Energy Efficient Investigation of Oceanic Environment using Large-scale UWSN and UANETs

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***Abstract*—Investigating coastal oceanic environment is of great interest in pollution monitoring, tactical surveillance applications, exploration of natural undersea resources and predicting wave tides. Deployment of underwater sensor networks for real time investigation is the major challenge. Acoustic communication intends to be an open solution for continuous wireless sensor network in underwater scenarios. In this paper large-scale underwater Sensor Networks (UWSN) and Underwater Ad-hoc Networks (UANETs) using Solar-Powered Autonomous Underwater Vehicles (SAUV) to explore the oceanic environment is proposed. A kong wobbler carrying base station with acoustic communication devices is considered, which locates the pre-deployed underwater sensor modules through acoustic communication. The sensor modules are installed with various sensors and video capturing devices to study the underwater resources as well as for surveillance needs for predicting the environmental conditions. The simulation results are encouraging as this approach is extremely helpful in surveillance as the intruders are tracked and real-time video streaming is done.**

Keywords: *Underwater Ad-hoc Networks (UANET's), Underwater Sensor Networks (UWSN), Solar-Powered Autonomous Underwater Vehicles (SAUV), Acoustic Communication, Underwater Acoustic Sensor Networks (UW-ASN), Geographic Adaptive Fidelity (GAF) Protocol, Kong Wobbler.*

I. Introduction

Underwater environment investigation is vital in predicting wave tides, pollution monitoring, oceanic data collection, tactical surveillance applications, disaster prevention and exploring natural resources. The largely unexplored vastness of the ocean, covering about 79% surface of the earth, has fascinated human race for a very long time. The traditional approach for ocean-bottom or ocean column monitoring is to deploy underwater sensors that record data during the monitoring mission, and then recover the instruments finds disadvantages:

- Real time monitoring is critical especially in surveillance or in environmental monitoring applications such as seismic monitoring wherein the recorded data cannot be accessed until the instruments are recovered, which may happen several months after the beginning of the monitoring program.
- No interaction is possible between onshore control systems and the monitoring instruments which impedes adaptive tuning of the instruments nor it is possible to reconfigure the system.
- In case of failures, it is not possible to detect them before the instruments are recovered which leads to the complete failure of a monitoring mission.
- The amount of information that can be recorded during the monitoring mission by every sensor is limited by the capacity of the onboard storage devices in the instrument.[1]

To assess the aqueous environment, its role and function call for the need of large-scale, long term and distributed information collection networks for periodic oceanic monitoring. The large scale aquatic applications demand us to build large-scale underwater Sensor Networks (UWSN) and Underwater

Ad-hoc Networks (UANETs) to explore the inhibited oceans. A large number of sensor nodes are used for long-term exploration of oceanic environment and gathering scientific data in collaborative monitoring missions. Energy efficient routing protocols are the most important criteria for the design of underwater sensor networks since the sensor nodes will be powered by batteries with limited power capacity. Power failure of a sensor node not only affects the node itself but also its ability to forward data packets to the other nodes. It is seen that in simple acoustic propagation models that multi-hop routing saves energy in underwater networks with respect to single hop communications, especially with distances of the order of some kilometers. In the proposed work Underwater Acoustic Sensor Networks (UW-ASN) consisting of variable number of sensors that are deployed to perform collaborative monitoring tasks over a given area which is implemented adopting GAF (Graphical Adaptive Fidelity) protocol which proves to be an energy efficient routing protocol as the transmitting power is altered according to the distance of the neighboring nodes.

