Cognitive Radio Experimentation World

# Project Deliverable D7.7.4
# Showcase of experiment ready (Demonstrator)

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| **Authors:** | Stratos Keranidis (UTH), Virgilios Passas (UTH), Thanasis Korakis (UTH), Thierry Rakotoarivelo (NICTA) |
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**Abstract:** This public document demonstrates a working implementation of the developed by UTH and NICTA evaluation framework that support for evaluation of the Spectrum Sensing Delay and Energy Consumption of cognitive platforms.

**Keywords:** spectrum sensing, power consumption, sensing delay, testbeds, experimental evaluation

## Executive Summary

This deliverable presents a working implementation of the UTH-NICTA experiment. The main aim of the proposed experiment was to enable CREW testbed experimenters to evaluate their cognitive solutions in terms of Spectrum Sensing Delay and Energy Consumption. In order to achieve our goal, we proceeded by extending the existing testbed experimentation tools and developed new ones as well. The developed hardware and software solutions have been directly integrated in the w-ilab.t testbed and the OMF control and measurement framework.

In this showcase experiment, we present how a remote testbed experimenter can use the developed framework to evaluate the performance of four different cognitive platforms in terms of the aforementioned metrics. Devices under investigation are the well-established Universal Software Radio Peripheral (USRP) N210 Networked Series, the USRP E110 Embedded Series, the prototype IMEC Sensing Engine (SE) and a commercial wireless network interface card that features the Atheros AR9280 chipset. Considering the fact that the aforementioned sensing devices feature varying sensing capabilities, we evaluate them under a common reference scenario that allows all devices to be tested under their operational limits. The test signal consists of a bunch of 802.11 frames that are being transmitted between two w-ilab.t testbed nodes. The complete experimental setup along with the three steps that constitute the evaluation procedure are detailed in the document. First, we evaluate the Power Spectral Density (PSD) through FFT processing using each one of the sensing platforms. In parallel with the PSD evaluation, we use 4 NITOS ACM cards that act as high-end power meters to characterize the induced energy consumption. Finally, we quantify the distribution of the Total Sensing Delay between the different sub-processes of the sensing procedure. The various steps of our experiment are executed through a fully automated procedure that is orchestrated by a single OMF-compatible experiment description.

# Revision History

| Version | Date | Author | Description |
|---|---|---|---|
| 1.0 | 16/04/2014 | UTH-NICTA | Ready for Review |
| 1.1 | 18/04/2014 | IMEC | Minor revision, final version |

## List of Acronyms and Abbreviations

| | |
|---|---|
| ACM | Advanced Chassis Manager |
| CREW | Cognitive Radio Experimentation World |
| CS | Channel Switching |
| Dx.x | CREW Deliverable x.x |
| FFT | Fast Fourier Transform |
| FTP | File Transfer Protocol |
| ISM | Industrial Scientific Medical |
| OMF | cOntrol and Management Framework |
| PSD | Power Spectral Density |
| SS | Spectral Scanning |
| UHD | USRP Hardware Driver |
| USRP | Universal Software Radio Peripheral |

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# 1 Testbed Architecture and Experimental Scenario

In this experiment, we investigate the performance of the well-established Universal Software Radio Peripheral (USRP) N210 Networked Series [2], the USRP E110 Embedded Series [3], the prototype IMEC Sensing Engine (SE) [4] and a commercial wireless network interface card that features the Atheros AR9280 chipset [5] in terms of Spectrum Sensing Delay and Energy Consumption. We configure all the available spectrum sensing platforms to operate in parallel, in order to detect a signal generated by a pair of Wi-Fi nodes. The communicating pair of nodes consists of one transmitter and one receiver w-ilab.t testbed nodes that communicate over a single channel of the 2.4 GHz band. The bandwidth of the transmitted signal is 20 MHz corresponding the standard 802.11 channel bandwidth. Figure 1 illustrates the experimental setup that is configured in w-ilab.t testbed [1], for the purposes of this experiment.

