3rd Smart Radio Challenge 2009

Emergency Radio Information System

Geolocation Based Cooperative Sensing System to Mitigate Interference in Emergency Communications

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TokyoTech Team
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International Development Engineering,
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2010/06/17

Team Members

- Student Members
  - Md. Abdur Rahman
  - Azril Haniz
  - Santosh Khadka
  - Mutsawashe Gahadza
  - Iswandi
- Supervisors
  - Jun-ichi Takada, Professor
  - Dr. Minseok Kim, Assistant Professor
- Challenge overview: http://www.radiochallenge.org

Challenge Results

- Participating teams were:
  - University of NotreDame
  - Penn State University
  - **TokyoTech**
  - University of Calgary
  - Stevens SDR Group
  - Virginia Tech
  - Worchester Polytechnic
- Time-lines
  - Challenge Announced - 6 March 2009
  - Proposals Due - 10 April 2009
  - Teams Announced - 22 April 2009
  - Final Results - 16 April 2010
- Final Result
  - First place and a scholarship prize of $4000: University of Calgary
  - **Second place and a scholarship prize of $3000: Tokyo Institute of Technology**
  - Best Design and a scholarship prize of $2000: University of Calgary
  - Best Presentation and a scholarship prize of $2000: WPI
  - Best Report and a scholarship prize of $1000: WPI team

Outline

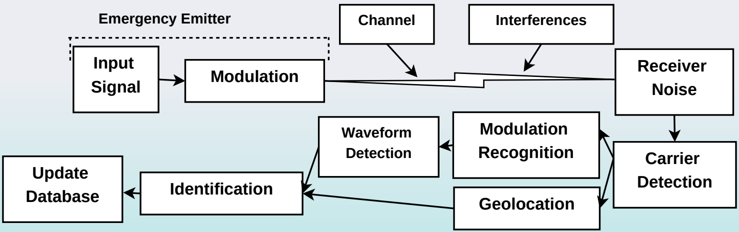
1. Introduction
2. Framework
3. Spectrum Sensing
4. Modulation Classification
5. Conclusions

Introduction

- Human civilization has always been devastated by natural/manmade disasters.
- Aftermath of big disasters (i.e Earthquakes, Terrorist attacks)
    - Loss of Human Life
    - Collapse of Infrastructure
    - Necessity of Emergency rescue efforts
- Different rescue teams (Police, Medical, Fire etc.) come from everywhere and create interference

Objectives

- Design and implementation of a spectrum sensing system for disaster scenario
- Propagation channel simulation for disaster scenario
- Automatic modulation recognition for emergency emitters
- Geolocation simulation with multipath effects
- Implementation of database server



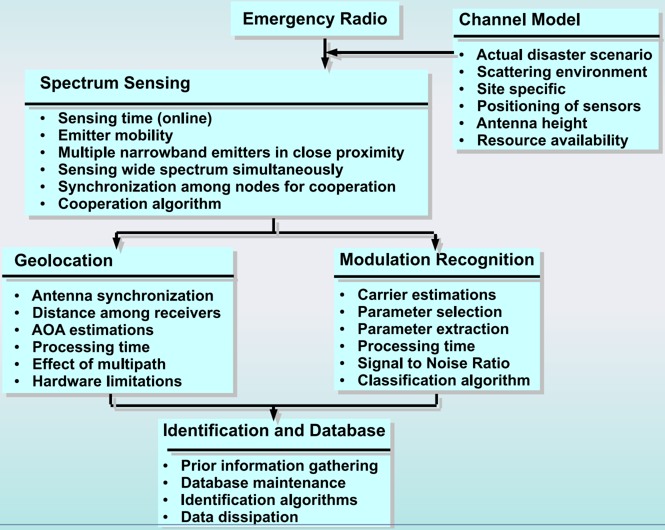
Assumptions

- We assumed some issues to make the system more realistic
  - No communication with the emergency emitter. (If the modulation is successfully identified, still the communication is not possible due to the encryptions especially in the digital systems)
  - Possible to setup a spectrum sensor network in the disaster area
  - Availability of some prior information of the potential rescue teams
  - Rescue teams will check the availability of spectrum before setting up individual networks

