*International Journal of Engineering & Technology*, 7 (2.6) (2018) 6-11

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

***Research Paper***

# Design, development and deployment of a RSSI based wireless network for post disaster management

**Vivek Kaundal [1] *, Paawan Sharma [2], Manish Prateek [3], ¬Vinay Chowdary [4]**

[1] *Assistant Professor (Selection Grade), University of Petroleum & Energy Studies*
[2] *Assistant Professor (Selection Grade) University of Petroleum & Energy Studies*
[3] *Professor, University of Petroleum & Energy Studies*
[4] *Assistant Professor, University of Petroleum & Energy Studies*
**Corresponding author E-mail: vkaundal@ddn.upes.ac.in*

## Abstract

The wide spectrum of applications of wireless sensor networks in real time monitoring of disaster prone areas makes it very promising and reliable. The present work focuses on communication link establishment for the first 72 hours just after disaster, highlighting the capability of wireless sensor network especially in disaster prone area. The complete network consisting of 8 wireless nodes with integrated Xbee as a sensor to establish a communication link in between the pursuit team and trapped people. The network is deployed in Dunga Valley of Dehradun, Uttarakhand, a seismic zone with a population of more than 1 lakh. The nodes are capable of recognizing the traveler's location whenever they are passing by the disaster prone areas. The nodes gather RSSI values along with the estimated distances of the traveler (having anchor node) from the pursuit team (having pursuit node). The system has proven its validity by tracking the trapped people in communication deprived area in Dunga Valley by doing mock drill several times. The paper reports the design of wireless network as well as deployment aspects of the nodes in such disaster prone areas.

***Keywords***: *Wireless Sensor Network; Post Disaster Management; Real Time Monitoring; RSSI; Zigbee.*

## 1. Introduction

Disasters like earthquake, flooding is very destructive and can cause the communication link failure of the traditional cellular networks. The traditional communication methods are infrastructure based, like cellular network is having base station that covers up to 1.5 miles (approx.) area. The disasters may damage the infrastructure of these cellular networks. This eventually leads to the shutdown of all the base station and Main station of that particular network. India faces these disasters almost every year with a threat to human life and estimated huge infrastructural and human loss [1].

The level of disaster is also highly unpredictable making it more complex to establish the infrastructure less communication network for post disaster condition. Hence technology has to be developed for managing communication for post disaster conditions.

To establish a successful network in disaster prone area it requires a device that can handle large amount of data with more accuracy[2] and less delay in transmission of data. The power consideration is also one of the major factor[3]. These factors can be managed intelligently with wireless sensor networks. WSN is capable to tackle substantial amount of data and is able to process and transmit it anywhere to main central node for analysis. Also, the nodes are low cost and can be easily replaced when needed.

In present work, the main focus is to establish the communication network in post disaster scenario. To localize the trapped person there are two methods in WSN i.e. range based localization[4] and range free localization. Range based localization consists of TOA[5] Time of Arrival, TDoA [6] Time difference of arrival, AOA[7] angle of arrival and RSSI [8] Received signal strength Indicator. On the other hand in range free localization one can use proximity sensing to estimate the position of the nodes. The paper aims at RSSI (Range based localization) based localization. RSSI based localization does not require any extra hardware to implement unlike other range based localizations. RSSI is an inbuilt feature in many wireless modules like ZigBee. Similar sensor in range based solutions are RFID, Bluetooth etc. which however have low range (few meters) [9] and are not capable to establish wide area network. Though RSSI values and distance estimation through ZigBee is very noisy but can be solved with modeling the wireless channel established in between nodes like log normal shadowing model [10]. The wireless network for post disaster communication link established using two algorithms, Location Fingerprinting [11] and Unilateral [12]. Location Fingerprinting is the well-established classical algorithm to set up the WSN in initial stages and unilateral is the improved and optimized technique than trilateration algorithm. The location fingerprinting is based on storing all RSSI values and representation of those values in logarithmic scale. The stored values of RSSI in array also known as radio map. The array of stored RSSI values for all locations is also known as RF signature and fingerprinting. In this paper the network is established for predefined path with location fingerprinting technique. The RF signature for all travelers across the disaster prone area is stored in the nodes and to the main center node. This helps in tracking the real time positioning of the travelers. Even when disaster happens, the last location can be known through the RF signature of the traveler. Unilateral technique comes into role after the disaster happens only. In unilateral technique the pursuit node will estimate the probable distance of the anchor node through RSSI values. The pursuit node starts searching the anchor node from the location tracked from RF signature of the anchor node as discussed above in location fingerprinting technique. The