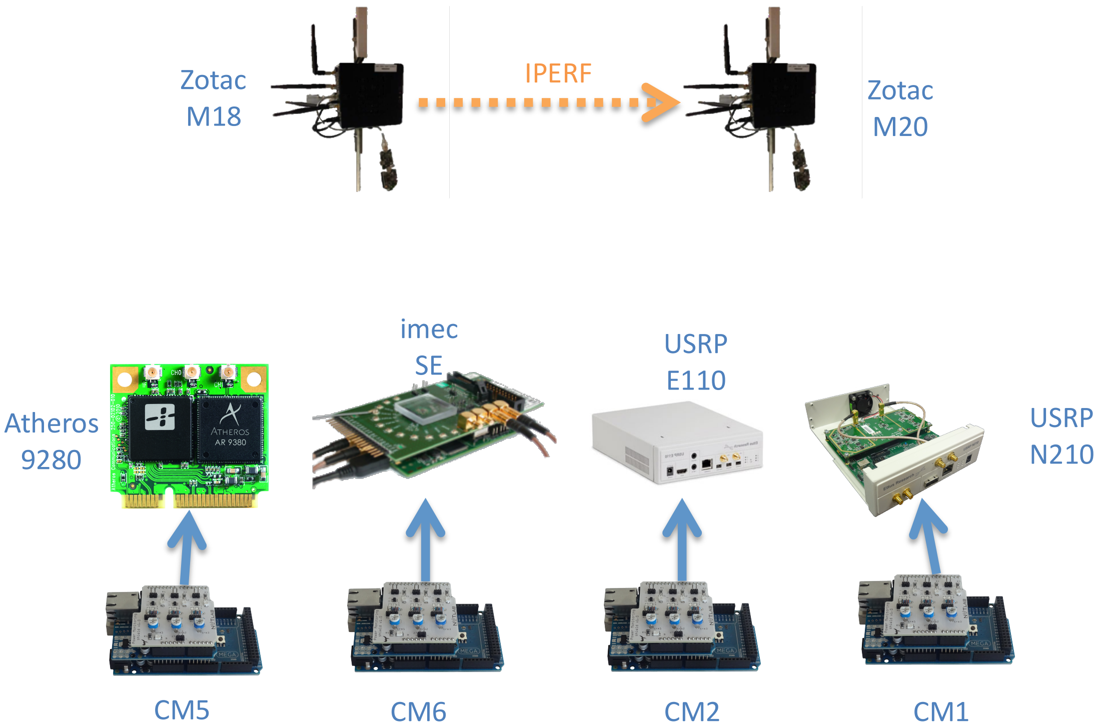


**Figure 1: Experiment Setup**

In order to provide for a fair comparison of the different sensing devices, we designed an experimental scenario that allows all devices to be tested under their operational limits. The scenario has been designed on top of the imec SE's hardware restrictions, which requirements necessitate the adoption of a common spectrum observation time of 64μs for all the considered devices, within which interval potentially ongoing 802.11 frame transmissions are being detected. Having specified a common monitoring interval, the different devices will sense the medium for the same duration and collect a different number of samples as specified by their sampling rate configurations.

# 2 Working demonstration

Considering the experimental setup that was detailed above, we will present a working demonstration that is executed in two phases. First, we configure the 4 sensing devices that are available in the CREW testbeds to detect a Wi-Fi signal that is transmitted on a given frequency of the 2.4 GHz band. In parallel with the PSD evaluation, we characterize the resulting power consumption and also focus on the distribution of the overall sensing delay among the various sensing sub-processes. In the second phase, we configure all the sensing devices to monitor the whole 2.4 GHz band that has total bandwidth of 80 MHz. As the bandwidth of the targeted band exceeds the maximum bandwidth of all considered sensing devices, in this scenario all devices have to perform channel switching to provide for proper monitoring and as a result the impact of the channel switching delay is highlighted as well.