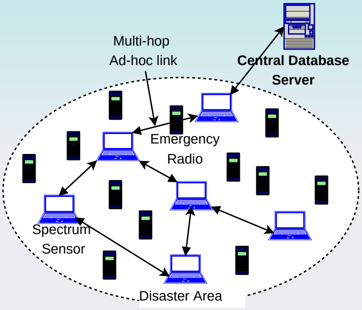
- We have divided the whole system into 5 subsystems
  1. Spectrum Sensing and Network Implementation – Azril Haniz
  2. Disaster Channel Modeling – Santosh Khadka, Iswandi
  3. Geolocation – Mutsawashe Gahadza
  4. PHY parameter extraction – Md. Abdur Rahman
  5. Network and Database design – Md. Abdur Rahman

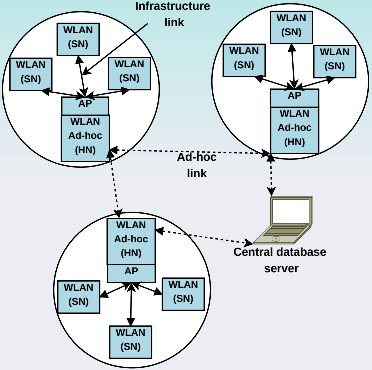
Challenges

- Issues to address in different subsystems are:



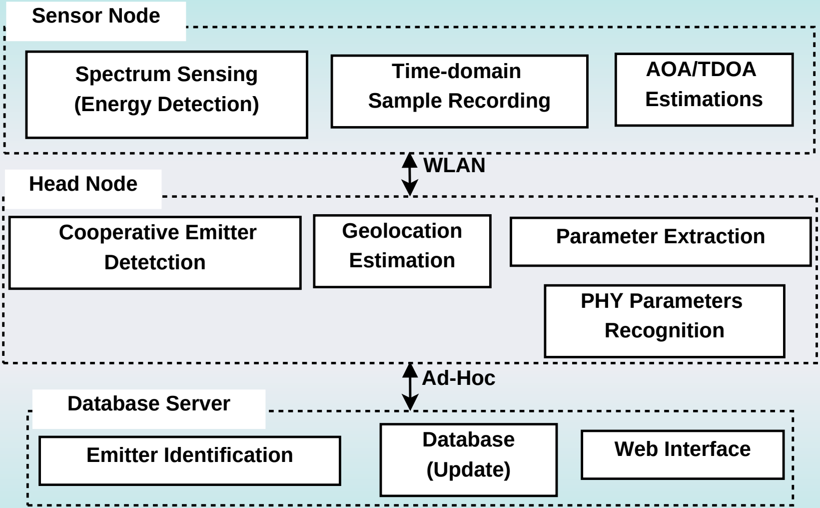
Disaster Scenario





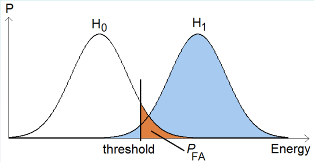
- For the prototype we used wi-fi
- In wi-fi, we used omnidirectional antennas (for placement and routing flexibility)
- A cluster based approach is proposed for better management

Node Activities



Spectrum Sensing

We used the Energy detection technique



$\mathcal{H}_0$: Signal absent
$\mathcal{H}_1$: Signal present

Probability of Detection (P_{D})
→ Probability of successfully detecting PU signal
Probability of False Alarm (P_{FA})
→ Probability of deciding signal is present even though signal is absent

$$\gamma = \mathrm{Q}^{-1}(P_{\mathrm{FA}})\sqrt{\frac{1}{M}{\sigma_{\mathrm{n}}}^4} + {\sigma_{\mathrm{n}}}^2$$

$$P_{\mathrm{D}} = \mathrm{Q}\left(\frac{\gamma-({\sigma_{\mathrm{n}}}^2+{\sigma_{\mathrm{s}}}^2)}{\sqrt{\frac{1}{M}({\sigma_{\mathrm{n}}}^2+{\sigma_{\mathrm{s}}}^2)^2}}\right)$$