paper discusses the deployment and validation of such network in Dunga Valley (seismic zone in Dehradun, Uttarakhand).
The paper is organized as follows. Section 2 describes the related work in disaster management with WSN. Section 3 discuss the design of wireless node especially for capable of establishing communication in disaster prone area which is able to communicate when traditional cellular network fails. Section 4 discusses in detail the system architecture and network design in disaster prone area. Section 5 shows the deployment of the network in real time and Section 6 summarizes the validation of the whole network by making mock drills. Finally the paper conclude with the prospective future work can be done in the post disaster management.

## 2. Related work

The scenario of post disaster especially in the first 72 hours is very critical because of inability of affected people to make a rescue decision. In[13] it is reported that the people in locality should have the opportunity to communicate with the recue team for their immediate needs. There is a growing need of flexible, dynamic WSN for post disasters as reported in [14]. In [15] it is suggested that an emergency communication link can be established using existing or newly deployed WSN. The design reported the use of cellular network and satellite network too. Many researches have stated the use of robotics application for disaster management also. UAV (Unmanned Aerial Vehicles)[16] are one of them. In [16] UAV reporting human existence in disaster prone area. In [17] it has been shown that communication after the disaster is very important to take the right decision so that minimum causalities will happened. The authors also propose a framework in MAC to improve the network throughput and report the energy aware routing protocol for the same. Author in [18] discussed the network for disaster recovery. The network establishes the internet in the disaster affected area. Whenever the disaster occur the network controller initialize the internet network across the disaster prone area. The network handled the mobility of the node and its failure issues too. In [19] the TDRAN (Tree based disaster recovery access network) providing connectivity during post disaster has been discussed. The network has two operational modes. One mode is to manage its own network and other mode is useful to manage other network connection. There is another emergency communication establishment reported in [20] known as COMVIVOR (Communication for survivor). In this framework a smart node positioning is reported for fastened the information propagation. In paper [21] a hybrid network consist of cellular and ad-hoc is presented. In this network the node connects to Base stations but switches to ad-hoc once the cellular network fails. To achieve the reliable communication a framework has been reported in paper [22]. The network deployed here is less infrastructural.
The currently available systems as discussed above are focused on the designing of framework for quick communication link establishment rather than designing a low cost wireless node that will able to track the person. Also the research finds a gap in self-dependency of networks as most of the networks reported above are hybrid in nature and dependent upon either cellular or broadband network. So it becomes very essential to study and find the device or network that will not be dependent on any of the pre- existing network and run parallel to the existing infrastructure based networks. In this paper, a network is proposed and deployed which is infrastructure less, flexible, scalable and low cost which is not dependent on any of the pre-existing networks, thereby providing networks capability to issue the communication link failure in post disaster scenario.

## 3. Wireless node for post disaster communication link

The wireless network to be deployed in the disaster prone area consists of anchor nodes. Anchor node saves the RF signature of the travelers passing by the disaster prone area. Each traveler is having the transceiver node that will send their individual RF signature to the nodes deployed in the predefined path of disaster prone area. Wireless Node is equipped with all basic as well as advanced interfaces. The wireless node architecture in detail is shown in Fig.1. The node is having external peripherals interfaces like Xbee- RF unit based on ZigBee protocol. The Xbee-RF unit is the heart of the wireless network proposed. The module is capable of transmitting and receiving the RF signature. Xbee – S2 series is a low cost and low power consumption and flexible device with communication range of 1.5 miles to 3 miles. It transmission power is 2mW 3dBm and transmission and receiving peak current is 40mA at 3.3V with receiver sensitivity of -96dBm [23]. The node is also able to save the RF signatures in SD card module (4GB extended to 64 GB). The wireless node is running on 2600mAh battery backup which can be extended to 20000mAh if needed. The node can run for long 14 hours with 2600mAh. The battery is rechargeable and screw pin connectors are provided separately to connect it to solar PV modules to run the wireless node on solar energy. This feature of node makes it run for long hours to months to years. The node is having 16×2 / 20×4 alphanumeric LCD display. The backlight and contrast is adjusted via preset based filter. Through FTDI port connector the RSSI values can be stored or observed via serial monitor/ terminal in server also. Through the same port one can change the firmware also if needed during maintenance of the network or an individual node. The overall view of the node is shown in Fig.2.