II. Kong Wobbler

A wireless access point with kong wobbler structure is made to float on the surface of sea around the area of investigation to which the structure of the base station is fixed on the top. The weight of the base station is less than the wobbler base structure, maintaining a ratio of 1:4 to prevent the whole structure from toppling. Kong wobbler is made up of non toxic FDA approved polypropylene chosen for its overall strength, impact absorption, sound deadening and non toxicity on the surface of sea made up of high strength polymer and is PBA and phthalate free. Vacuum is maintained inside the structure that allows it to float and uses play grade sand for its weight. The sand remains in a compartment that has been permanently sealed using ultrasonic technology. The kong wobbler is made to float on the surface of sea and anchored to the sea bed through cables to keep in position such that due to its unique structure it floats vertically. They are hand-launched over the side of a ship or air dropped in the area of investigation. The column of fluid has greater pressure at the bottom of the column of ocean than at the top. This difference in pressure results in a net force that tends to accelerate the kong wobbler structure upwards. The magnitude of that force is equal to the difference in the pressure between the top and the bottom of the column, and is also equivalent to the weight of the fluid that would otherwise occupy the column. For this reason, if the density of the structure is greater than that of the fluid in which it is submerged, tends to sink. The buoyancy of the kong wobbler exceeds its weight and tends to rise. Density is maintained lesser than the liquid and shaped appropriately so that force can keep the whole structure afloat. The floating kong wobbler tends to restore itself to an equilibrium position after a small displacement. It has vertical stability, in case it is pushed down slightly, which will create a greater buoyancy force and unbalanced by the weight force, will push the object back up. Rotational stability is of great importance as given a small angular displacement, the structure returns to its original position, (stable).

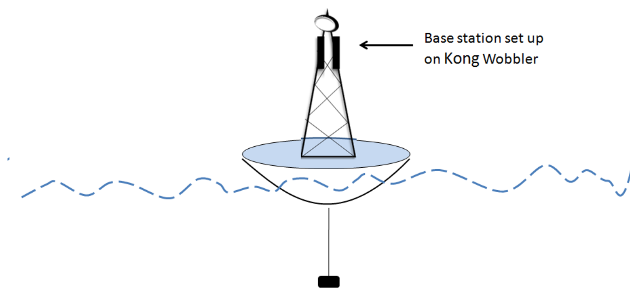

Fig. 1. Kong Wobbler structure

III. Solar-Powered Autonomous Underwater Vehicles (SAUV)

The SAUV is a solar powered AUV designed for long endurance missions that require monitoring, surveillance, or station keeping, with real time bi-directional communications to shore.

- The SAUV is a solar-powered autonomous vehicle which is equipped with rechargeable lithium ion batteries to allow maximum mission endurance even under conditions where minimal solar radiation is available.
- Operate autonomously at sea for extended periods of time from weeks to months. Typical missions require operation at night and solar energy charging of batteries during daytime.
- In case of failure of Kong Wobbler Sauv's Communicate with a remote operator on a daily basis via Satellite phone, RF radio, or acoustic telemetry.
- Operate at speed up to about 3 knots when needed and cruise at speed of about 1 knot.
- Battery system is to provide a total capacity of about 1500 whrs.
- Capability to acquire GPS updates when on the ocean surface and compute SAUV position at all times using GPS when on surface.
- Capability to maintain fixed depth and fixed altitude and to smoothly vary depth or altitude profile.
- Capability to log and upload all sensor data correlated in time and SAUV geodetic position.
- Provide sufficient volume, power, interfaces, and software hooks for future payload sensors.
- Allow user to program missions easily using a Laptop PC and provide for graphical display of mission.[13]

IV. Acoustic Communication

Wireless underwater communication is challenging task with the growing need for underwater surveillance and

Fig. 2. SAUV

develop persistent long-term ocean observation has led to many underwater wireless technologies. Present underwater communication involves transmission of data in the form of optical waves, electromagnetic or sound waves. Optical waves involved in underwater communication are generally limited to very short ranges because of the strong backscatter from the suspended particles in the ocean, severe absorption by water at optical frequencies and high level of ambient light in the upper part of the water column. Even the clearest water has 1000 times the attenuation of clear air and turbid water has more than 100 times the attenuation of densest fog. Acoustic communication is the most versatile and widely used technique in underwater wireless communication which has low attenuation of sound in water used as the primary carrier for underwater wireless communication systems that holds well in thermally stable and deep water settings.[2]

A. AD-HOC Networks

A wireless ad hoc network is a system of self-directed nodes which form a decentralized communications network. Wireless communication allows for a dynamic network topology where new nodes can be rapidly deployed and likewise rapidly removed. Nodes act as both host and router, performing tasks and forwarding information to each other. Mobile nodes can form dynamic networks where they are linked with their nearest neighboring node and when they move too far from their neighboring nodes might lose connection but come into contact with other nodes to begin interacting and changing the network topology. Efficient routing protocols is needed to communicate new data over multi-hop paths consisting of possibly several links to cope with noise and interference as well as sharing limited bandwidth. A class of Ad hoc networks, Underwater Ad-hoc Networks (UANET) are used in underwater explorations.