σ_n^2 : Noise variance
σ_s^2 : Signal variance
M : No. of samples

GNU Radio and USRP

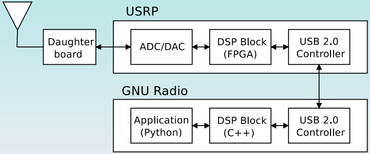
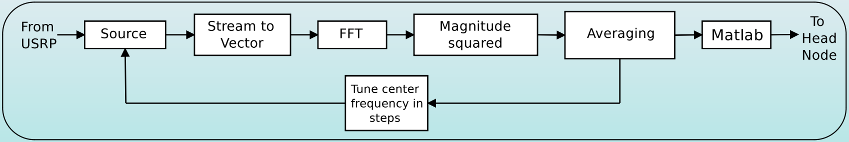
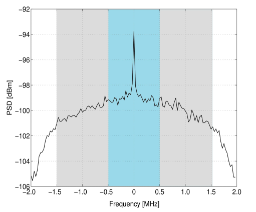


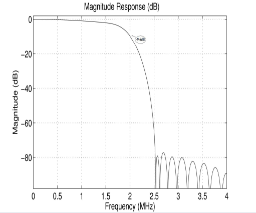
Fig : Architecture of GNU Radio & USRP

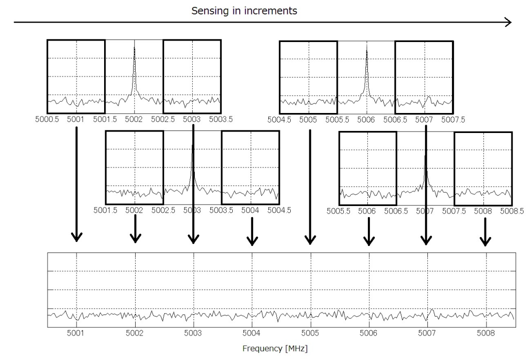
- **GNU Radio**
  - Open source signal processing software package
  - Offers many digital signal processing blocks
- **USRP (Universal Software Radio Peripheral)**
  - Digital intermediate frequency (IF) and baseband section
  - Used with daughterboards (Support frequencies ranging 50MHz to 5.9GHz



Wideband sensing



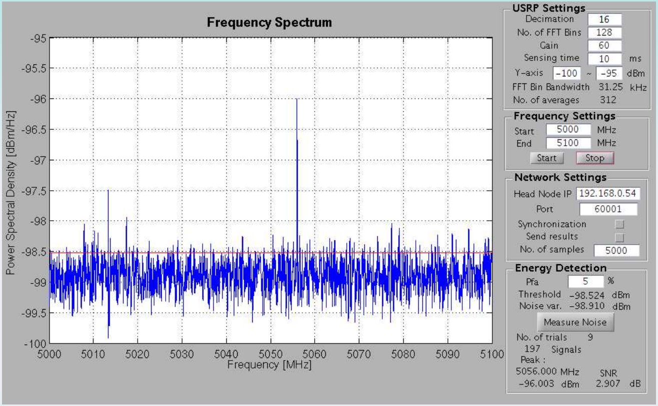




- The hardware introduces a DC offset in the baseband output
- The noise floor has a curved shape due to the slow filter roll-off in the Digital Down Converter

- Slow filter roll-off is compensated by removing 25% of both ends and subtracting the filter response
- The spike at the center frequency was avoided
- Sensing was performed sequentially in small steps

Matlab GUI



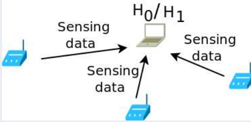
- Sensing output is displayed in a graphical user interface (GUI) created in Matlab
- GUI can control USRP settings directly from Matlab

Cooperative Spectrum Sensing

Soft Decision Combining

- Base station sums up received signal power to decide between $\mathcal{H}_0$ or $\mathcal{H}_1$

$$P_{\mathrm{D,coop(soft)}} = \mathrm{Q}\left(\frac{\gamma - \sum_{j=0}^{J-1}({\sigma_{\mathrm{s},j}}^2 + {\sigma_{\mathrm{n},j}}^2)}{\sqrt{\frac{1}{M}\sum_{j=0}^{J-1}({\sigma_{\mathrm{s},j}}^2 + {\sigma_{\mathrm{n},j}}^2)^2}}\right)$$

