Emergency Radio Information System for Post-Disaster Communication

Azril Haniz, Md. Abdur Rahman, Minseok Kim and Jun-ichi Takada
Department of International Development Engineering
Graduate School of Science and Engineering
Tokyo Institute of Technology, Meguro, Tokyo 152-8552, Japan
Email: {azril, abdur, mskim, takada}@ap.ide.titech.ac.jp

***Abstract*—Wireless communication is the part and parcel of modern emergency rescue operations. In a post disaster scenario, generally rescue teams set individual networks to communicate with mobile teams. So, there is a possibility of interference among the rescue teams (that try to transmit on the same frequencies). In this demonstration a spectrum sensing network has been implemented to collect the emergency radio information and store in a central database server. These information can be used by network management team to restrict the entrance of new emitters that may interfere the existing communications. The prototype has been developed by using mostly software defined radio peripherals.**

I. Introduction

After a big disaster generally emergency rescue teams from all over the world come to the scene and try to participate in the rescue activities. Usually each agency sets its own wireless network to coordinate the mobile teams. As the number of wireless channels for emergency communications is limited, it is quite possible that two teams are configured to communicate through the same wireless channel. The result is severe interference between the two networks that hinders the rescue efforts. A well informed wireless environment may help the systems to avoid interferences and perform rescue operations smoothly.

In this study a cooperative emergency radio sensing and identification system has been developed by using GNU radio and USRP (Universal Software Radio Peripheral) [1],[2] which are an open-source software radio and its evaluation hardware respectively. A number of related subsystems have been developed and integrated together to perform the tasks effectively. Performance of these subsystems have also been presented in this study. A prototype of emergency radio information system has been implemented by using currently available technologies. Figure 1 is showing the architecture of a cluster based spectrum sensing network that can collect necessary information by detecting occupied channels. Details of the architecture used to develop the prototype is available in reference [3].

II. System Description

The whole system is divided into five subsystems: spectrum sensing, propagation channel, geolocation, PHY parameter recognition and database maintenance. In the developed prototype spectrum sensing with automatic modulation recognition and database maintenance have been implemented.

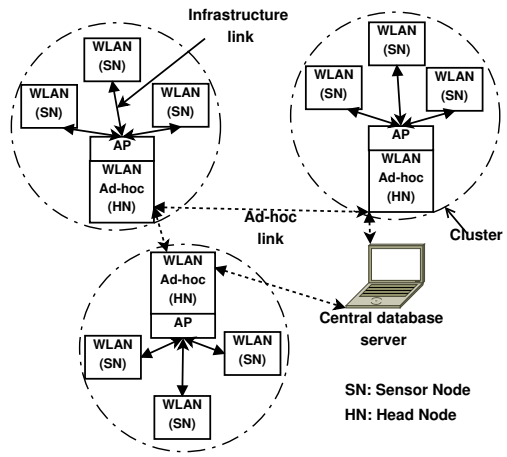

Fig. 1. System architecture

A. Spectrum sensing

In a disaster scenario, sensors do not have any information about the bandwidth of the primary users signal. So it would be difficult to apply a filter matched to that bandwidth. The averaged periodogram approach has been used as the test statistic $\mathcal{T}_k$ for energy detection in the target frequencies.

$$\mathcal{T}_k = \frac{1}{M}\sum_{m=0}^{M-1}\frac{|Y_m(k)|^2}{L}, \quad (1)$$

where L is the FFT size, M is the total number of segments, and $k(=0,\ldots,L-1)$ is the frequency bin index, and $Y_m(k)$ is the Fast Fourier Transform (FFT) of a windowed sample segment. As M sets of periodograms were used to calculate the test statistics, the number of samples used to calculate one FFT bin is also M. Obtained test statistics are compared with a predetermined threshold to make the final decision.

Cooperative sensing is necessary to combat the adverse environment in a post-disaster scenario. In soft decision combining, data from each sensor are combined and then compared to a threshold to determine the presence of a signal [4]. Further

CROWNCOM 2011, June 01-03, Osaka, Japan
Copyright © 2012 ICST
DOI 10.4108/icst.crowncom.2011.245916

explanation regarding the spectrum sensing techniques used in this prototype can be found in [5].

