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## 1 Introduction

In this deliverable we discuss the system performance of the PLEASSED prototypes introduced in D3.2. mainly focusing on the analysis of timing constraints and energy consumption.

While the applicability of the classification algorithms in ready-to-market solution still require stronger experimental evidences, the results discussed in this document shows that the developed sensor nodes are good starting points to support the development of the PLEASSED vision.

We thus envision a future in which energy efficient sensor networks made of the nodes similar to the ones presented in D3.2 will locally run classification algorithms like the ones presented in this document and will be able to establish a network connection to share their results in order to improve the overall performance in a global classification algorithm perspective.

The same technology discussed in this report, will be presented and discussed during the PLEASSED demo.

## 2 System Performance

### 2.1 PLANTSENSE board performance evaluation

Within WP4, an extensive performance evaluation was done in order to analyze all the different critical features needed:

#### 2.1.1 Duty cycle Timing

One duty cycle covers all the process to analyze the results of the three algorithms after acquiring 1024 samples. We have used three frequencies for the timing study: 4, 12 and 25 MHz.

##### 1. Acquisition time for 1024 samples

Frequency [MHz]	4	12	25
Time to acquire 1024 ADC samples [s]	12,88	4,52	1,52

Based on algorithms develop in WP3, we must collect 1024 samples from the electrodes connected to the plant. Obviously, as expected, acquisition time is lower when frequency is higher.



2. Processing duration of each algorithm depending on the frequency

<b>Algorithms execution time versus Microcontroller Frequency</b>		
<b>Algorithm</b>	<b>Microcontroller Frequency [MHz]</b>	<b>Time Execution [secs]</b>
<i>Hurst Exponent</i>	4	12,4
	12	4,16
	25	2,06
<i>DFA</i>	4	17,44
	12	8,24
	25	5,76
<i>Hjorth mobility and complexity</i>	4	9,84
	12	3,4
	25	2,1

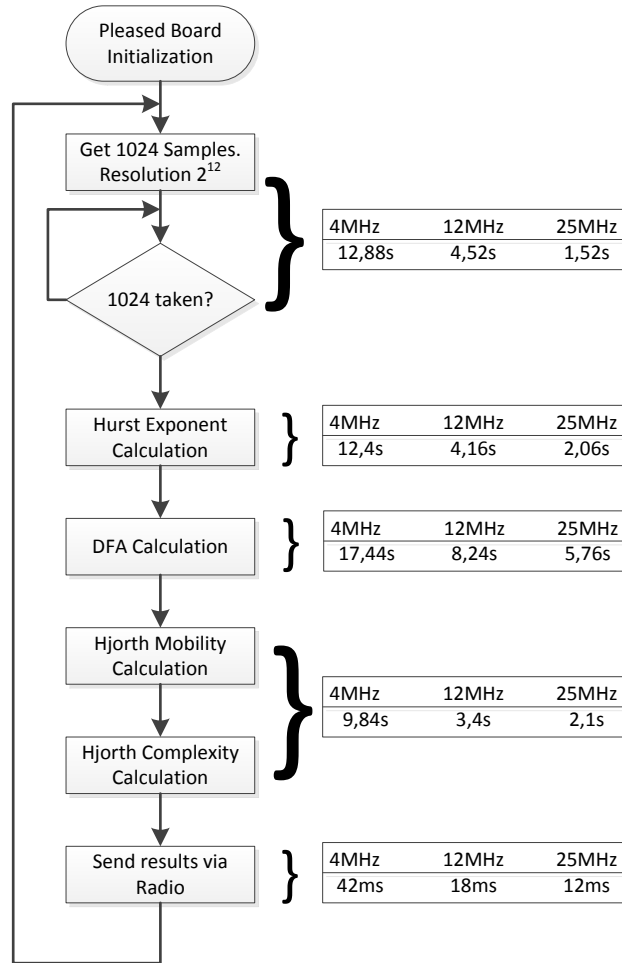
This comparison is particularly interesting. Since DFA algorithm is the most complex one, time execution is also higher. For further works, we will need to identify if we can reduce complexity within the algorithm or just to avoid using it for particular cases.

3. Radio processing and transmission time depending on the frequency

<b>Frequency [MHz]</b>	<b>4</b>	<b>12</b>	<b>25</b>
<b>Time to send via Radio the results [ms]</b>	42	18	12

Also, as expected, radio processing and transmission time is directly dependent on used frequency. As shown in the table above, this time is completely irrelevant compared to acquisition and algorithms processing steps duration.