1) UWSN and UANETs: Large scale Underwater Ad-hoc Networks (UANET) and Underwater Sensor Networks (UWSN) are essential to explore large uninhibited oceans. In the characteristics of these new networks, the propagation delay, floating node mobility, and limited acoustic link capacity are hugely different from ground based mobile ad-hoc networks (MANET) and wireless sensor networks (WSN). UANET and UWSN rely on low-frequency acoustic communications because RF radio does not propagate well due to underwater energy absorption. Unlike wireless links amongst land-based ad hoc nodes, each underwater acoustic link features large-latency and low bandwidth. Most ground sensor nodes in a WSN are typically stationary and large portion of UWSN sensor nodes, except some fixed nodes mounted on the sea floor are with low or medium mobility (3-5 knots) due to environmental water current. The large-scale aquatic applications demand to build large-scale Underwater Ad-hoc Networks (UANET) and Underwater Sensor Networks (UWSN) to explore the large uninhabited oceans. The difference between UANET and UWSN is due to controlled mobility and associated implementation cost. In a UANET, mobile nodes can be implemented by Solar-Powered Autonomous Underwater Vehicles (SAUV) and Autonomous Underwater Vehicles (AUV) or Remotely Operated Vehicles (ROV), which are high cost robots that can move under the water by following pre-programmed or autonomous motion patterns. On the other hand, UWSN only incurs a fraction of implementation cost of UANET at the same network scale. All sensor nodes in a UWSN are of low-cost.[3]

The advantages of the new UANET and UWSN paradigm are:

- Localized and coordinated sensing and attacking is far more precise than the existing remote telemetry technology, eg, those relying on directional frequency and ranging (DIFAR) sonobuoy or magnetic anomaly detection (MAD) equipment.
- Scalability of UWSN ensures that a large area can be covered for time-critical applications.
- Casualty ratio is expected to be zero if unmanned UANET and UWSN platforms are used.
- Implementing reusable underwater nodes reduces the deployment and maintenance cost. Each underwater sensor unit can be bundled with an electronically controlled air bladder device. Once the network mission is accomplished, the command center issues commands to trigger all air-bladder devices and all sensor units float to surface to be recollected for next mission.[1]

V. GAF PROTOCOL

In underwater applications, it is vital to let every underwater node know its current position and the synchronized time with respect to other coordinating nodes. GAF protocol uses Global Positioning System (GPS) to get the node location.As Global Positioning System (GPS) is unavailable under the water surface as the high-frequency radio waves used by Global Positioning System (GPS) is quickly absorbed by water, hence cannot propagate deeply under the water surface. Therefore underwater networks rely on Doppler Instrumentation or distributed GPS-free localization and time synchronization schemes to let the sensor nodes know their positions and the network clock value. In other words, before the network can use geo-routing schemes, it needs a multi-hop packet delivery service, which must be GPS-free. Geographic adaptive fidelity protocol is an energy effective position based routing protocol. Position based protocols are also referred to as geographic routing protocols as the sensor nodes are addressed by means of their locations instead of the information that they carry. Location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. In GAF protocol, each node uses location information to associate itself with a virtual grid so that the entire area is divided into several square grids, and the node with the highest residual energy within each grid becomes the master of the grid. Only a single node from a cell of a given virtual grid is chosen to be active at any given time. Nodes will select one sensor node to stay awake for a certain period of time which is responsible for monitoring and reporting data to the sink on behalf of the other nodes in the zone is known as the master node. Other nodes in the same grid can be regarded as redundant with respect to forwarding packets, and thus they can be safely put to sleep without sacrificing the routing fidelity.

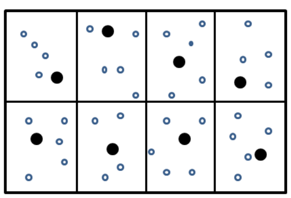

Fig. 3.