B. Modulation recognition

Statistical signal characterization (SSC) is a little unconventional way to perform frequency-domain analysis of a waveform without using the Fourier transform or the fast Fourier transform [6]. In SSC a waveform is characterized as a function of its relative amplitude and phase [7]. SSC exploits the fact that a signal can be considered as a set of consecutive segments. As mean and variance of the segments are consistent for a certain type of waveform these characterization can be used to classify the incoming waveform.

SSC segments are defined by the area bounded by two consecutive extrema. A waveform with N extrema (N/2 Maxima + N/2 Minima) has $N-1$ SSC segments. For example, six extrema will produce five SSC segments. Mathematically, the segment amplitudes are calculated by $A_i = |a_i - a_{i-1}|$ and $T_i = |t_i - t_{i-1}|$, where A_i, T_i are amplitude and period of the i-th segment, a_i, t_i are amplitude and period at the concluding extremum of the segment, and a_{i-1}, t_{i-1} are amplitude and period at the beginning extremum of the segment respectively. Four SSC parameters are amplitude mean, period mean, amplitude deviation and period deviation. The corresponding equations can be found in [8].

For the proposed system the target modulation classes are assumed to be known in advance. Rescue teams use both analog and digital modulation schemes for communication. As the modulation classes are finite a supervised learning based decision tree classification algorithm can be used here. A brief review of the supervised learning based algorithms is available in [9]. Decision trees visualize what steps are taken to arrive at a classification.

In this study the decision tree is generated by using 50 instances of each of the four attributes for the target modulated schemes and saved as a model in WEKA (Waikato Environment for Knowledge Analysis) data mining tool [10]. Afterwards this model is used to classify received signals with unknown modulation schemes. In this study decision tree algorithm based on C4.5 [11] is used for training set generation and classification purposes. The algorithm is developed in JAVA environment called as J48 and included in WEKA.

III. Results and Analysis

Experiment has been conducted to evaluate the performance of the proposed system setup based on the performance criteria for energy detectors. An USRP, which was used to transmit modulated signals, was connected to an attenuator via coaxial cable to control the power of the input signal. One output of the power splitter was connected to a signal analyzer to observe the signal power, and the other output was connected to the daughterboard's (XCVR2450) [1] RF input of the USRP which is assumed to be used as a sensor node. Experiment parameters are summarized in Table I. For this specific experiment frequency band 5 GHz has been chosen because of the availability of four daughter boards. However, experiments on 2.4 GHz. and 800 MHz. (with two sensor nodes) also showed similar performance.

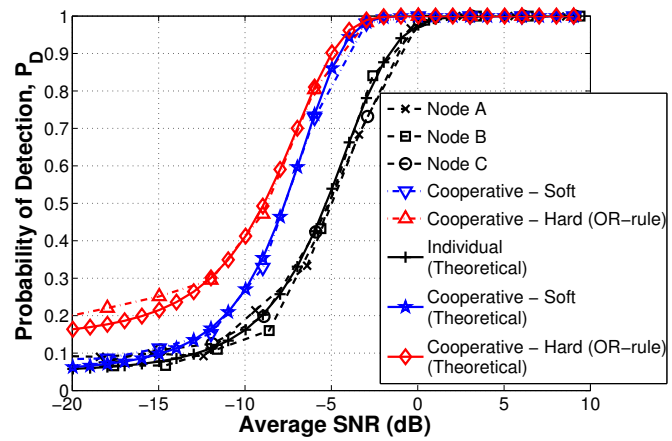

Fig. 2. P_D for various SNRs for individual and cooperative sensing

TABLE I
Experiment Parameters

Signal generator settings	
Center Frequency	5.003 GHz
Signal	BPSK modulated signal
SNR Range	-20 dB $\sim$ 10 dB

USRP Settings	
Sampling Frequency	64 MHz
USRP Decimation	16
FFT Size	128
FFT Bin Resolution	31.25 kHz
Receiver Gain	60 dB
Tune Delay	20 ms
Sensing Time	100 ms
Samples per FFT Bin	3125
P_{FA}	5 %

Figure 2 shows the measured P_D and the theoretical P_D curve for SNRs ranging from -20 dB to 10 dB. In the fig., the curve of each node matches roughly with the theoretical curve. At $P_D = 0.9$, the cooperative sensing schemes managed to detect signals at 3 $\sim$ 4 dB lower than individual sensing. Increasing the number of sensor nodes would further increase the sensing performance. However, in a limited area, increasing the number of sensor nodes would also increase the shadowing correlation and this will limit the cooperation gain [12].