In the following figure, a detailed workflow including all the different sequential states and their respective duration are shown:



4. Total time spent for all the process depending on the frequency

Frequency [MHz]	4	12	25
<b>Total time processing an ADC channel [s]</b>	52,602	20,338	11,452



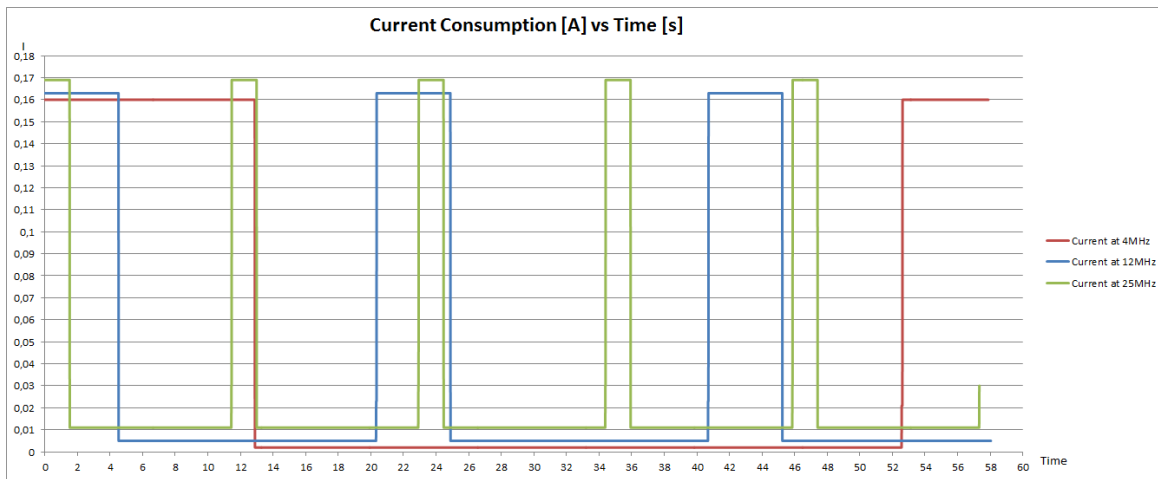
### 2.1.2 Energy Consumption

The consumption study has been made using three frequencies, 4, 12 and 25 MHz.

1. Current consumption for each process

Algorithms Time execution versus Microcontroller Frequency		
Process	Microcontroller Frequency [MHz]	Current consumption [mA]
Algorithms execution	4	2
	12	5
	25	11
Samples acquisition	4	160
	12	163
	25	169
Radio Transmission	4	21
	12	23
	25	30

Since we designed the PLANTSENSE board to be a low-power device, we selected a very specific microcontroller with low current consumption. Thus, it is clear, according to above results, that samples acquisition process is the most energy consuming step within the workflow. Considering this, for further exploitation of the device, we will need to improve the analog acquisition circuitry to reduce these figures.



2. Algorithm's consumption per hour

Algorithms Time execution versus Microcontroller Frequency		
Algorithm	Microcontroller Frequency [MHz]	Current consumption per hour [mAh]



<i>Hurst Exponent</i>	4	0,006888889
	12	0,005777778
	25	0,006294444
<i>DFA</i>	4	0,009688889
	12	0,011444444
	25	0,0176
<i>Hjorth mobility and complexity</i>	4	0,005466667
	12	0,004722222
	25	0,006416667

3. Total consumption per hour using the three algorithms

<b>Process</b>	<b>Microcontroller Frequency [MHz]</b>	<b>Current consumption [mAh]</b>
<b>Three algorithms execution</b>	4	0,02204444
	12	0,02194444
	25	0,030311111

4. Sampling acquisition consumption per hour

<b>Process</b>	<b>Microcontroller Frequency [MHz]</b>	<b>Current consumption [mAh]</b>
Acquisition 1024 samples	4	0,572444444
	12	0,204655556
	25	0,071355556

For this process, it is notable that the lowest current consumer is the fastest frequency. This occurs because the acquisition for this case is shorter in time than the others, and this process is the most energy spender.