VI. System Architecture

The general architecture of underwater sensor network is reviewed before describing the specific applications. The rough capabilities of a sensor node are estimated on its interaction with the environment, other underwater nodes, and applications. At the lowest layer is the large number of sensor nodes to be deployed on the sea floor which has computing power, and storage capacity. They collect information through their sensors and communicate with other nodes through short-range acoustic communication. In large networks, there exists a type of nodes, called supernodes, having access to higher speed networks and can relay data to the base station very effectively with rich network connectivity creating multiple data collection points. Battery power and the ability to carefully monitor energy consumption are essential for the sensor node. All components of the system operate at as low a duty cycle as possible which is enabled by examining each layer of system software to minimize energy consumption and in addition nodes entirely shut off for very long periods of time, up to hours or days when not in use. In a harsh, underwater environment, some nodes will be lost over long deployments due to fishing trawlers and underwater life affecting cables or node which needs redundancy in communication and sensing as loss of a node will not have wider effects. In addition, multiple failures can be recovered, either with mobile nodes, or with human deployment of replacements.[4]

A. *Sensors*

All nodes are integrated with temperature, vibration, pressure, viscosity, turbidity, seismic, proximity, chemical & gas, fluid flow, speed, water level, altitude and visibility sensors to measure the different parameters in the marine environment which are small, robust, inexpensive, low power consuming yet efficient.

- Temperature sensors: Temperature measurements in marine applications make high demands on sensor reliability. They may be subject to changes during their lifetime. A periodic calibration of temperature sensors is required to make sure that they display a correct value of temperature.
- Turbidity sensor: Turbidity is measured in terms of the amount of scattering and absorption of light rays by small particulate matter suspended. It is an ecologically important factor because a high value of turbidity means a high amount of suspended particles which can affect the aquatic life. Thus this sensor works by the illuminating the medium by infrared light emitted by two LEDs to a common centre and received by a symmetrically placed photodiode of the required wavelength. The amount of backscattered light is the measure of the turbidity of the medium measured in NTU (Nephelometric Turbidity Unit).
- Seismic sensors: Seismic sensors detect the vibrations or sounds. A standard piezo sensor is used to detect vibrations/sounds due to pressure changes. They are very sensitive and can detect vibrations caused by any movement. So it can be used to monitor area of investigation.
- Pressure sensors: Pressure sensors are used for permanent immersion in freshwater and sea-water to measure the level of rivers, seas and tidal waters.

Real-time readings are taken from all the sensors, when the readings cross the threshold values necessary actions are taken.

VII. Implementation

Initially the UWSNs and UANETs are deployed in the ocean. Sensor nodes with limited battery power are deployed to record the environmental changes underwater. The recorded data is transferred to the surface of the earth through the nearest access point, the base station fixed to the specially designed kong wobbler floating on the surface of the water by the multi-hop network of sensor nodes which results in energy savings and increased network capacity. The base stations

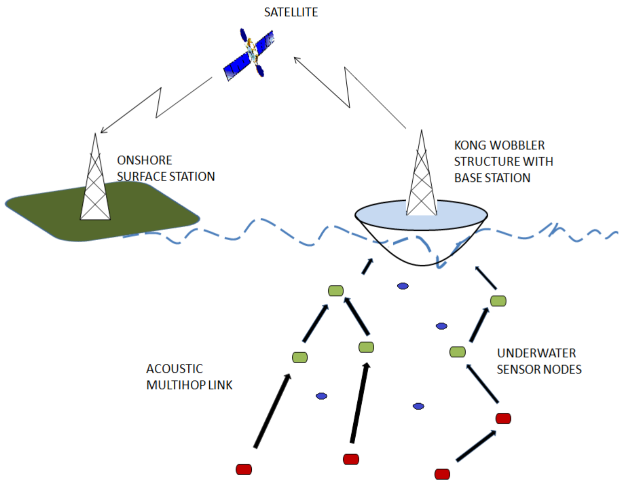

Fig. 4. Logical diagram of System Architecture.