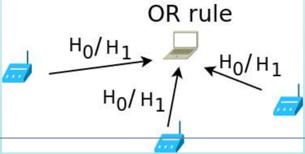


${\sigma_{n,j}}^2$: Noise variance and ${\sigma_{s,j}}^2$: Signal variance

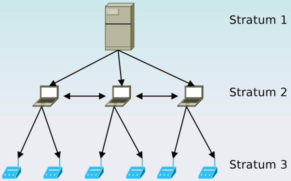
Hard Decision Combining

- Base station uses OR-rule to make final decision

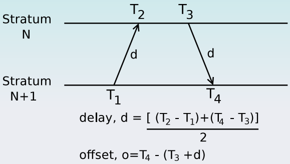
$$P_{\mathrm{D,coop(hard)}} = 1 - (1 - P_{\mathrm{D}})^n$$



Network Synchronization



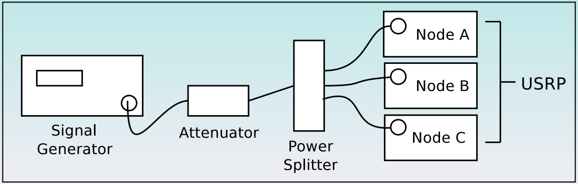
(a) NTP Hierarchy



(b) NTP Synchronization Mechanism

- Clock synchronization using Network Time Protocol (NTP)
  - Accuracies of less than 1 millisecond in LANs, a few milliseconds in WANs
  - Hierarchical system of time sources

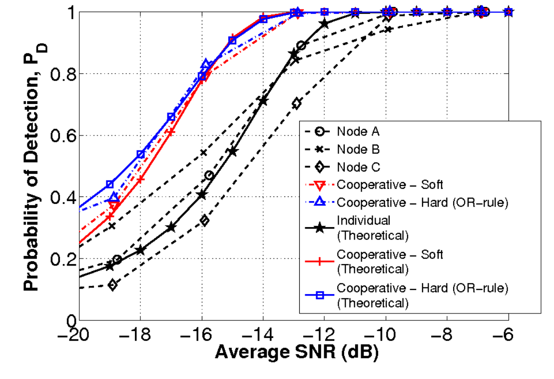
Experiment Setup



Sampling frequency	64 MHz
USRP Decimation	16
FFT Size	128
FFT Bin Resolution	31.25 kHz
PG Gain	60 dB
Tune Delay	20 ms
Sensing Time	100 ms
P_{FA}	5
SNR Range	10 dB to 20 dB
Trials	100
Signal	Sine wave

- Sine wave was generated
- SNR was changed from 10 dB to -20 dB
- USRP was used to sense signal
- Probability of detection P_{D} was measured

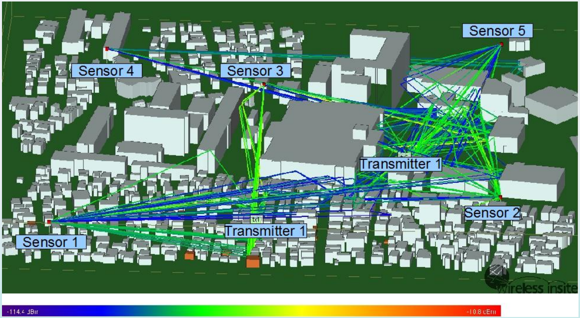
Sensing Results



- Measurement data was similar to the theoretical curve
- Hard decision combining slightly outperformed soft decision
- However, P_{FA} was higher

Channel Model

- To model disaster channel Ray Tracing Method was chosen
- A commercial software "Wireless Insite", product of Remcom, was chosen for Ray Tracing simulation
- Provided to Takada Laboratory by KKE Inc.