5. Radio processing and transmission

<b>Process</b>	<b>Microcontroller Frequency [MHz]</b>	<b>Current consumption [mAh]</b>
Radio processing and transmission	4	0,000245
	12	0,000115
	25	0,0001

Consumption in this stage is so ridiculous that it is irrelevant in total consumption

6. Global power and consumption



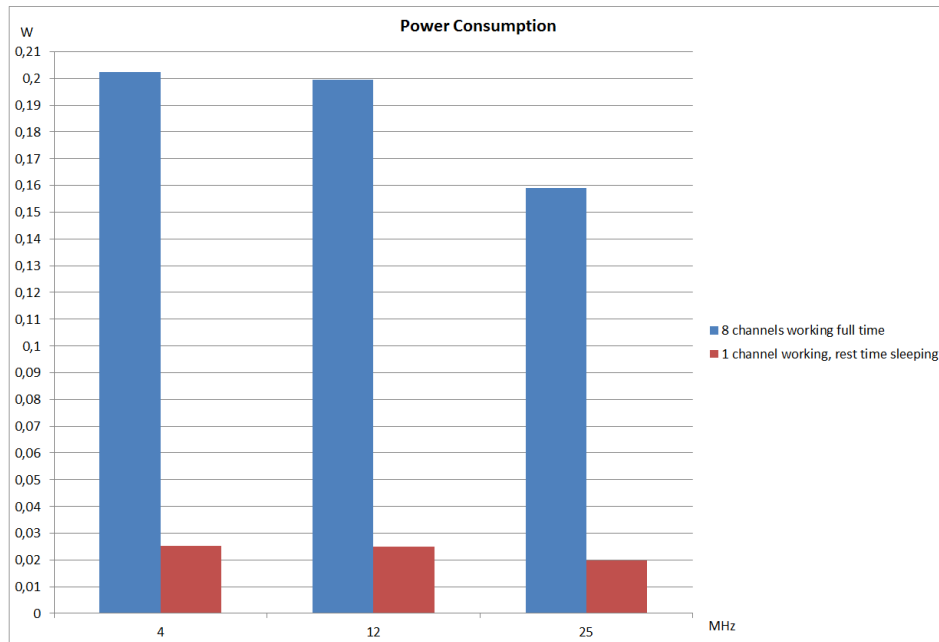
- All channels continuously working

Permanent Execution with all the channels	Vinput [Vdc]	Frequency [MHz]	Current Consumption per Hour [Ah]	Energy [Wh]
	4,97	4	0,040702673	0,202292284
		12	0,040130495	0,199448558
		25	0,031990919	0,158994866

- One channel acquired while the others circuitry is sent to deep power down mode (2 $\mu$ A)

One channel acquired	Vinput [Vdc]	Frequency [MHz]	Time sleeping [s]	Total Time Cycle [s]	Total current consumption per hour [Ah]	Energy [Wh]
	4,97	4	368,214	420,816	0,005089584	0,025295233
		12	142,366	162,704	0,005018062	0,024939767
		25	80,164	91,616	0,004000615	0,019883056

In the next graph we can view the difference between both modes of operation and their consumption:







### 2.1.3 Battery Operation Evaluation

One of the key requirements to be fulfilled by the system was to achieve a low-power and autonomous device. Based on consumption tests previously described, we have studied four batteries capacities performance: 1Ah, 2Ah, 4Ah and 7Ah. We consider 5Vdc as maximum voltage output.

In the following table, an autonomy comparison between using different batteries, clock frequency, and 8 or single channel has been described.

5Vdc Battery Statistics					
Capacity [mAh]	Work Frequency [MHz]	Hours Working continously	Approximate days	Hours working with single channel	Approximate days
1000	4	24,56841108	1,023683795	196,4797079	8,186654497
	12	24,91870606	1,038279419	199,2801272	8,303338635
	25	31,25887106	1,302452961	249,9615792	10,4150658
2000	4	49,13682216	2,04736759	392,9594159	16,37330899
	12	49,83741212	2,076558838	398,5602545	16,60667727
	25	62,51774211	2,604905921	499,9231584	20,8301316
4000	4	98,27364433	4,09473518	785,9188317	32,74661799
	12	99,67482424	4,153117677	797,120509	33,21335454
	25	125,0354842	5,209811843	999,8463168	41,6602632
7000	4	171,9788776	7,165786566	1375,357956	57,30658148
	12	174,4309424	7,267955934	1394,960891	58,12337045
	25	218,8120974	9,117170725	1749,731054	72,9054606

Thus, as it can be seen in previous table, in the best case (maximum frequency), when we acquire just one signal channel with a 7Ah battery, we will achieve no more than 72 days-autonomy. That means the device developed can be used for non-fixed monitoring applications like measurement campaigns.