## 2.1 Phase 1 – Monitoring a single channel of the 2.4 GHz band (20 MHz bandwidth)

Below, we list the various steps that need to taken in order to successfully execute the experiment of Phase 1.

*1) OMF experiment*: 2 Zotac nodes are configured as transmitter and receiver setting an ad-hoc network that operates on the central frequency of 2432 MHz. The application that the nodes will use is the Iperf [6] and the required configurations such as bit-rate and duration are defined. In addition the ACM card ids that will take part in this experiment are given as input on the script for handling the ACM cards. When the execution of the OMF [7] experiment starts and all the configurations have been made the aforementioned script is called and the experiment proceeds by instrumenting the nodes to start transmitting. When the transmissions end the OMF experiment waits until the ACM cards complete the measurements transferring process and as soon as all the results have been stored in the sqlite3 database, the experiment ends.

*2) ACM Power Monitoring*: The ACM cards start monitoring the sensing devices on which they are attached for the specified duration and store the measurements in files to the integrated SD cards. When the logging ends the ACM cards are instructed to upload the collected measurements to the FTP server. Then the script starts the computations of the power consumption of each device and stores the corresponding results utilizing the OML Library [8] to the experiment's database file.

*3) Sensing process*: When the ACM cards are triggered to monitor the power consumption, all the sensing devices that take part in the experiment are instrumented to perform spectrum sensing. Due to the fact that the capabilities of the platforms are different, appropriate configurations had to be defined, so that the common sensing interval could be defined for all devices. Next, the FFT calculations take place considering as input the spectrum measurements that have been captured by each device. During the sensing process the developed software reports the exact duration of each Spectrum Sensing sub-process. More specifically the time intervals that are reported for each device follow:

- Configuration time
- Actual sensing time of the spectrum
- Processing time for producing the PSD results

In the end of the Sensing Delay evaluation process, measurements that have been temporarily stored in the memory of the program under execution are transfered to the OML database.

*4) PSD results*: The PSD evaluation results that have been collected through the execution of the specified experimental scenario are presented through a specially generated for this purpose GUI. A representative screenshot of the PSD evaluation GUI is presented in Figure 2. Through this representation, we clearly observe how the maximum bandwidth and FFT-bin size specifications of each device affect the sensing efficiency. The imec SE along with the Atheros AR9280 device detect that the 20 MHz bandwidth are fully utilized, while the limited USRP E110 is able to monitor only 5 MHz of bandwidth. On the other hand, the USRP N210 is able to detect the drop is PSD when considering frequencies that exceed the central frequency by 10 MHz and thus is the only device able to characterize that the Wi-Fi transmission has the central frequency of 2432 MHz (channel 5).