A. Modulation recognition simulation

A recorded continuous voice signal modulated by AM and FM schemes has been generated as the input signal for the classification system. For the digital modulation, PN sequence modulated with ASK, FSK, BPSK and QPSK scheme have been used as the input signal. The carrier and bandwidth of the signal is assumed to be known by the parameter extractor. However, in real implementation the estimation error of the carrier frequency will have some significant impact. This is

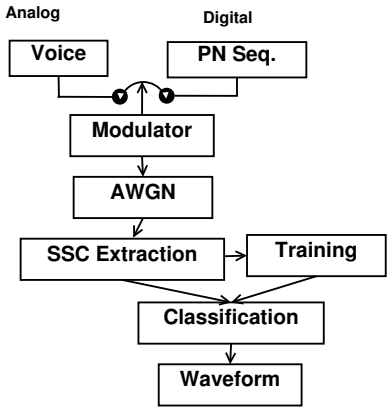

Fig. 3. Modulation recognition simulation flowchart

TABLE II
CLASSIFICATION SIMULATION PARAMETERS.

Parameters	Analog mod.	Digital mod.
Input	Voice	PN Seq.
Rate	8KHz., 16-bits	6.4 ksym/s
SNR	0-15 dB	0-15 dB
Carrier Freq.	50kHz	50kHz
Freq. Deviation	AM Index: 1 FM: 25kHz	FSK: 10kHz

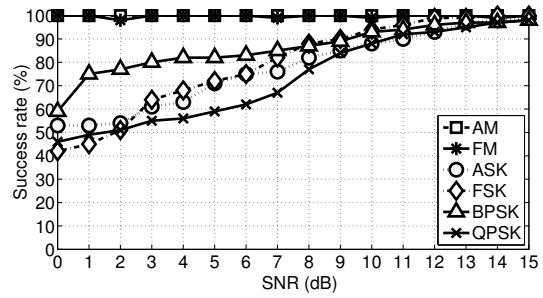

Fig. 4. Modulation classification performance

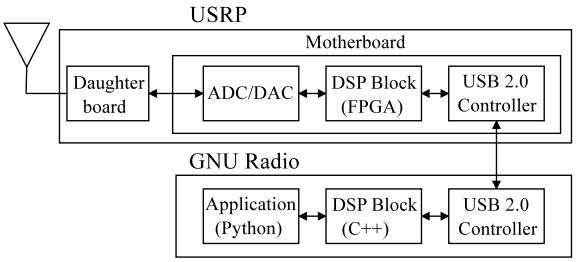

Fig. 5. Architecture of GNU Radio & USRP [3]

identified as one of the future studies of this work. In digital modulations roll-off factors are not considered for simplicity. Figure 3 shows the simulation steps for both analog and digital modulations. Table II represents the simulation parameters used to generate the input signals. For this simulation the carrier frequency is chosen as 50 kHz for testing purposes only. In real implementation the carrier parameters may vary. Increase in the carrier frequency increases the processing time.

The generated waveforms have been sampled properly to extract four SSC parameters. First, signal streams were generated for each type of modulation with different SNRs. Then the signal was sampled, divided into segments and SSC parameters were extracted for each of these segments.

At first 50 segments of each modulations are generated to produce the training set, hence the decision tree. Later another 100 segments are generated to test the performance of the classifier. In this simulation the training set is limited only for specified modulation parameters.

The performance of the classifier to recognize the target modulation classes is shown in Fig. 4. Performance of the digital modulation in the lower SNR is not so satisfactory, because the SNR damages the original extrema information as well as the bit information. Performance of the classifier can be increased by improving the input attributes. A threshold based approach to calculate the SSC parameters can be employed for better performance.

IV. DEVELOPED SYSTEM

The prototype of the proposed sensor network has been implemented inside the laboratory. Our proposed sensor network architecture is shown in Fig. 1. For better management of the sensors, a hierarchical network architecture has been employed. A cluster based sensing network has been utilized in order to provide spectrum sensing coverage over a wide area. Implementation of the nodes will be explained in the following subsections. Database is implemented by using MySQL and the maintenance scripts are implemented in PHP [13]. Python scripts were used to transfer the sensed data from sensors to the head node of each cluster. Standard ubuntu drivers for the infrastructure mode is used for the communication between the sensor and head nodes. Babel [14] multihop ad-hoc protocols are used for head to database communications. For the hardware universal software radio peripherals (USRP) with GNU radio have been used. A brief description is given below.