If we plan to use it on a regular basis, we will need to use external solar cells which is a feature already considered from the design phase.

## 2.2 Testbed setup

Connection between the PLANTSENSE board and the plant to be monitored must be done as shown in the following picture:

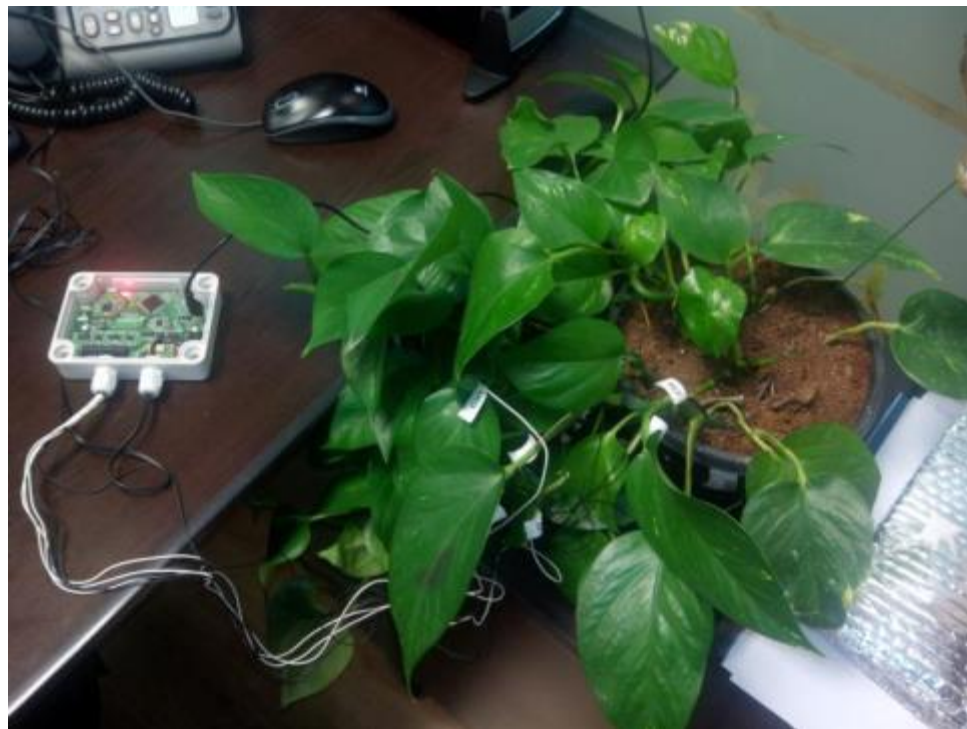
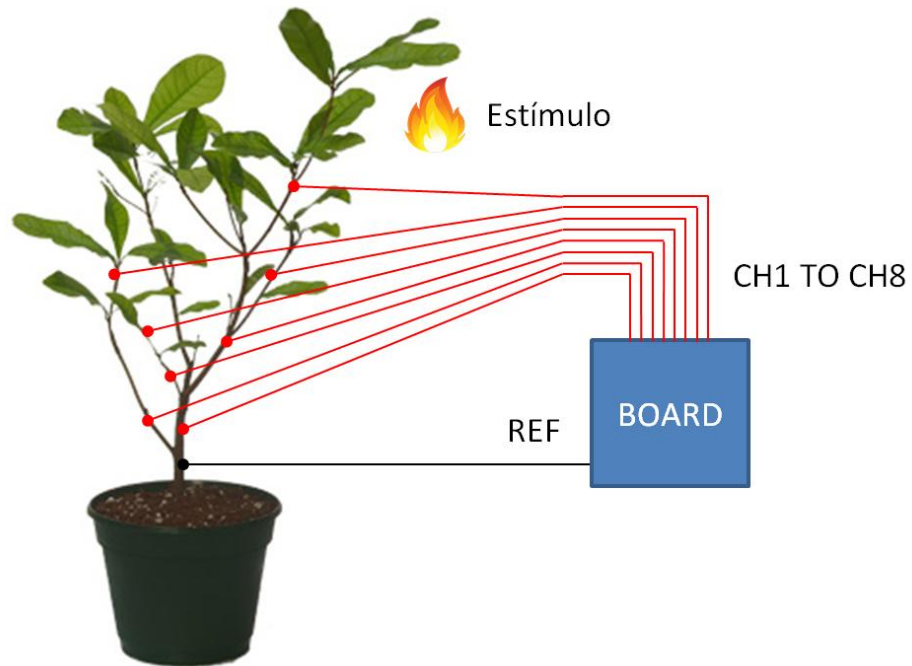