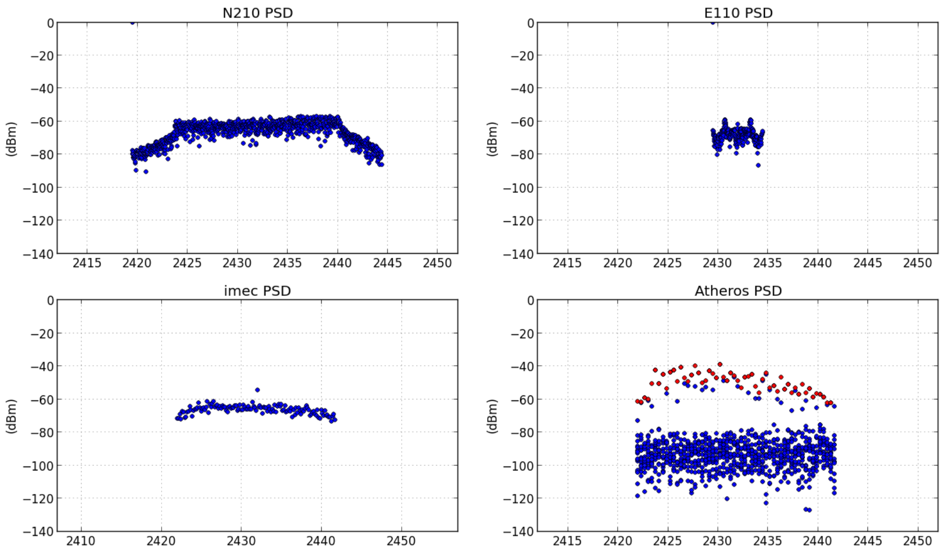


**Figure 2: PSD Evaluation**

*5) Energy Consumption results*: Accessing the sqlite3 database we are able to represent through the GUI, the energy consumption of each one of the spectrum sensing devices that is induced during the spectrum sensing procedure. A representative screenshot of the Power Consumption evaluation GUI is presented in Figure 3. Based on the plotted data, we observe that the commercial Atheros AR9280 Wi-Fi chipset presents the most energy-efficient operation, while the embedded prototype imec SE is also characterized by a low power consumption profile, in comparison with the energy harvesting research oriented USRP devices.

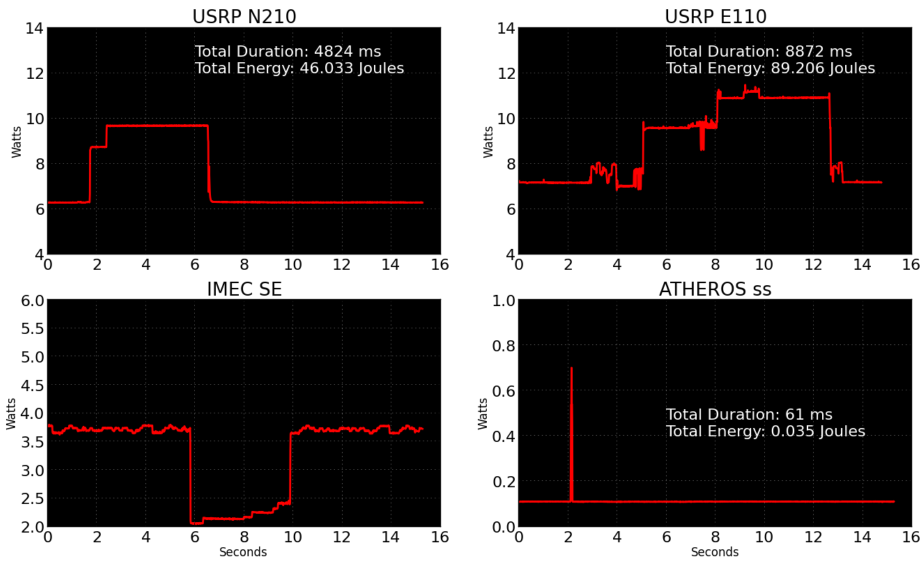


**Figure 3: Power Consumption Evaluation**

*6) Sensing Delay results*: In this phase, we plot through the Sensing Delay evaluation GUI the data corresponding to the distribution of sensing delay sub-processes per device. Figure 4 illustrates results related to the Sensing Delay evaluation of the 4 sensing devices in the specified experimental scenario. First, considering the configuration time, we observe that the USRP devices require significant amount of time prior to establishing an operational setup. Second, we observe that the USRP E110 spends most of the time during measurements transferring, which fact results due to the use of SD card for storage of samples instead of the fast Gigabit Ethernet interface of the USRP N210. Regarding the AR9280 device, we notice that although the sampling procedure can be repeated very fast and more specifically during each symbol transmission (4 μs), the overall sensing procedure requires approximately 67 ms. This limitation comes due to the use of the ath9k driver [10], which performs spectral scanning only during the standard scanning operation for collection of Beacon frames that are transmitted by neighboring Wi-Fi APs. As the default Beacon transmission interval is 100ms, the ath9k driver configures the default time spent on each available channel approximately equal to 67 ms, thus controlling the duration of the spectral scanning procedure as well. Concluding, we remark that the only device able to approximate the real-time spectrum sensing capabilities of the imec SE, is the USRP N210 that nearly equally spends time between the sensing, transferring and processing sub-processes.

