'

    sendln 'radiotest rx 0x0400 1 255'
    waitln 'Rx completed'
    sendln 'radiotest stat'
    waitln 'Radio Test Statistics:'

    sendln 'radiotest rx 0x0020 1 255'
    waitln 'Rx completed'
    sendln 'radiotest stat'
    waitln 'Radio Test Statistics:'

    sendln 'radiotest rx 0x0001 1 255'
    waitln 'Rx completed'
    sendln 'radiotest stat'
    waitln 'Radio Test Statistics:'
    beep 3
    yesnobox 'Do you want to test again?' 'Testing...'
    if result then
        goto Testing
    endif

    logstart

    for i 1 3

        beep 1
        sendln 'radiotest rx 0x0001 15 255'
        waitln 'Rx completed'
        sendln 'radiotest stat'
```

```
        waitln 'Radio Test Statistics:'

        sendln 'radiotest rx 0x0020 15 255'
        waitln 'Rx completed'
        sendln 'radiotest stat'
        waitln 'Radio Test Statistics:'

        sendln 'radiotest rx 0x0400 15 255'
        waitln 'Rx completed'
        sendln 'radiotest stat'
        waitln 'Radio Test Statistics:'

        sendln 'radiotest rx 0x8000 15 255'
        waitln 'Rx completed'
        sendln 'radiotest stat'
        waitln 'Radio Test Statistics:'

    next
    beep 3
    yesnobox 'Do another measurement?' 'External PA Mote - !'
loop while result