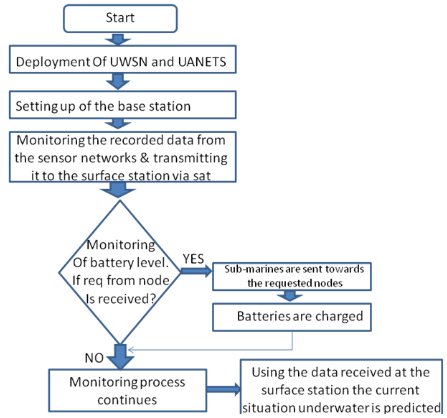

Fig. 5. Flow Chart of the system

monitor the entire sensor nodes within the network and receive as well as stores the recorded sensor data within its area of range. These data are further relayed to an onshore surface station via satellite transceiver. Acoustic communication proves to be efficient in data transfer underwater from the sensor nodes to the base station. During the process, the base station monitors the battery power level of all the nodes. Upon receiving the request from the nodes to recharge its batteries, the base station then guides the submarines towards the requested nodes which is continued with all the sensor modules deployed underwater. The sub-marines would in turn charge themselves at the base stations, which are installed with the solar panels. The power required by the base station for the reception of the data from the sensor modules and transmission is supplied by the solar panels. Once the surface station has finished collecting data from each sensor module the processing and analysis of data is performed to get the real time study of the underwater scenario. As the nodes have limited battery power, it is essential to implement an energy efficient routing protocol that conserves power during transmission and reception of data. Power failure of a node not only affects the node itself but also its ability to forward packets on behalf of other nodes and thus the overall network lifetime. GAF is an energy efficient routing protocol as the transmitting power is altered according to the distance of the neighboring nodes. The flow chart explains the process undertaken in the investigation of underwater environment.

The investigation of the underwater resources is thus collected at real time. Compilation of all the recorded sensor data is done in the surface station which acts as the command center and thus predicting the current scenario of the environment underwater.

VIII. Simulation and Results

Continuous network development and higher functionality requirements have created the need for tools that could monitor network transmissions and analyze them. Network Simulator (NS) for communication networks works under UNIX and Windows system platforms and is mainly used for network research. The simulation is performed using NS2 (version 2.34) running on LINUX platform (ubuntu 11.04). The graphical representation of this simulation is shown with Network Animator(nam-1.14). 20 nodes are considered for each kong wobbler base station on the surface of ocean bed. The kong wobbler carrying base station act as the center that monitors the entire sensor node within the network and receives as well as stores the recorded sensor data. UANETs along with kong wobbler structure is hand dropped by the side of the ship. Kong wobbler structure starts to float on the surface of the ocean and the UANETs start moving randomly. The black fixed nodes are anchored to the ocean bed at specific co-ordinates, Fig:6. Some of the nodes in UANET are mobile which are implemented by Solar-Powered Autonomous Underwater Vehicles (SAUV) and Autonomous Underwater Vehicles (AUV) or Remotely Operated Vehicles (ROV), which are high cost robots that move under the water by following pre-programmed or autonomous motion patterns. And remaining nodes in UWSN are stationary, mounted on the sea floor are with low or medium mobility (3-5 knots) due to environmental water current. The trace file and nam file results provided by the ns2 gives enormous amount of information. It specifies position of the node, number of nodes within the network of access point and also visualizes in detail about the packet transmission among the nodes and the kong wobbler carrying base station is simulated. The red nodes represent nodes in UANET on the ocean bed which are moving around collecting data. The black nodes are fixed nodes anchored to oceanic bed. The blue node indicate the Kong wobbler structure with base station which covers the area under investigation.

UANETs continue their random motion gathering data. Both stationary UWSNs and mobile UANETs collect information and relay it to base station which is carried by kong wobbler structure, Figs:7,8,9,10,11,12.