Figure 1: Demo set up

A screen shot of the PLATSENSE board extracting the relevant features is shown in the following picture.



Node 1

**ID :** 1

**Timestamp :** 20150529 15.57.08

**Hurst Exponent :** 0,7624076

**DFA [dfa] :** 0,7344506

**HJORTH Mobility :** 0,1301807

**HJORTH Complexity :** 1,606196

```
29/05/2015 15.57.08;1;00FFFF0100100005;3F432D253F3C04F53E054E1A3FCD97D5
29/05/2015 15.56.58;1;00FFFF0100100005;3F3432453F2595CD3E0FF8E63FCC4455
29/05/2015 15.56.48;1;00FFFF0100100005;3F254E8D3F1695F13E2E8D9C3FD1A4A7
29/05/2015 15.56.39;1;00FFFF0100100005;3F23970C3F1DF7103E5899163FCE8132
29/05/2015 15.56.29;1;00FFFF0100100005;3F294A663F242E8A3E55BA873FCF0570
29/05/2015 15.56.20;1;00FFFF0100100005;3F11391D3F0403BB3E4B597333FCD6DFB
29/05/2015 15.56.10;1;00FFFF0100100005;3F2FF8713F295C313E3868323FCD1CCA
29/05/2015 15.56.00;1;00FFFF0100100005;3F2AAAD03F1BE4EB3E1DCCE83FCD89
29/05/2015 15.55.51;1;00FFFF0100100005;3F2254C23F19A3663E34B4213FCE34DE
29/05/2015 15.55.41;1;00FFFF0100100005;3F22F5173F1C91C33E2C02203FCBC788
29/05/2015 15.55.32;1;00FFFF0100100005;3F17F9693F0FAF9A3E4B0A8F3FCCDC8E
29/05/2015 15.55.22;1;00FFFF0100100005;3F22EF2A3F18988A3E6654CE3FCA13C
29/05/2015 15.55.12;1;00FFFF0100100005;3F1BA5D03F171AE73E2F66833FCAB58E
29/05/2015 15.55.03;1;00FFFF0100100005;3F1D66493F1AA0333E53F3F83FCF9A20
29/05/2015 15.54.53;1;00FFFF0100100005;3F19238E3F0A5CE43E5DFFE63FCD294E
29/05/2015 15.54.44;1;00FFFF0100100005;3F31C63A3F2103DA3E4870C53FCC9D0B
29/05/2015 15.54.34;1;00FFFF0100100005;3F0E2A323F0965F63E72638C3FCFCE8E
29/05/2015 15.54.25;1;00FFFF0100100005;3F151F513F118A463E804C5A3FCFF6E4
29/05/2015 15.54.15;1;00FFFF0100100005;3F106A743EF5F5FC3E6C01B63FCB9916
29/05/2015 15.54.05;1;00FFFF0100100005;3F21FCCD3F1940C03E65A3253FCE14FA
29/05/2015 15.53.56;1;00FFFF0100100005;3F289553F22D6743E7D8F4D3FCC873D
```

Clear Console

Save to CSV

Port : COM3

Disconnect

## 2.3 MagoNode performance evaluation

### 2.3.1 Power consumption of MagoNode Revision A

The main constraints of a sensor node are due to energy consumption. In order to measure the power consumption of the acquisition board, we set up a series of test applications in order to highlight the single components' consumption as well as the overall draw in different usage scenarios.

The testing methodology adopted was the following for all the tests:

- the board was powered through a benchtop power supply, providing a 4.2 voltage with a maximum current draw of 100, in order to avoid the FTDI chip from powering up and therefore skewing the results;
- power consumption was measured using a high-precision multi-meter, connected in series between the power supply and our board;
- each test was run 5 times for about 5 minutes each run, in order to rule out anomalies;



- both pins of the input channels were directly connected to ground, in order to minimize the external influence on our tests;
- the ADC had Turbo Mode enabled, to account for worst case scenarios.