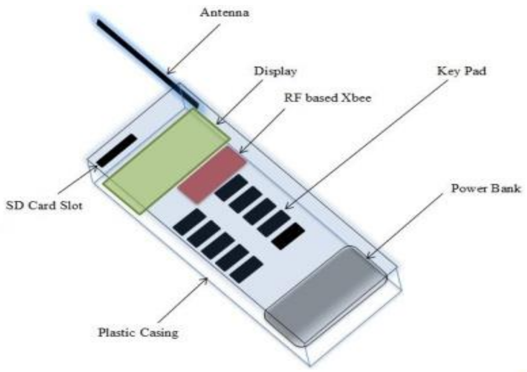


**Fig. 2:** Wireless Node.

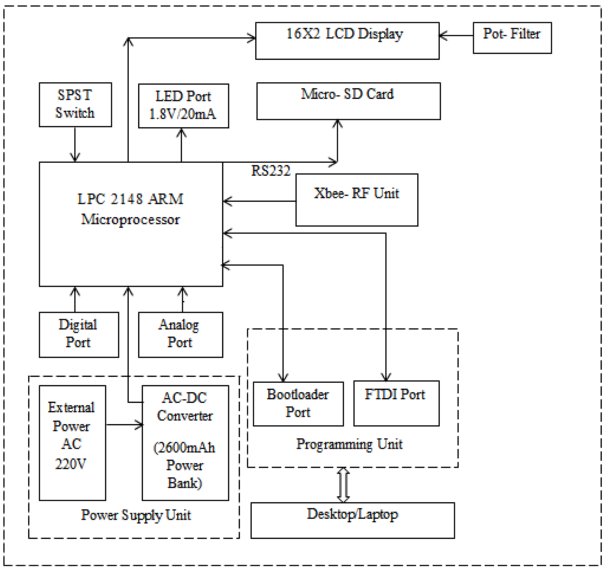


**Fig. 1:** Wireless Node Architecture.

## 4. System architecture and design of wireless network

The total system is design by keeping in mind the two algorithms used together for tracking the trapped traveler. The first one is location fingerprinting and second one is unilateral algorithm. Location fingerprinting is used to capture the RF signature of all the travelers passing by the disaster prone area. Let us discuss first the system architecture of the location fingerprinting. The wireless nodes discussed in section 3 is installed in the predefined path of the disaster prone area. The wireless node named as anchor node (AN1). The AN1 range is 1.5 miles having omnidirectional RF signals i.e. 2415 mtrs. So the distance between the two AN1 will be 2415 ×2 = 4830 mtrs (see Fig. 3). The AN1 will be installed in safety zone after evaluation through physical survey in the disaster prone areas. The safety zone will be identified by careful evaluation of the area and it is declared so because it was believe technically that even after the disaster occurs, the safety zones will be least affected. Additionally it is also kept in mind that the AN1 will not be placed so far from the road so that it will lose the connection from the nodes kept with travelers as shown in Fig.4. The travelers get the wireless node named as MN1 (Movable Node) from the registration point one as shown in Fig.4. Once they get registered in the network, the AN1 starts keeping their RF signature within themselves through SD card and also updates their RF signature to the registration point 1. Registration Point 1 is having the main server and it is located in safety zone which is far from disaster prone area. The MN1 is collected in registration point 2 after the traveler crosses the disaster prone area.