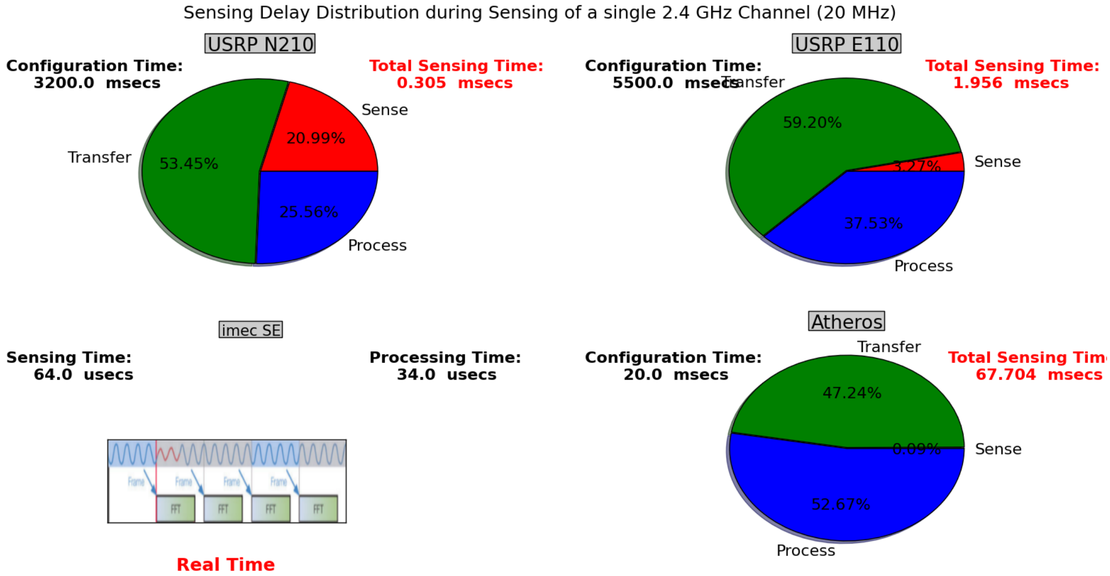


**Figure 4: Sensing Delay Distribution during Sensing of a single 2.4 GHz Channel**

## 2.2 Phase 2 – Monitoring the 2.4 GHz band (80 MHz bandwidth)

Under this second phase, we configure the communicating pair of nodes to transmit on various channels within the 80 MHz wide band and evaluate the total sensing delay of all devices, which now further varies due to impact of the channel switching overhead. Based on the bandwidth specification of each device, the USRP N210 (25 MHz) needs to switch its operational frequency 4 times, the USRP N210 (5 MHz) 20 times, the imec SE (20 MHz) 4 times and the AR9280 (20 MHz) 4 times, towards sensing the whole 80 MHz wide 2.4 GHz band.

*1) OMF experiment*: The OMF experiment remains the same with the one in Phase 1 with only change to transmission frequency, which now is defined to 2412 MHz.

*2) ACM Power Monitoring*: The alteration in this experimental scenario from the previous is the duration of the monitoring of the ACM cards.

*3) Sensing process*: In this experiment another metric is introduced and included to the calculations of the Spectrum Sensing Delay which is the Channel switching overhead. This overhead occurs when the devices want to sense a different frequency from which they currently are and have to configure some parameters to achieve this.

*4) PSD results*: Figure 5 represents the PSD evaluation GUI as plotted in this second phase of the showcase experiment. We observe that all devices detect channel 1 (freq. 2412 MHz) to be busy by the transmissions executed by the orchestrated w-ilab.t nodes.