A. GNU Radio & USRP

We have utilized the GNU Radio and the USRP (Universal Software Radio Peripheral) to implement a cooperative spectrum sensing system. GNU Radio is an open-source signal processing package mainly used for building software defined radios. The USRP serves as a digital baseband and IF section of the GNU Radio. The USRP is used with a daughterboard, which is the RF front-end of GNU Radio. By mounting specific daughterboards onto the USRP, we can receive and transmit signals at various frequency bands, ranging from 50 MHz until 5.9 GHz. The basic architecture of GNU Radio & USRP is shown in Fig. 5.

B. Prototype development

Figure 6 shows a photograph of the experimental setup. Two sensor nodes in conjunction with a cluster head and database

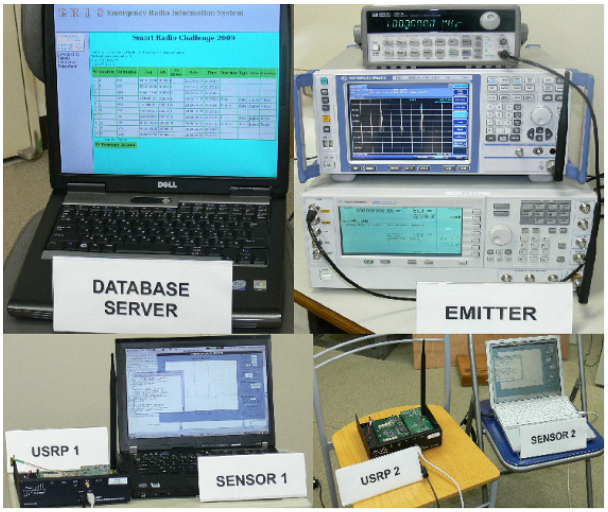

Fig. 6. Experiment setup

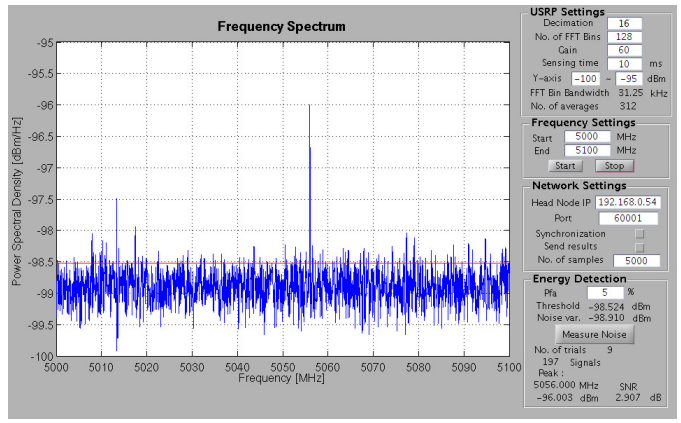

Fig. 7. Graphical User Interface (GUI) developed using python

server have been setup for the demonstration setup. An USRP is used to transmit modulated signal while a signal analyzer was used to observe the presence of signal.

Average periodogram (calculated by GNU radio) of the received signal is directly fed to a python software module. A graphical user interface (GUI) was also created in python language, and a screen-shot of this GUI can be seen in Fig. 7. Basic parameters of the USRP as well as the network can be set by this interface. The interface can show the frequency spectrum with the noise threshold. Inside the laboratory the noise threshold was calculated as -98.52 dBm for $P_{\text{FA}} = 5\%$. The sensing bandwidth is limited by the USB 2.0 data transfer interface between the USRP and the GNU Radio installed on personal computer. Sensing bandwidth above 4 MHz suffered from data loss in the USB interface.