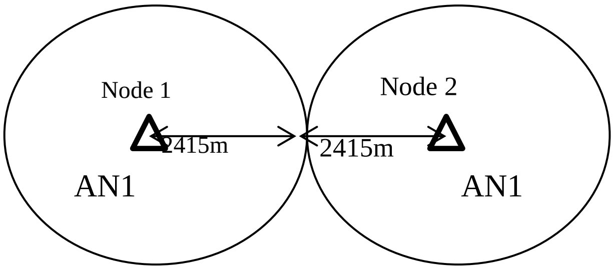


**Fig. 3:** Node Placement Distance.

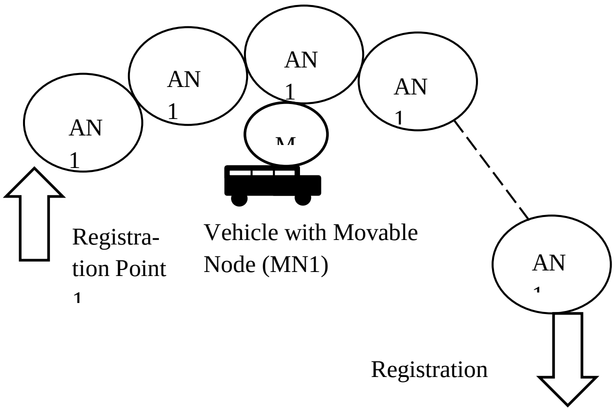


**Fig. 4:** Location Fingerprinting Architecture.

The second aspect is of unilateral algorithm. Unilateral algorithm comes into role post disaster. The detail of unilateral is shown in Fig.5. Let us assume that in post disaster condition the vehicle will trap near AN (near node 3). Now the pursuit node will come into role. Pursuit node will be with the rescue team. Pursuit node (PN1) will get the RF signature from AN (near node 3) of the vehicle that is trapped. Now the PN1 after reaching near AN (node3) will switch to unilateral algorithm. Unilateral algorithm is an improved trilateration algorithm. In trilateration algorithm using three nodes, the trapped node can be located using euclidian distance in between the fixed nodes and localized node. In unilateral algorithm the PN1 at x, y location can move in the direction towards $x'$, $y'$ or towards $x''$, $y''$. Let us assume the distance travelled in both the direction is X mtrs. As the RSSI value (in dBm) in both the positions will be same because the antenna radiation pattern is omnidirectional. But if the PN1 node move towards the direction of $x'''$,$y'''$, the same RSSI value (in dBm) can be achieved. Here Y<X. So the best possible move towards the MN1 is $x'''$,$y'''$. Now the updated location is $x'''$,$y'''$. The same move will be adopted till the PN1 will reach to MN1.

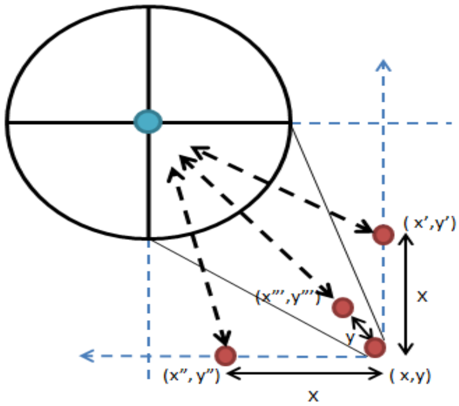


**Fig. 5:** Unilateral Approach Towards MN1 (Movable node).

## 5. Field deployment

The wireless node for post disaster management is deployed at Dunga valley of Dehradun, Uttarakhand, India as shown in Fig. 6. The site has been selected after seen the background of disaster in Dunga valley. The site is seismic zone very prone to earthquake and also the cellular network is not present. The population of the site is more than 1 lakh but distributed in the hilly region. The Dunga valley is in the foot of Mussoorie hills. The travelers are very prone to the area to visit Mussoorie. Even the hikers and bicyclers are very prone in this area. The wireless node for post disaster is deployed in 25 acres of land. The total area contains 8 wireless sensors. Each wireless sensor contains one Xbee RF unit that will transmit RF signal. The AN1 nodes first installed in the site and extensive experiments have been performed to check the reliability of the network.

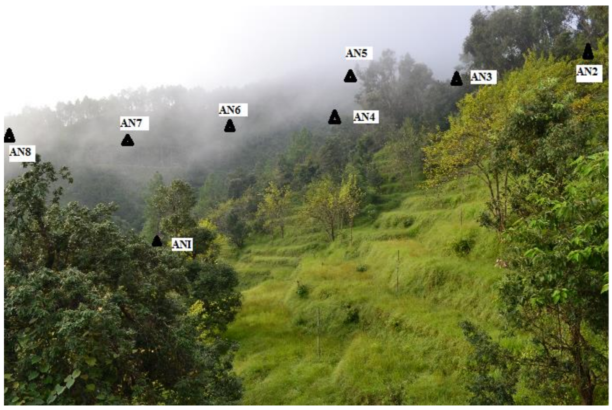


**Fig. 6:** Node Deployment Locations at the Dunga Valley Region, Dehradun, Uttarakhand, India.

### 5.1. Field selection

Before the installment of the wireless network around the seismic zone, an exhaustive investigation was conducted. Some of the sites were studied with reference to their earthquake history like Surkha Ridge, Thal area, eastern Uttarakhand, Pokhri-Gopeshwar region, Bangina region, Chamoli-Pipalkoti region, Dharchula region, Pilang-Bhitwari region, Rameshwari region, Dunga region, Indo-China Border (north-east Uttarakhand). Out of these ten locations

Dunga valley (30.420017, 77.959991) was selected for the deployment of wireless network which is situated in foot hills of Mussoorie. The conditions of all the investigating sites are same with reference to disaster. So if the network to be deployed in Dunga Valley is accepted then same network can be deployed on other sites also. Only the node placement is different for different geographical regions.