Localization Methods

- VITA 49 standard has a great potential to be used for geolocation.
- The VRT packets transferred among the emergency emitters can be intercepted by the sensors and retrieve the identification information from the VRT packets
- But for the digital systems to retrieve the Transport layer packets, we must pass through the MAC and PHY layers
- Additionally, synchronization of VITA 49 standard is also not tested for wireless environment
- For digital systems generally there are encryptions on the lower layers
- To make the system more realistic we investigated some other potential geolocation techniques
- Unavailability of VRT hardware is another decisive factor
- However, we have a plan to use the VRT in the further developments

Geolocation

- We investigated the possibility of the phase Interferometry based AOA measurement as a candidate for geolocation in a post disaster area.
- We did some preliminary simulation assuming a Rayleigh fading channel in order to investigate the effect of angular spread and SNR on the error performance of the AOA measurement.
- We also translated the result into the positioning algorithm in order to see effect of the two factors on geolocation as a whole.
- Preliminary simulations for the AOA method give reasonable geolocation error.
- Multipath is mitigated by power weighting of each path

Classification Overview

- Identification algorithm extracts information and infer characteristics based only on the collected signal.
- Done by extracting useful information from amplitude, frequency and phase information contained in a signal.
- For online processing the classification algorithms should be simple and quick
- Decision-theoretic and ANN based approaches have been widely used by many researchers
- Most of the current approaches perform better in higher SNR cases
- In this study we tried to classify both analog and digital modulations with relatively lower SNR

Supervised Learning based Classification

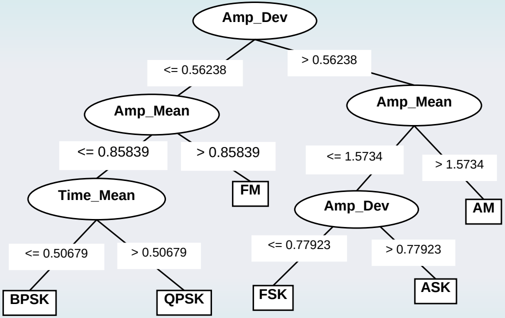
- Supervised learning based approach is applicable when the classifier has prior knowledge about the classes
- For the proposed system, the set of Modulation and Carrier used by the rescue teams are assumed to be known
- In this study a decision tree based algorithm is applied
- Decision tree begins with a root node, considered to be the "parent" of every other node.
- Each node in the tree evaluates an attribute in the data and determines which path it should follow.
- Decision test is based on comparing a value against some constant.
- Three steps of the algorithm are
  - Key feature extraction
  - Training set generation
  - Modulation classification

Decision Tree

- J48 Decision tree selects the parameter with maximum Information Gain as the root node
- Information gain of an attribute A

$$\mathrm{Gain}(A) = I(p, n) - E(A)$$

Here,
I= Information bits,
E= entropy.

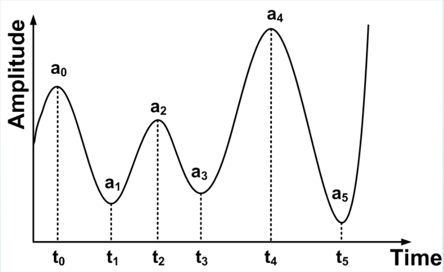


Key Features

- For our system we need to identify both Analog and Digital Modulated signals (AM, FM, FSK, BPSK, QPSK etc.)
- Statistical Signal Characterization (SSC) parameters can be used for the identification
- A waveform can be considered to consist of a set of consecutive segments with amplitude and period characteristics which are
    1. Statiscally well behaved,
    2. Indicative of particular combinations of frequency components
- Statistical measures (mean and variance) should be consistent when the waveform is properly sampled

SSC Technique

- Waveform is a combination of different frequency components and exhibits a series of extrema
- SSC segment is bounded by consecutive extrema
- Waveform with N extrema has N-1 segments