One of the most important challenges for the cooperative sensing in this environment is the synchronization. There are several methods to achieve synchronization among nodes. One method is to utilize the Global Positioning System (GPS), but this would require the installation of GPS receiver hardware on each node. From an implementation point of view, a simpler method would be network-based clock synchronization, and one example is the Network Time Protocol (NTP), which is widely used in computers nowadays [15]. NTP uses a hierarchical system of time sources, and each level in this hierarchy is called a *stratum*. In proposed architecture, the database will be in the highest stratum and serve as the reference time, head nodes will synchronize their clocks with the database and sensor nodes will synchronize their clocks only with head node in that cluster. NTP typically provides accuracy of less than a millisecond on LANs and up to a few milliseconds on WANs. For the proposed system, the target is to detect the presence of emergency radio around the sensor node. In emergency situation, the emitters are expected to transmit signal more frequently. So, for the proposed system the time delay of NTP is quite acceptable. To start the sensing after the NTP synchronization, the head node will inform sensor nodes in a cluster about when to begin spectrum sensing (e.g. 12:00:00 PM). Once that time is reached, sensor nodes will begin spectrum sensing simultaneously, and each node will send the data to the head node. After the head node has collected data from all sensor nodes, it will inform sensor nodes about the next sensing time and so on.

After receiving the time samples for each occupied wireless channel, the modulation recognition subsystem tries to identify the modulation schemes used. Supervised learning based classification discussed in earlier section is used for this purpose. The training set for the channels have already been generated by receiving some known signals. The carrier and bandwidth has already been identified by energy detection. As the system is trained with the data received by same USRP sensors, the carrier offset is also assumed to be unchanged.

For the identification of the emitter, some prior information about the possible emergency emitters are assumed to be stored beforehand. The PHP script compares the extracted information with the existing database. If it finds a match for frequency, bandwidth, modulation scheme, predicted transmitting power for any emitters in the data, the emitter is identified as a node of that specific network. Tables and corresponding fields of the database have been chosen as the Fig. 8.

Table “Emitter” in Fig. 8 contains the extracted information received from the sensors. The ‘date’ and ‘time’ fields are used to check activity duration of sensors. The extracted information is used to extract the network identity from the “Network” table that already has some previously collected information. “Frequency” and “Modulation” tables are maintained to check the conflicts or the interference among the emitters. “Sensor” table holds the information about the active sensors on-site and the “Country” table is used to distinguish different systems from different countries. Data sent by the head nodes are saved to a directory of the database server. The developed PHP script checks for new text files received by the server. Whenever a new file is received, it reads the content from the file and update the database if necessary. The file consists of the center frequency, bandwidth, received power, modulation

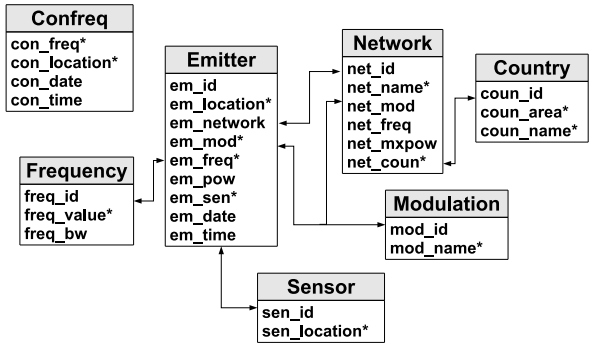

Fig. 8. Database design

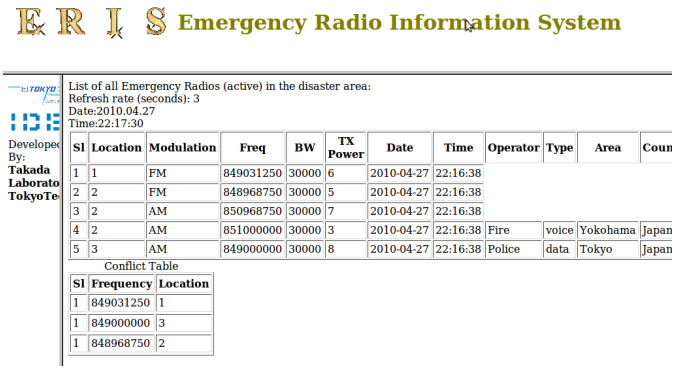

Fig. 9. Snapshot of the database viewer

scheme, geolocation, cluster number and sensor ID. Among these first four information are compared with the existing data in "Network" table to detect the association with which the emitter belongs to. If no prior information is found, an entry is made to the corresponding tables in the database. After finishing the identification process the corresponding tables are updated accordingly. Apache web server is also configured to make the data available through the Internet. Figure 9 shows the snapshot of the final view of the emitter information. First table is showing the active emitter information detected by the sensors. For some emitters the extracted information matched with the prior information. So their name and country can also be seen from the table. Second table is showing the conflicting frequencies.