All title and author details must be in single-column format and must be centred.

Only the first word in a title must be capital and other word should be in small case. Author details must not show any professional title (e.g. Managing Director), any academic title (e.g. Dr.) or any membership of any professional organization (e.g. Senior Member IEEE).

To avoid confusion, the family name must be written as the last part of each author name (e.g. John A.K. Smith).

Each affiliation must include, at the very least, the name of the company and the name of the country where the author is based (e.g. Causal Productions Pty Ltd, Australia). Email address is compulsory for the corresponding author.

### 5.2. Section deployment of ANI (anchor nodes)

In the total area of 25 acres of hilly region (Dunga Valley), eight wireless nodes are going to be deployed. ANI (Location1), ANI (Location2), ANI (Location3), ANI (Location4), ANI (Location5), ANI (Location6), ANI (Location7), and ANI (Location8). The location1, location2, location3, location4, location5, location6, location7, location8 were identified as ideal location in which all the nodes are connected to MN1 nodes with travelers. And also they are treated as safety zone in disaster prone area after doing survey. The anchor nodes are placed in safety zones 8 mtrs above the ground level so that they have clear connection with all the MN1 nodes travelling through the passage.

- AN1 (Location1): It is a location present in off road. As the traveler after disaster may trapped in the pits away from the main road. AN1 can provide the RF signature to PN1. The node is transmitting the RF signature up-to 2418 mtrs and after connection can have the range of 4836 mtrs along with PN1 node RF signature. The location is covering around location 4, location 6, location 7, and location 8.
- AN1 (Location2): It is a location near the road treated as safety zone.
- AN1 (Location3): It is placed top of the hills in Dunga Valley. Coverage becomes more as compared to the other AN1 nodes.
- AN1 (Location4): It is placed 70mtrs away from the road is not having much coverage. The geographical region in location4 does not need much coverage.
- AN1 (Location5): Location 5 AN1 is more prone to disaster. As in this location we are not able to find the more appropriate safety zone.
- AN1 (Location6): Location 6 AN1 is supporting coverage of location 5 AN1.
- AN1 (Location7): Location 7 AN1 is 50 mtrs away from road covering 2418 mtrs area.
- AN1 (Location8): The geographical conditions are same as the AN1 of location1.

## 6. Validation of the wireless networks

A wireless network has been deployed at the site selected. Some experiments are conducted for location fingerprinting algorithm and some experiments have been conducted for unilateral algorithm. For location fingerprinting AN1 nodes for location1, location2, location3, location4, location5, location6, location7, and location8 were communicating with MN1 nodes. The MN1 nodes are subjected to move from disaster prone area many times and RF signatures were captured. The failure ratio in terms of not capturing the RF signature is very less. Vehicle is subjected to move in different speeds of 20 Km/h, 40 Km/h and 50 km/h. The packet loss at speed more than 45 Km/h is more as compared to speed less than 40 Km/h. As the terrain is hilly so vehicle cannot move more than 50 Km/h. There is loss of one or two packets only at speed more than 45 Km/h. Vehicle is also subjected to handshake between two AN1 say location1 to location2 and to location3 and so on. Results were captured for these situations also. The handshaking was smooth and continuous signal sharing of RF values were captured in location fingerprinting algorithm. The same data in excel format is captured in SD card module and same data is routed to main center node. In Fig.7 RF signature is captured by ANI node location1 while vehicle carrying MN1 node moving towards the AN1. The signal varies from-90dBm to -48dBm. And the same node MN1 when move away from the AN1 node then the signal varies from -40 dBm to -90dBm as shown in Fig.8. Same scenario has been shown in location 2, location 3, and location 4 in Fig.9, Fig.10, and Fig.11 respectively. In Fig.12 handshaking in between location 1 and location2 with AN1 has been shown. The handshaking mode is smooth enough at speed 32km/h. In Fig.13 it has been shown that if speed of the vehicle goes more than 45km/h then packet loss can be observed. The peak in the fig.13 shows the packet loss during retrieving RF signatures. Fig.14, Fig.15 and Fig.16 shows the behavior of AN1 and MN1 node at various speeds. The results show the exceptional behavior of reliability of AN1 and MN1 node.