- $a_0 - a_5$ is the amplitude association of the extrema of the waveform
- $t_0 - t_5$ is the time association of the extrema of the waveform

$$A_i = |a_i - a_{i-1}|$$
$$T_i = |t_i - t_{i-1}|$$

A_i=Amplitude of i-th segment

T_i=period of i-th segment

SSC Parameters

- Sampling rates should follow the Nyquist theorem
- All amplitude measurements are relative, so no need to compensate for DC component (constant zero-offset)
- Four SSC parameters:

$$A_{\mathrm{M}} = \sum_{i=1}^{N_{\mathrm{S}}} (A_i)/N_{\mathrm{S}}$$

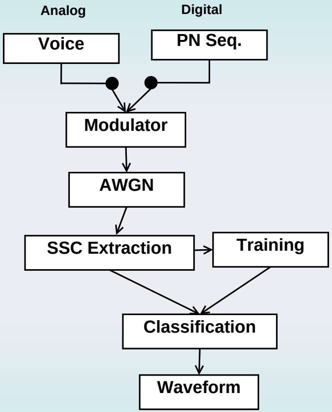
$$T_{\mathrm{M}} = \sum_{i=1}^{N_{\mathrm{S}}} (T_i)/N_{\mathrm{S}}$$

$$A_{\mathrm{D}} = \sum_{i=1}^{N_{\mathrm{S}}} (|A_i - A_{\mathrm{M}}|)/N_{\mathrm{S}}$$

$$T_{\mathrm{D}} = \sum_{i=1}^{N_{\mathrm{S}}} (|T_i - T_{\mathrm{M}}|)/N_{\mathrm{S}}$$

here,
A_{M}= Amplitude mean,
T_{M}= Period mean,
A_{D}= Amplitude deviation,
T_{D}=Period Deviation,
N_{S}=Number of SSC segments

Modulation Classification System



Classification simulation parameters.

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

- The training signal is generated 50 times for a certain type of modulation at different SNR.
- SSC parameters are calculated for each SSC segment.
- Maximum and minimum for each SSC parameters are obtained
- These steps are repeated for all target modulations

Simulation Performance

- MATLAB and WEKA (an open source implementation of j48) tool is used in this study
- 100 samples from different dataset have been generated to check the performance of the classification system

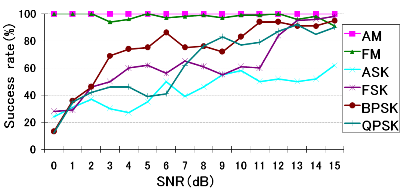


Figure: Classification performance

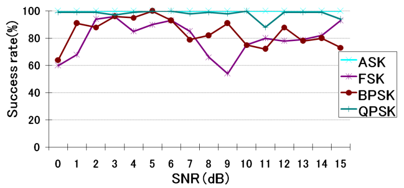
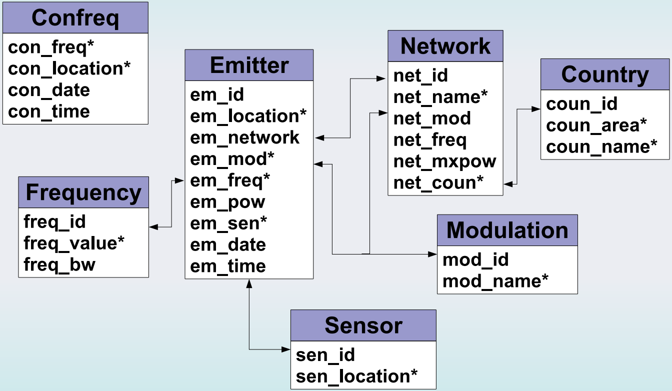


Figure: Classification performance with threshold

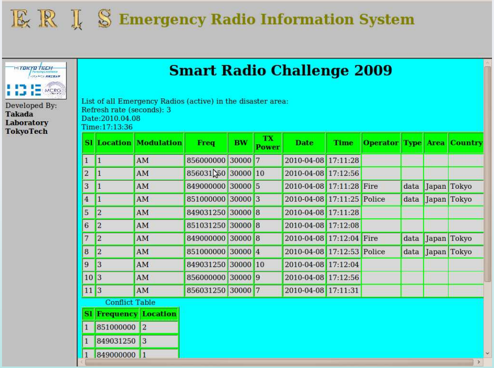
Database Design

- We have implemented the database on MySQL



Emitter Identification

- We received the "carrier frequency", "bandwidth", "modulation scheme", "received power" and "sensor number" from the head nodes
- These information are compared with the existing corresponding values in the "Network" table
- After retrieving the "net_id" the information is written into the "emitter" table.
- If no match is found the "em_net" field in the "emitter" table is set to NULL