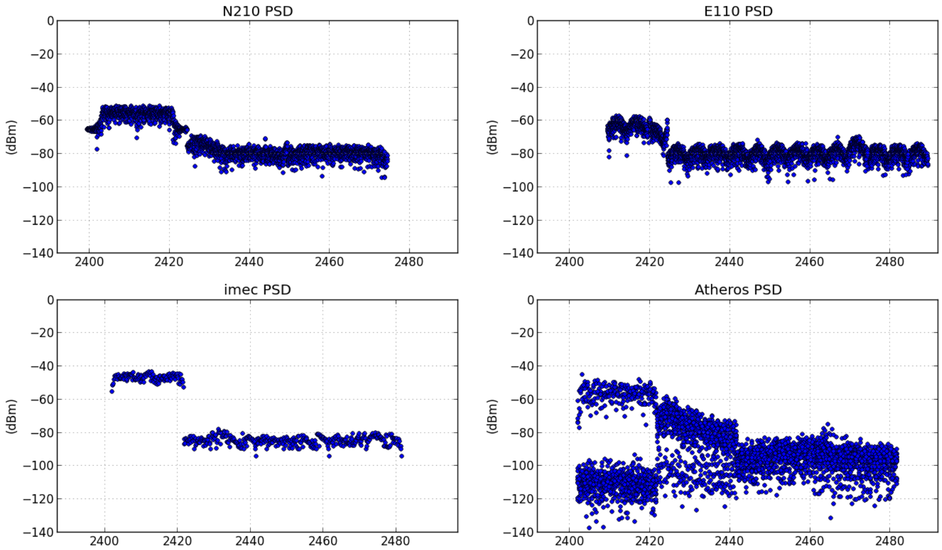


**Figure 5: PSD Evaluation during Sweeping of the 2.4 GHz ISM Band**

*5) Energy Consumption results*: Considering the Power Consumption evaluation, we observe that as the interval of the total sensing procedure is prolonged due to channel sweeping, the resulting energy consumption is increased. Figure 6 plots how power consumption is progressively affected by the various steps of spectrum sensing, while also characterizing the total amount of energy spent during the execution of the Phase 2 experiment.

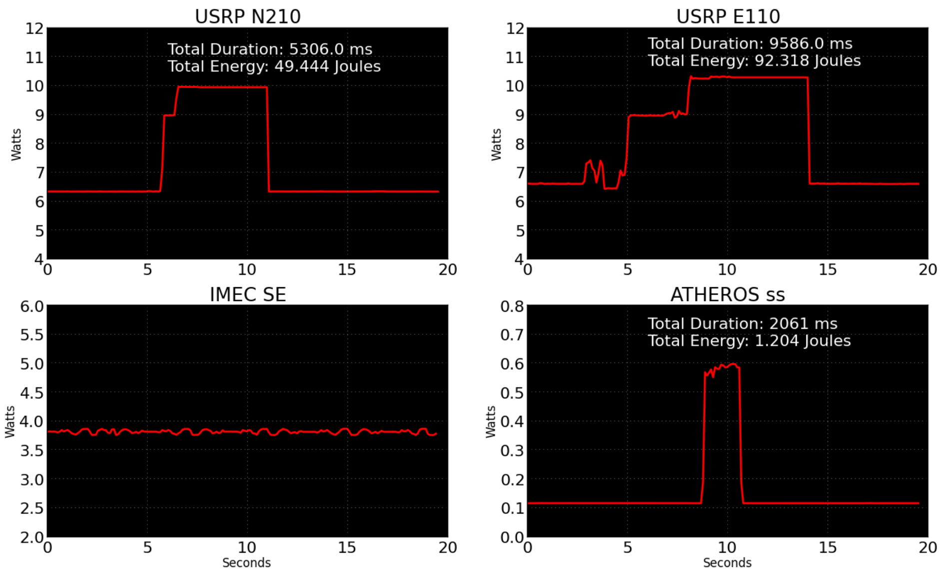


**Figure 6: Energy Consumption during Sweeping of the 2.4 GHz ISM Band**

*6) Sensing Delay results*: Figure 7 represents the Sensing Delay evaluation GUI as plotted in this second phase of the showcase experiment. Regarding the impact of the **Channel Switching** (CS) overhead per device on the distribution of the total Sensing Delay, we observe that the most affected devices are the USRP ones. This comes due to the fact that the CS overhead for the USRP devices is approximately 30 times higher than the overhead induced by the AR9280 (1.723 ms) and 3 orders of magnitude higher than the CS overhead of the imec SE (50 μs). In this case, we remark that the high CS overhead of the USRP N210 makes the device incapable of performing real-time Spectrum Sensing, even in the case that rest procedures are efficiently executed in multi-threaded mode.