V. Conclusion

A spectrum management system that detects active emergency radios in disaster area and dissipated the information through a web interface has been implemented in this study. A USRP and GNU radio based cooperative energy detector was used to detect the active radios. The cooperative sensing system was able to provide probability of detection of around 100% with a false alarm of 5% and SNR=-10dB. For the proposed architecture sensors are placed on site (close to the emergency emitters). So, the SNR are assumed to higher that usual cases. In case of the modulation recognition SSC parameters were used to identify the unique signatures of each target modulation schemes. It is quite difficult to classify the modulations with very low SNR signals. Sensors may receive lower SNR signals due to the distance and multipath in between. Supervised learning based J48 decision tree algorithm has been used for classification of the received samples. For this work the carrier and bandwidth are assumed to be correctly estimated by the energy detector. The training sequence is also limited to only some specific modulation parameters. Development of the disaster channel model with geolocation is future study of this work.

Acknowledgments

Authors are grateful to the Smart Radio Challenge 2009 (SRC'09) for providing the problem statement for this study [16]. Authors also show their gratitude to Mr. Lee Pucker (Wireless Innovation forum) and Mr. John Irza (Mathworks and SRC'09 challenge Chair) for their support. Special thank goes to Mathworks for providing individual licenses for all the authors. Authors are also thankful to the KKE inc., Japan for providing the "Wireless Insite" simulator for raytracing simulations.

References

[1] "Ettus Research LLC," available at http://www.ettus.com/.
[2] F. Hamza, "The USRP Under 1.5X Magnifying Lens!," available at http://gnuradio.org/redmine/wiki/gnuradio/UsrpFAQ.
[3] M. A. Rahman, S. Khadka, Iswandi, M. Gahadza, A. Haniz, M. Kim, and J. Takada, "Development of Spectrum Sensing System with GNU Radio and USRP to Detect Emergency Radios," *IEICE Technical Report*, SR2009-57, Software Radio, pp.39-44, Oct. 2009.
[4] J. Ma, Y. Li, "Soft Combination and Detection for Cooperative Spectrum Sensing in Cognitive Radio Networks," *IEEE Trans. Wireless Commun.*, Vol. 7, Issue 11, Part 2, Nov. 2008.
[5] A. Haniz, M. A. Rahman, M. Kim, J. Takada, "Spectrum Sensing on Emergency Radio Spectrum Management System," *2010 Int. Symp. on Communications and Information Technologies (ISCIT)*, pp. 985-990, Oct. 2010.
[6] H.L. Hirsch, "Statistical Signal Characterization - New Help for Real-time Processing," *IEEE Aerospace and Electronics Conference*, vol. 1, pp. 121-127, 1992.
[7] A. Hossen, F. Al-Wadahi, J. A. Jervase, "Classification of Modulation Signals using Statistical Signal Characterization and Artificial Neural Networks," *Engineering Applications of Artificial Intelligence*, vol. 20, no. 4, pp. 463-472, Jun. 2007.
[8] M. A. Rahman, A. Haniz, M. Kim, J. Takada, "Automatic Modulation Classification in Wireless Disaster Area Emergency Network (W-DAEN)," to appear in *Cognitive Radio Oriented Wireless Networks and Communications*, Jun. 2011.
[9] S. B. Kotsiantis, "Supervised Machine Learning: A Review of Classification Techniques," Informatica, **31**, pp. 249-268, 2007.
[10] "WEKA Documentation," available at http://www.cs.waikato.ac.nz/ml/weka/.
[11] R. J. Quinlan, "C4.5: Programs for Machine Learning," *Morgan Kaufmann Pub. Inc.*, 1993.
[12] A. Ghasemi, E.S. Sousa, "Collaborative Spectrum Sensing for Opportunistic Access in Fading Environments", *IEEE Proc. of DySPAN'05*, Nov. 2005.
[13] "XAMPP Documentation," available at http://www.apachefriends.org/en/xampp-linux.html.
[14] "Babel - a loop free distance vector routing protocol," available at http://www.pps.jussieu.fr/~jch/software/babel/.
[15] T. Neagoe, V. Cristea, L. Banica, "NTP versus PTP in Computer Networks Clock Synchronization," *Proc. IEEE of 2006 Int. Symposium on Ind. Electron.*, vol. 1, pp. 317-362, Jul. 2006.
[16] "3rd Smart Radio Challenge 2009," available at http://www.radiochallenge.org.