E R I S Emergency Radio Information System

Developed By:
Takada Laboratory TokyoTech

Smart Radio Challenge 2009

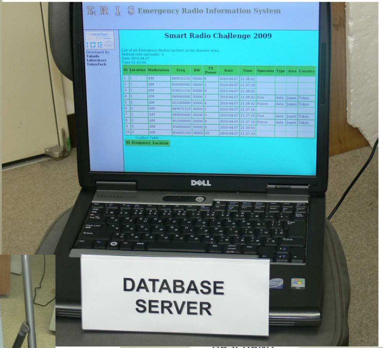
List of all Emergency Radios (active) in the disaster area:
Refresh rate (seconds): 3
Date:2010.04.08
Time:17:13:36

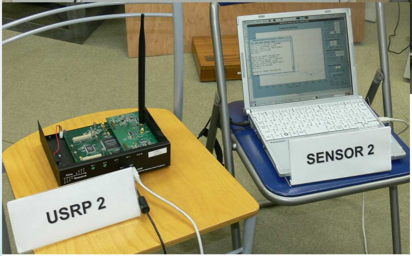
Sl	Location	Modulation	Freq	BW	TX Power	Date	Time	Operator	Type	Area	Country
1	1	AM	856000000	30000	7	2010-04-08	17:11:28				
2	1	AM	856031[illegible]50	30000	10	2010-04-08	17:12:56				
3	1	AM	849000000	30000	5	2010-04-08	17:11:28	Fire	data	Japan	Tokyo
4	1	AM	851000000	30000	3	2010-04-08	17:11:25	Police	data	Japan	Tokyo
5	2	AM	849031250	30000	8	2010-04-08	17:11:28				
6	2	AM	851031250	30000	8	2010-04-08	17:12:08				
7	2	AM	849000000	30000	8	2010-04-08	17:12:04	Fire	data	Japan	Tokyo
8	2	AM	851000000	30000	4	2010-04-08	17:12:53	Police	data	Japan	Tokyo
9	3	AM	849031250	30000	10	2010-04-08	17:12:04				
10	3	AM	856000000	30000	9	2010-04-08	17:12:56				
11	3	AM	856031250	30000	7	2010-04-08	17:11:31				

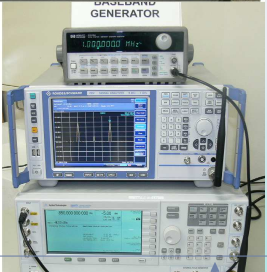
Conflict Table

Sl	Frequency	Location
1	851000000	2
1	849031250	3
1	849000000	1

Demonstration







Demonstration setup photos

Conclusions

- We have successfully implemented data sharing network among the sensors, head and database server
- Successfully implemented the cooperative sensing subsystem by using USRP, GNU radio and Matlab
- Successfully integrated the modulation recognition subsystem to detect the modulation of received signals
- We simulated the geolocation subsystem
  - Implementation was not possible for hardware limitations
  - Will require about 6 more months to implement the system
- We simulated the channel subsystems with "Wireless Insite"
  - Not implemented to avoid complexity
  - We are working to integrate Matlab and Wireless Insite
  - We are also working on the codes on Matlab simulations for raytracing
  - Will require some more time to implement

Further Developments

- Development of a spectrum management system from disaster scenario
- Implementation of cooperative sensing system
- Develop the raytracing simulation for disaster channel
- Improving the thresholding algorithm for the modulation classification
- Combining denoising techniques with modulation recognition

Acknowledgements

- We express our sincere gratitude to
  - Wireless Innovation Forum for giving us the chance to participate in SRC
  - Mathworks for providing free Matlab
  - KKE inc, Japan for providing "Wireless Insite" simulator
  - Mr. Lee Pucker for all his support throughout the year
  - Prof. Jun-ichi Takada and Dr. Minseok Kim for all the support and advice

Thank you