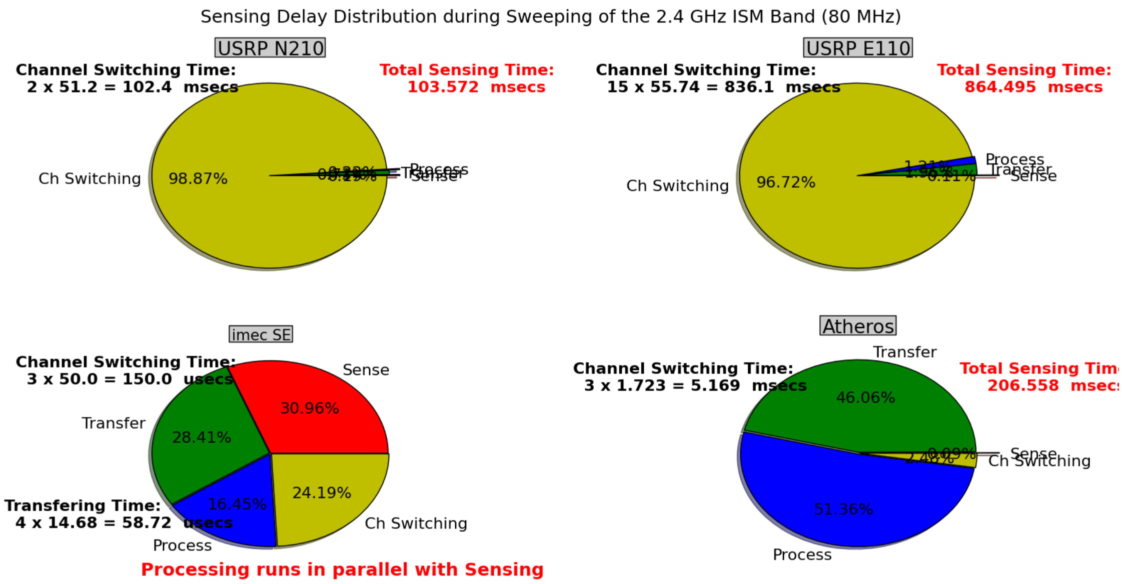


**Figure 7: Sensing Delay Distribution during Sweeping of the 2.4 GHz ISM Band**

# 3 Conclusions

In this public document we presented a working implementation of the proposed UTH-NICTA experiment. Four different cognitive platforms are evaluated under a specified experimental scenario and through live representation of the collected results, we manage to highlight the tradeoffs existing between the considered metrics of Sensing Performance, Delay and the resulting Power Consumption.

# 4 References

[1] w-iLab.t : http://www.iminds.be/en/develop-test/ilab-t/wireless-lab
[2] USRP N210 Networked Series : https://www.ettus.com/product/details/UN210-KIT
[3] USRP E110 Embedded Series : https://www.ettus.com/product/details/UE110-KIT
[4] imec Sensing Engine : http://www2.imec.be
[5] Atheros AR9280 Chipset : http://goo.gl/TXsaQr
[6] Iperf application: http://iperf.fr/
[7] OMF-cOntrol & Management Framework : http://omf.mytestbed.net/
[8] OML Measurement Library : http://mytestbed.net/projects/oml/wiki/
[9] An integrated reconfigurable engine for multi-purpose sensing up to 6 GHz
http://goo.gl/2OeIRJ
[10] Ath9k Wireless driver : http://goo.gl/VrHtj