end
```

2.4 Procedure

One experiment consists of the following steps:

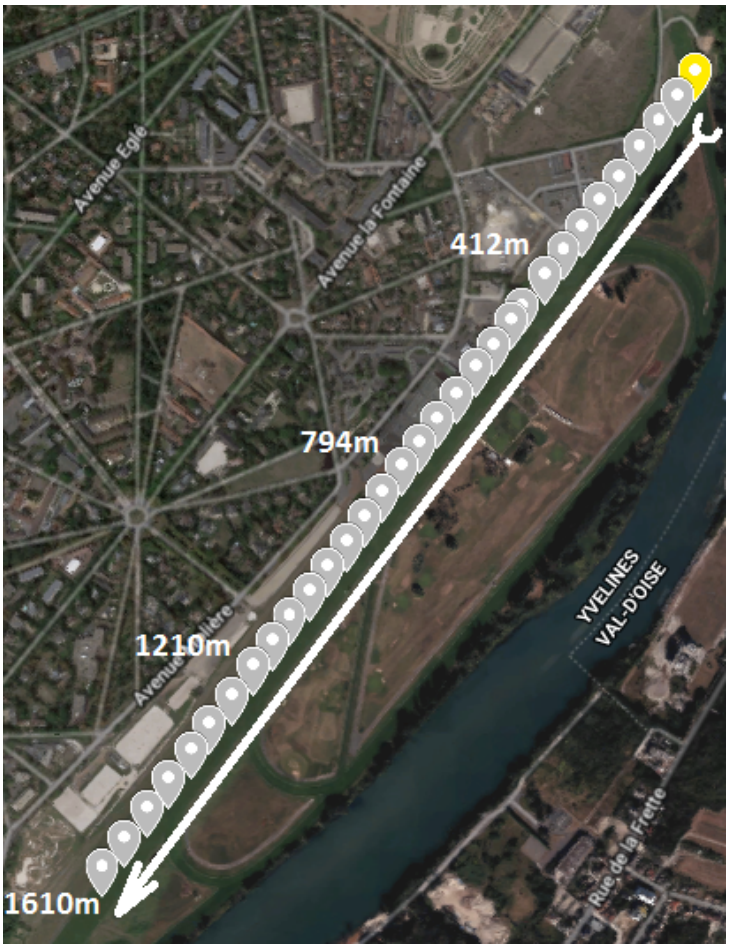
1. Place the TX and RX motes at their location.
2. Mark these positions with the hand-held GPS.
3. Turn on the motes.
4. Enter the `radiotest tx` command on the TX mote (Section 2.2).
5. Start the script on the RX mote (Section 2.3).
6. Wait about 1 min for the measurements to finish and log the results.
7. Move the RX mote and repeat.

This is repeated for the two types of motes and the two antenna heights. We did this experiment with 2 people.

3 Results

3.1 Line of Sight

Nodes are deployed at the Maisons-Laffitte racetrack, in the Paris region in France. Specifically, in a 40 m wide 2000 m long straight patch of grass, surrounded by tall trees. Fig. 6 shows the map of the deployment and the resulting PDR as a function of distance.



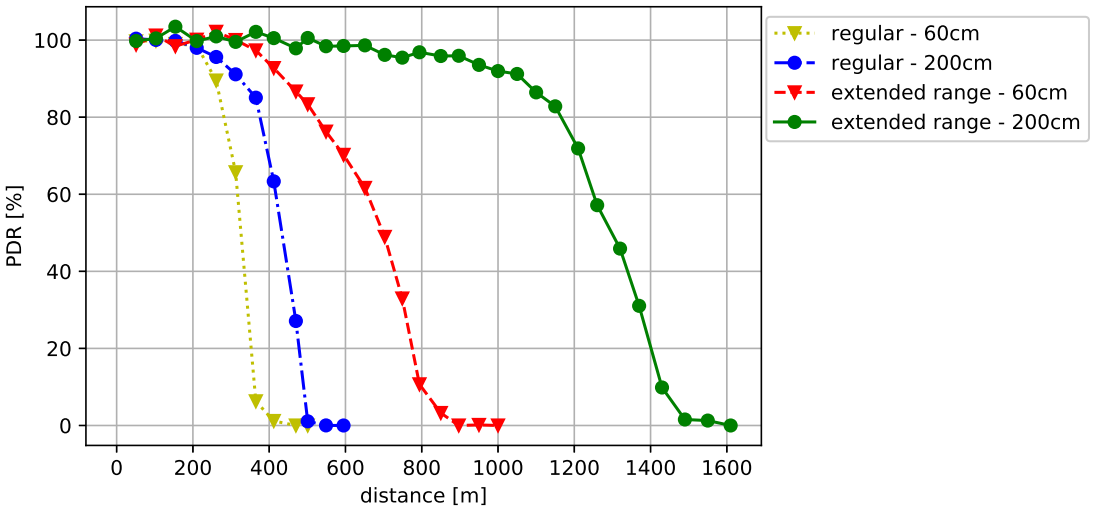