In particular, we designed the following suite of tests:

- **Idle:** the board (and the underlying MagoNode) is powered on, however the Buck-Boost converter is disabled and the only active component is the voltage regulator; this should equal the MagoNode power consumption in sleep mode.
- **Idle - Boost:** same as before, however the Buck-Boost converter is turned on.
- **Radio:** this test is intended to measure the ATmega128rfa1's radio power consumption; the situation is analogous to the Idle scenario, however the Radio is turned, and left, on.
- **Radio - Boost:** same as the Radio test, however the Buck-Boost converter is turned on.
- **ADC - 90SPS:** SPS stands for *samples per second*, it determines the data conversion frequency. In this test, the ADC is powered up, by external means, in single supply mode (without the Buck-Boost converter); the microcontroller is processing the interrupts coming from the ADC, however no data is sent via radio.
- **ADC - 90SPS - No Interrupts:** this scenario closely resembles the previous one, however, the interrupts aren't being processed.
- **ADC - 90SPS - Boost:** similar to the 90SPS test, but this time the Buck-Boost converter is online and used to power the whole circuit.
- **ADC - 2000SPS variants:** the three previous tests with the ADC set to acquire data at the highest possible speed.
- **ADC - 2000SPS - Radio:** in this test, data is collected and then sent via radio.
- **ADC - 2000SPS - Radio - Boost:** same as before, but with the Buck-Boost Converter powering the entire board.

The results can be seen in table 1.

Tests				
Boost	Radio	ADC	Interrupts	Current Drawn ()
N	N	N	-	0.0031
Y	N	N	-	11.04
N	Y	N	-	16.68
Y	Y	N	-	27.77
N	N	90SPS	Y	0.446



N	N	90SPS	N	0.446
Y	N	90SPS	Y	11.45
N	N	2000SPS	Y	1.15
N	N	2000SPS	N	1.15
Y	N	2000SPS	Y	11.45
N	Y	2000SPS	Y	21.26
Y	Y	2000SPS	Y	28.66

**Table 1: Power Consumption Tests for Pleased board RevA**

In order to interpret these results, we need to note that the Boost being disabled also means the Instrumentation Amplifiers lack power supply and therefore part of the consumption contribute from the Buck-Boost converter should be attributed to the amplifiers instead. That said, the Radio and the Buck-Boost converter are definitely the biggest offenders when it comes to power consumption.

### 2.3.2 Power consumption of MagoNode revision B

The new board does not have a Buck-Boost converter, therefore we expect the overall power consumption to be greatly reduced. However, we must consider that we have an extra regulator as well as some additional circuitry; even if disabled, we expect the idle power consumption to be slightly higher.

We modified the tests in order to replace the Buck-Boost Converter's presence with the new power circuitry, i.e. the voltage references and MOS switches.

In order to compare the results with previous ones, we keep those components disabled during tests where the Boost was previously disabled, while we enable them in tests where the boost was active.

The results obtained for the second revision of our board can be seen in table 2.

#### **Tests**

Components	Radio	ADC	Interrupts	Current Drawn ()
N	N	N	-	0.0057
Y	N	N	-	0.063
N	Y	N	-	16.41
Y	Y	N	-	17.04
N	N	90SPS	Y	0.430
N	N	90SPS	N	0.430





Y	N	90SPS	Y	1.157
N	N	2000SPS	Y	1.082
N	N	2000SPS	N	1.082
Y	N	2000SPS	Y	1.745
N	Y	2000SPS	Y	17.01
Y	Y	2000SPS	Y	17.50

**Table 2: Power Consumption Tests for Pleased board RevB**

The results show that the power consumption without components enabled is roughly the same as before, with a very slight increase in idle current draw. On the other hand, in applications where all components are active, we can see that removing the buck-boost converter allowed us to cut the power consumption by up to 90% in some cases.

An interesting thing to note is that enabling interrupt handling has no effect on measured power consumption, meaning the interrupt handling routine is fast enough to allow the processor to get back into sleep without producing any noticeable change in average power draw.