For unilateral technique various mock drills were conducted in Dunga Valley and with the help of PN1 node MN1 node were tracked. It has been observed that in all cases the MN1 node is trackable.


**Fig. 7:** RF Signature Capturing by AN1 location 1 (Vehicle Carrying MN1 Moves Toward AN1).

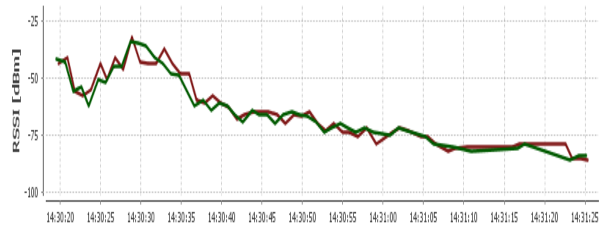


**Fig. 8:** RF Signature Capturing by AN1 Location 1 (Vehicle Carrying MN1 Moves Away from AN1).

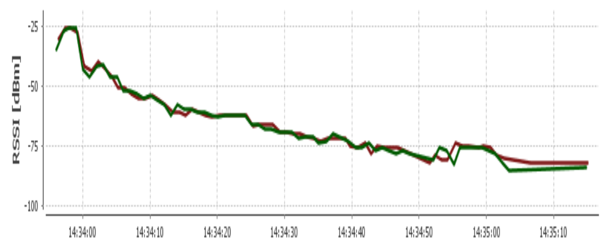


**Fig. 9:** RF Signature Capturing by AN1 Location 2 (Vehicle Carrying MN1 Moves Away from AN1).

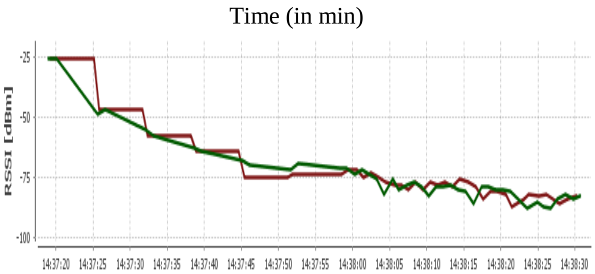


**Fig. 10:** RF Signature Capturing by AN1 Location 3 (Vehicle Carrying MN1 Moves Away from AN1).

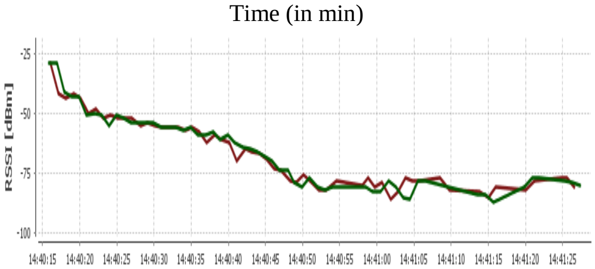


**Fig. 11:** RF Signature Capturing by AN1 Location 4 (Vehicle Carrying MN1 Moves Away from AN1).

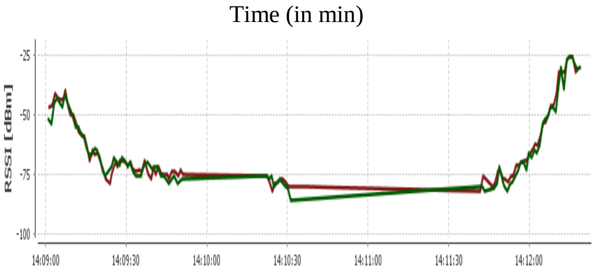


**Fig. 12:** Handshaking of MN1 from AN1 Location 1 to AN1 Location 2.

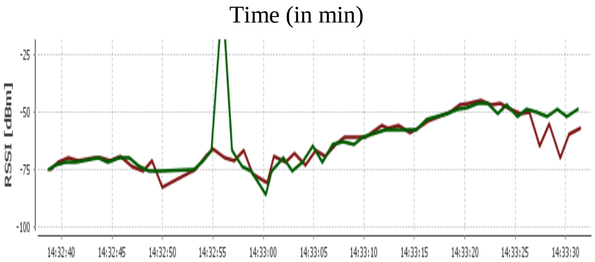


**Fig. 13:** RF Signature Capturing by AN1 Location 6 (Vehicle Speed Is 48 Km/H).

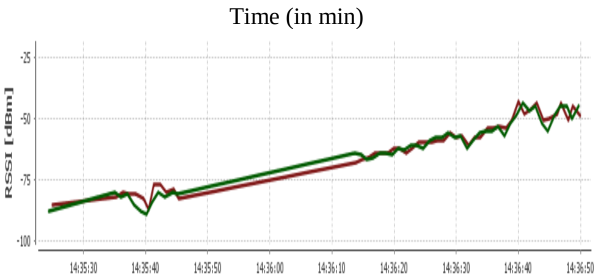


**Fig. 14:** RF Signature Capturing by AN1 Location 8 (Vehicle Speed Is 25 Km/H).

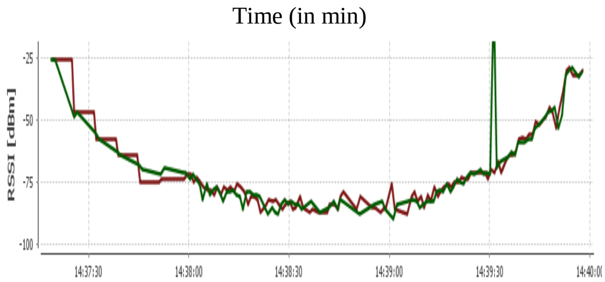


**Fig. 15:** Handshaking of MN1 from AN1 Location 7 to AN1 Location 8 (Vehicle Speed Is 46 Km/H).

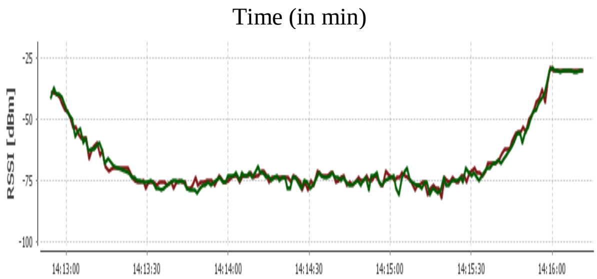


**Fig. 16:** Handshaking of MN1 from AN1 Location 3 to AN1 Location 4 (Vehicle Speed Is 34 Km/H).

## 7. Validation of the wireless networks

Wireless sensor networks are one of the promising technologies for not only real time monitoring of disaster prone areas but also proves to be the suitable technology for managing post disaster conditions. The present study in this paper shows the design, development and deploying of such networks in disaster prone area. The network deployed has a capability of tracking trapped people post disaster. The location fingerprinting and unilateral techniques are the main back bone of the network. The location fingerprinting is capturing the RF signatures of travelers and tracking the people in real time pre disaster situation and if disaster will happen the network switch to unilateral technique to track the trapped people. Extensive experiments were conducted to check the reliability of location