Figure 6: Line of Sight. The yellow marker identifies the TX mote; grey markers are the successive positions of the RX mote.

3.2 Smart Agriculture

Nodes are deployed in the Bois de Vincennes in Paris, France. There are different-size trees (up to 10 m high) and vegetation obstructing the TX–RX line of sight. Fig. 7 shows the map of the deployment and the resulting PDR as a function of distance.

3.3 Urban Canyon

Nodes are deployed along the Avenue Daumesnil in Paris, France. This 40 m wide avenue consists of, on each side, a 5 m wide walkway, a narrow street with parked cars on both sides, a row of 20 m high trees, a bicycle lane, and the main (single-lane) street. Both sides of the avenue are flanked by 40 m high buildings. This is busy street with people, cyclists and cars continuously moving, and no direct line of sight between TX and RX motes. We deploy the motes on the pedestrian section of the avenue, approx. 5 m from the side. Fig. 8 shows the map of the deployment and the resulting PDR as a function of distance.

3.4 Forest Canyon

Nodes are deployed in the Bois de Vincennes, on a 12 m wide pedestrian tree-lined road. The road is covered in asphalt with a dense row of trees on both sides. In certain sections, the trees overhang, causing a "tunnel" effect. People and cyclists are moving along the path between the nodes, obstructing the TX and RX direct communication. Fig. 9 shows the map of the deployment and the resulting PDR as a function of distance.

3.5 Advanced Metering Infrastructure

Nodes are deployed along the street Jorge Semprún and its intersections in Paris, next to the Inria-Paris campus. The path between nodes is obstructed. Fig. 10 shows the map of the deployment and the resulting PDR as a function of distance.

3.6 Summary

Table 1 summarizes the results of the data presented previously. It identifies two "ranges":