### 2.3.3 Low Power data acquisition routine

We introduced additional circuitry because it allows us to have fine grained control on power consumption; enabling the required circuitry at the right time and keeping it disabled when not needed. In particular, we are using the following procedure:

1. At system boot, all components are disabled with the exception of the ADC (which is in low power mode);
2. a periodic timer is started;
3. every time the timer signals its *fired* event, a conversion is started;
4. right before starting a conversion, the MOS switch and Voltage Reference enable referring to the channel we are about to acquire from are activated;
5. once the conversion is done, we acquire a sample from the second channel as well, disabling the previous MOS and voltage reference and enabling the other ones;
6. once the second conversion is completed, the switches and references are turned off and the ADC goes back in low power mode, until the next conversion is initiated by the timer.

Concluding, with a data rate of 45 samples per second (no turbo) and a periodic timer set to 100ms we are able to acquire data from plants without noticeable losses, with a resulting current draw of about 150 $\mu$ A. With 3 AA batteries having a discharge rate of 2000mAh, we can operate (for the whole sensor node) *for more than one year* of continuous sensing.

### 2.3.4 Wireless data collection from groups of plants

We implemented a basic wireless polling algorithm to wirelessly collect data from group of plants.



We assume that nodes are all in visibility, namely each node can hear the transmission of all the others. All the nodes send in broadcast their data to the sink identified by the id 0. When the node with id  $k$ , hears the packet sent from the node with id  $k-1$ , it knows that it can transmit as soon as the communication of node  $k-1$  is finished. In other words the sequence of transmission of 4 nodes to the sink is  $\langle 1,2,3,4,1,2,3,4 \dots \rangle$  and by definition two nodes cannot generate collisions due to simultaneous transmission.

The pseudo code for the TinyOs Implementation is reported in the following.

```
(begin)
LOCK = false,
EXP = false,
start conversion
    continuously enqueue data & post sendPacket
        a) if EXP == false || LOCK == TRUE
            startTimer(1024)
        b) else
            AMsend.send in broadcast, LOCK = TRUE
    event timer fires: EXP = true
    event receive packet:
        a) if source node id is k-1 then then EXP = true // i.e. send a packet
        b) startTimer(1024)**
(end)
```

Timers are used to avoid deadlocks due to the loss of packets.

The maximum data rate of MagoNode radio transceiver is 250kbps, namely 31250Bps. Each packet contains 100B of payload and thus at most 50 samples of 16bit (2 Byte) each. Notice that 12 extra Byte are overhead due to protocol signalling (1B to inform the next node the current communication has been successful completed) and TinyOS overhead (11B header and footer). Thus the total size of a packet is 112 Byte.

This means that at most  $31250/112 \approx 280$  packets per second can be transmitted and consequently  $280 \times 50 = 14000$  samples per second. In other words, the network can in principle support a maximum sampling rate of the ADC that is indeed 14Ksps.

### 2.3.5 Streaming algorithms for feature extraction

We implemented on the MagoNode the streaming algorithm for the extraction of Skewness and Variance Features described in D3.2, that together with the LDA classifier [4] can provide good result in the classification of the signals in our dataset.

To read a chunk of 1024 samples and extract variance and skewness the MagoNode takes 812ms and consequently the classification of a whole chunk requires less than 1 second.



### 3 Conclusions

A number of tests have been performed mainly to evaluate time constraints and energy consumption of the PLEASSED sensor boards. In experimenting with the PLEASSED devices we identified some major development tasks that need to be properly addressed to further develop the PLEASSED technology in view of a commercial exploitation.

With regard to the PLANTSSENSE board:

- Physiological analog signals acquisition: energy consumption is currently over the foreseen objectives. Thus, we will need to improve hardware design to keep the consumption as low as possible.
- DFA algorithm demand high timing duty cycle. If we could reduce complexity, we could improve measurement frequency improving granularity of values collected from the plant for a better features extraction.
- External power supply. Although considered from design phase, we definitely need to implement a solar power supply to the board, especially for applications where online monitoring is needed.

With regard to the MagoNode board:

- Energy consumptions of rev. B are relatively low and can guarantee up to one year of continuous sensing. The main goal is to trigger the sampling process only when needed in order to further save energy and extend the node life time.
- The node life time can be also extended using appropriate energy harvesting techniques (e.g. solar power).
- The number of electrodes is limited to 2 plus a reference and could be insufficient in some application scenario.
- The implementation of more complex feature extraction algorithms and/or classification algorithms can be challenging both in terms of time constraints and computational resources





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