fingerprinting technique and mock drills were conducted to check the reliability of unilateral technique. In future we will study how to deploy network in lost cost and large area so that it can cover each and every disaster prone region even the region which is not accessible easily. In future we will also consider energy consumption during the routing of data in WSN.

## 8. Future scope

One essential requirement post disaster is path planning to safest place after localization. Authors of [24] present a novel path planning algorithm for anchor node. Simulation result indicates that their algorithm out performs the algorithm discussed in literature. Path planning can also implemented in cluster based networks viz., inter-cluster path planning and intra-cluster path planning[25]. One more area which needs attention in the future is research on energy consumption of node in post and pre-disaster situations.

## Acknowledgement

The authors would like to express gratitude for the resources provided by research & development department of University of Petroleum & Energy Studies, Dehradun, India. The authors would also like to acknowledge each and every faculty of department of Electronics, Instrumentation & Control Engineering for their motivation and research solutions provided. The author would like to thanks supporting staff of university for the support in deployment of network designed in the Dunga Valley, Dehradun.

This is a text of acknowledgements. Do not forget people who have assisted you on your work. Do not exaggerate with thanks. If your work has been paid by a Grant, mention the Grant name and number here.

## References


[1] Nandy, s., *floods in india–disaster and management.* convenar moksha, member centre for built environment, 2005.

[2] Siqueira, i.g., et al., *coverage area management for wireless sensor networks.* international journal of network management, 2007. 17(1): p. 17-31. https://doi.org/10.1002/nem.604.

[3] Zussman, g. and a. segall, *energy efficient routing in ad hoc disaster recovery networks.* ad hoc networks, 2003. 1(4): p. 405-421. https://doi.org/10.1016/S1570-8705(03)00041-6.

[4] Mazomenos, e., j. reeve, and n. white, *an accurate range-only tracking system using wireless sensor networks.* procedia chemistry, 2009. 1(1): p. 1199-1202. https://doi.org/10.1016/j.proche.2009.07.299.