- The "50% PDR range" is the maximum distance between two node for the SmartMesh IP network to consider them "good" neighbors. For example, the SmartMesh IP deployment guidelines recommend for each node to have at least 3 "good" neighors, in order to be able to build a stable mesh network.
- The "max range" in the maximum distance between nodes such that they can exchange some packets, even at a very low PDR.

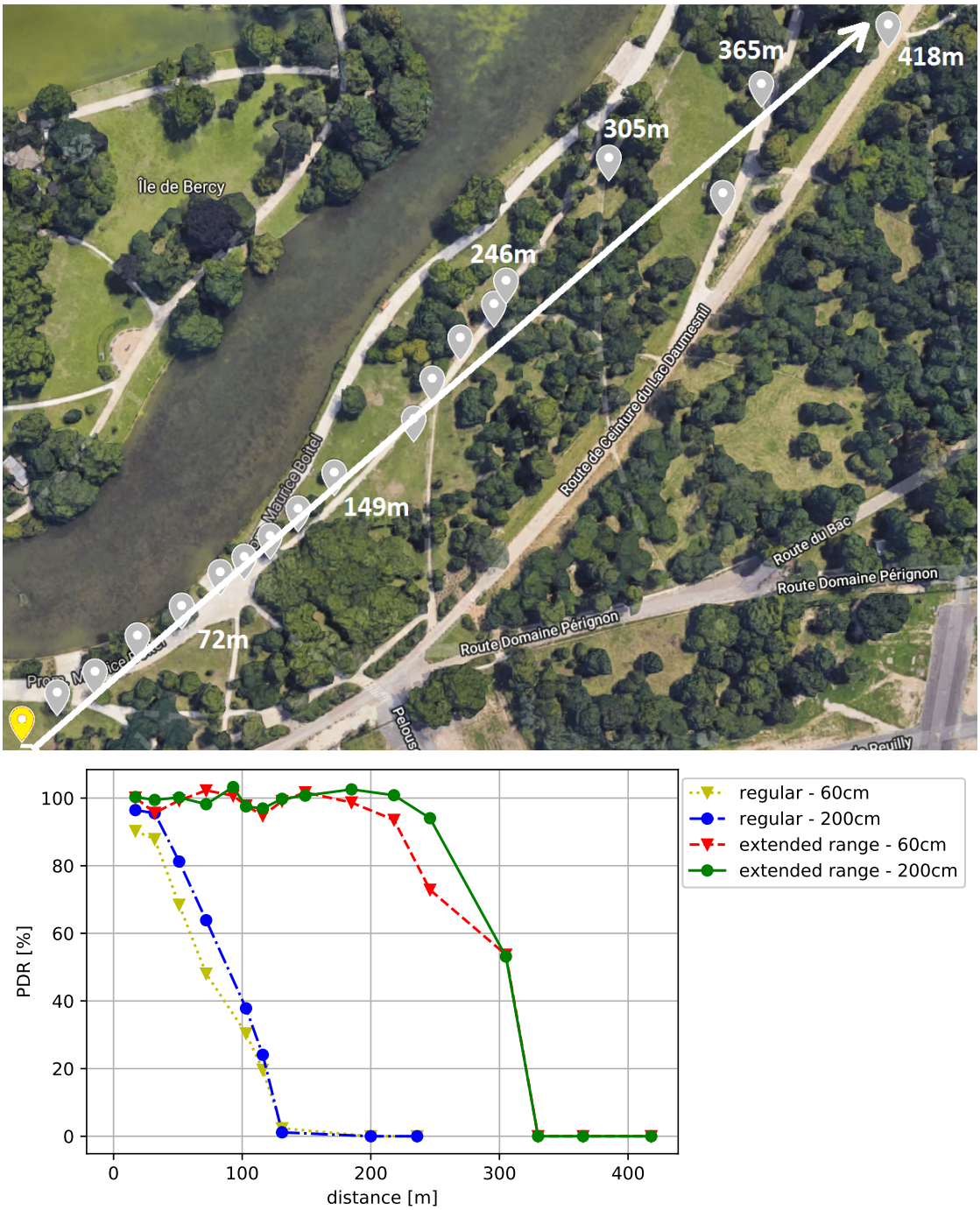


Figure 7: Smart Agriculture. The yellow marker identifies the TX mote; grey markers are the successive positions of the RX mote.

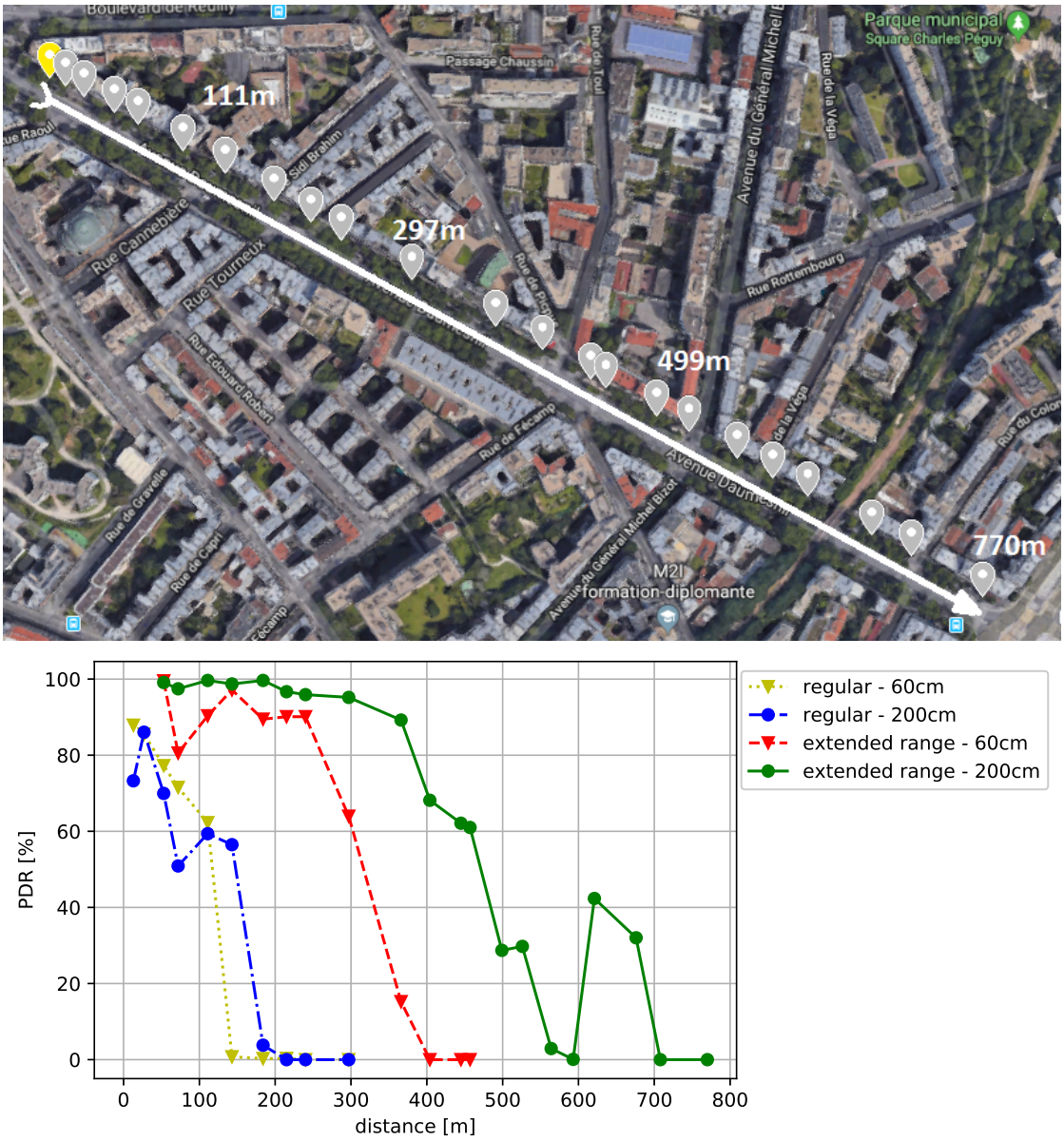


Figure 8: Urban Canyon. The yellow marker identifies the TX mote; grey markers are the successive positions of the RX mote.

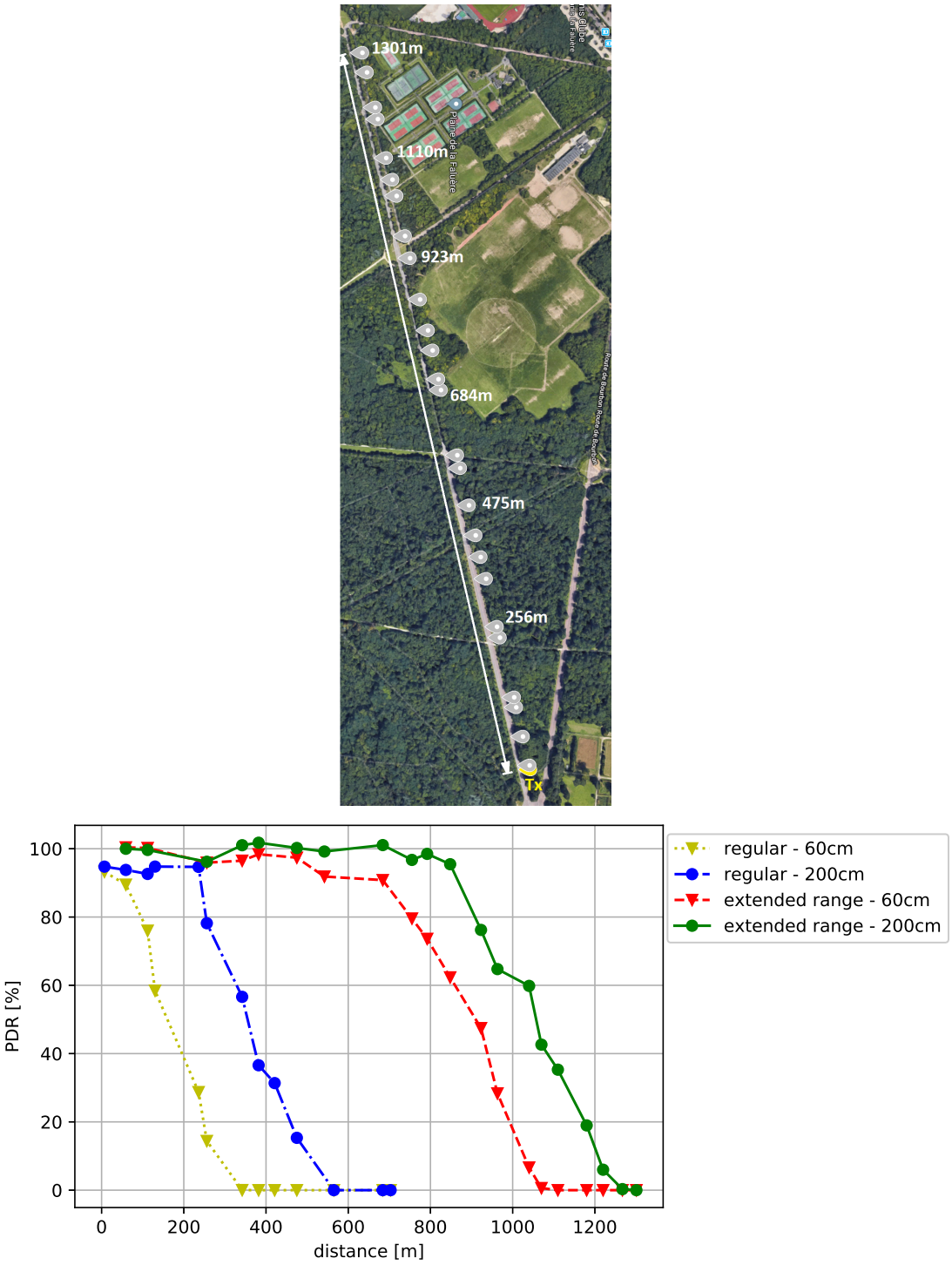
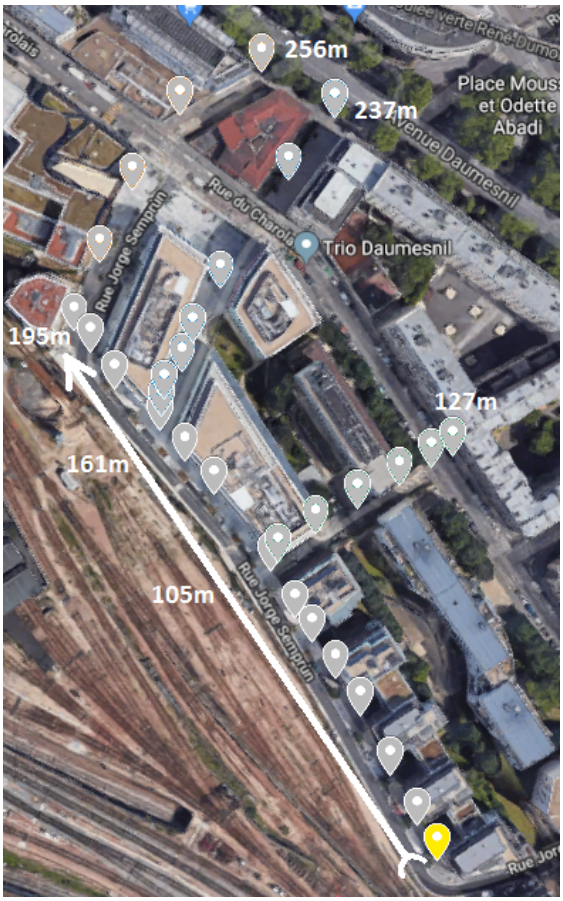


Figure 9: Forest Canyon. The yellow marker identifies the TX mote; grey markers are the successive positions of the RX mote.



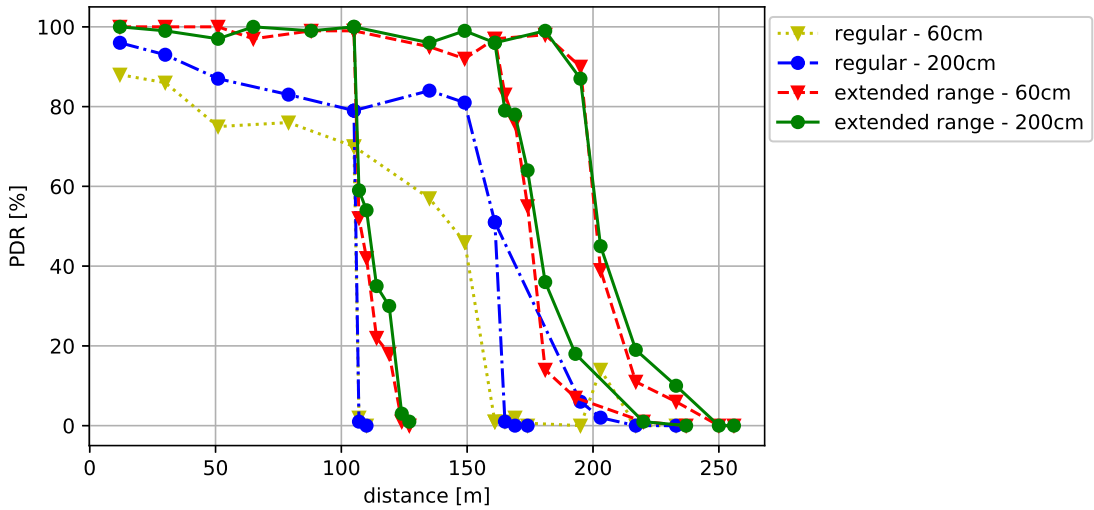


Figure 10: Advanced Metering Infrastructure. The yellow marker identifies the TX mote; grey markers are the successive positions of the RX mote.

Table 1: SmartMesh IP measured range as a function of the scenario

	regular DC9025				extended-range DC9025			
	50% PDR range		max range		50% PDR range		max range	
	60 cm height	2 m height	60 cm height	2 m height	60 cm height	2 m height	60 cm height	2 m height
Line of Sight	320 m	425 m	500 m	600 m	700 m	1300 m	1000 m	1600 m
Smart Agriculture	70 m	80 m	200 m	240 m	310 m	310 m	420 m	420 m
Urban Canyon	120 m	150 m	300 m	300 m	320 m	480 m	450 m	780 m
Forest Canyon	80 m	360 m	700 m	700 m	910 m	1050 m	1300 m	1300 m

4 Acknowledgments

We thank Edouard Boutolleau, Director of the training center and race course of Maisons-Laffitte, for allowing us to use the racetrack for Line of Sight measurements.

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