[5] Cheng, g., *accurate toa-based uwb localization system in coal mine based on wsn.* physics procedia, 2012. 24: p. 534-540. https://doi.org/10.1016/j.phpro.2012.02.078.

[6] Meng, w., l. xie, and w. xiao, *decentralized tdoa sensor pairing in multihop wireless sensor networks.* signal processing letters, ieee, 2013. 20(2): p. 181-184. https://doi.org/10.1109/LSP.2013.2237823.

[7] Dakkak, m., et al., *indoor localization method based on rtt and aoa using coordinates clustering.* computer networks, 2011. 55(8): p. 1794-1803. https://doi.org/10.1016/j.comnet.2011.01.010.

[8] Jin, r., et al., *an rssi-based localization algorithm for outliers suppression in wireless sensor networks.* wireless networks, 2015: p. 1-9.

[9] Aiello, m., r. de jong, and j. de nes. *bluetooth broadcasting: how far can we go? an experimental study*. in *pervasive computing (jcpc), 2009 joint conferences on*. 2009. ieee.

[10] Gharghan, s.k., et al., *accurate wireless sensor localization technique based on hybrid pso-ann algorithm for indoor and outdoor track cycling.* ieee sensors journal, 2016. 16(2): p. 529-541. https://doi.org/10.1109/JSEN.2015.2483745.

[11] Mao, g., b. fidan, and b.d. anderson, *wireless sensor network localization techniques.* computer networks, 2007. 51(10): p. 2529-2553. https://doi.org/10.1016/j.comnet.2006.11.018.

[12] Vivek kaundal, p.s., devender saini, manish prateek, *location fingerprinting supported unilateral algorithm based on experimental study of localization in disaster prone area* international journal of computer science and information security, 2016. 14: p. 162-175.

[13] Berke, p.r., j. kartez, and d. wenger, *recovery after disaster: achieving sustainable development, mitigation and equity.* disasters, 1993. 17(2): p. 93-109. https://doi.org/10.1111/j.1467-7717.1993.tb01137.x.

[14] O'brien, g., et al., *climate change and disaster management.* disasters, 2006. 30(1): p. 64-80. https://doi.org/10.1111/j.1467-9523.2006.00307.x.

[15] Bai, y., et al. *emergency communication system by heterogeneous wireless networking*. in *wireless communications, networking and information security (wcnis), 2010 ieee international conference on*. 2010. ieee.

[16] Erdelj, m. and e. natalizio. *uav-assisted disaster management: applications and open issues*. in *computing, networking and communications (icnc), 2016 international conference on*. 2016. ieee.

[17] Ray, n.k. and a.k. turuk, *a framework for post-disaster communication using wireless ad hoc networks.* integration, the vlsi journal, 2016.

[18] Minh, q.t., et al., *on-the-fly establishment of multihop wireless access networks for disaster recovery.* ieee communications magazine, 2014. 52(10): p. 60-66. https://doi.org/10.1109/MCOM.2014.6917403.

[19] Minh, q.t., et al., *on-site configuration of disaster recovery access networks made easy.* ad hoc networks, 2016. 40: p. 46-60. https://doi.org/10.1016/j.adhoc.2015.12.008.

[20] Briante, o., et al., *comvivor: an evolutionary communication framework based on survivors' devices reuse.* wireless personal communications, 2015. 85(4): p. 2021-2040. https://doi.org/10.1007/s11277-015-2888-y.

[21] Fujiwara, t. and t. watanabe, *an ad hoc networking scheme in hybrid networks for emergency communications.* ad hoc networks, 2005. 3(5): p. 607-620. https://doi.org/10.1016/j.adhoc.2004.08.007.

[22] Chipara, o., et al. *wiisard: a measurement study of network properties and protocol reliability during an emergency response*. in *proceedings of the 10th international conference on mobile systems, applications, and services*. 2012. acm.

[23] Specification, z., *zigbee alliance.* zigbee document 053474r06, version, 2006. 1.

[24] Han, g., et al., *a disaster management-oriented path planning for mobile anchor node-based localization in wireless sensor networks.* ieee transactions on emerging topics in computing, 2017.

[25] Han, g., et al., *mobile anchor nodes path planning algorithms using network-density-based clustering in wireless sensor networks.* journal of network and computer applications, 2017. 85: p. 64-75. https://doi.org/10.1016/j.jnca.2016.12.016.