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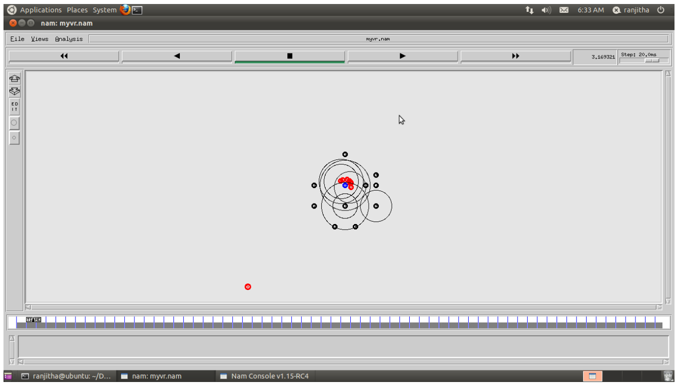

Fig. 6. Simulation in ns2

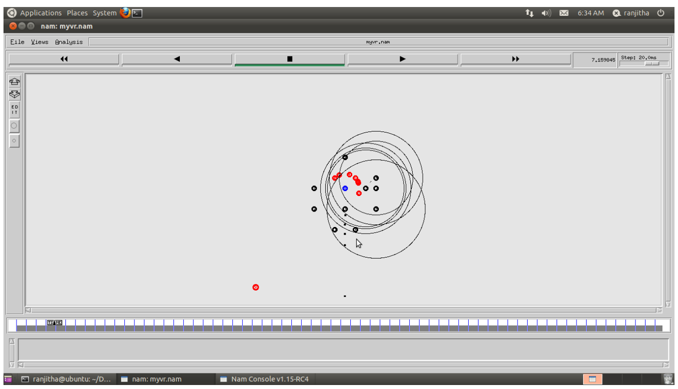

Fig. 7. Simulation in ns2

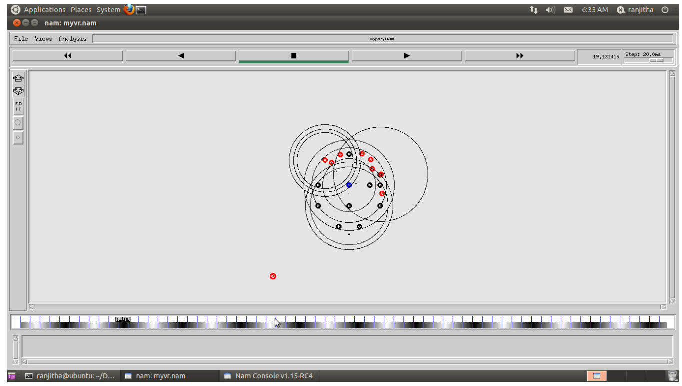

Fig. 8. Simulation in ns2

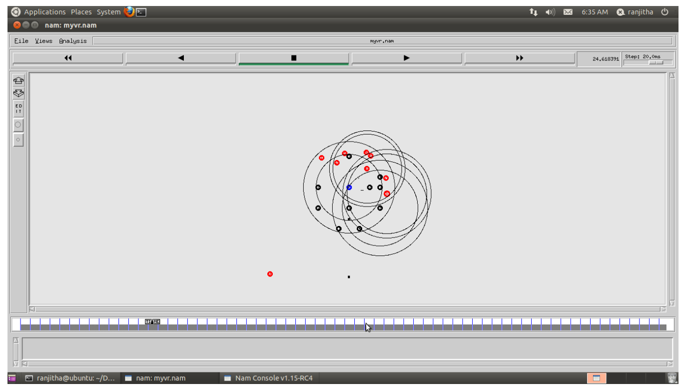

Fig. 9. Simulation in ns2

IX. Conclusion

This paper has summarized our ongoing research in underwater sensor networks, including applications and research challenges. It is explained that traditional approach to deploy underwater sensors that record data during the monitoring mission, then recovering the instruments is not a feasible and the need of large-scale long-term and distributed information collection networks for periodic oceanic monitoring is essential. GAF (Graphical Adaptive Fidelity) protocol was adopted as it proves to be an energy efficient routing protocol. it is also explained that acoustic communication is the most versatile technique in underwater wireless communication. The applications of large scale Underwater Ad-hoc Networks (UANET) using Solar-Powered Autonomous Underwater Vehicles (SAUV) and Underwater Sensor Networks (UWSN) and their reliability in implementing a localized, precise, and large-scale networking efficiently than any existing small-scale Underwater Acoustic Network (UAN) is described. The main objective of the paper is to develop advanced communication techniques for efficient real time investigation of large uninhibited oceans. Development of underwater communication and networking for enhanced oceanic monitoring is also essential for pollution monitoring, tactical surveillance, exploration of natural undersea resources, predicting wave tides and various applications.

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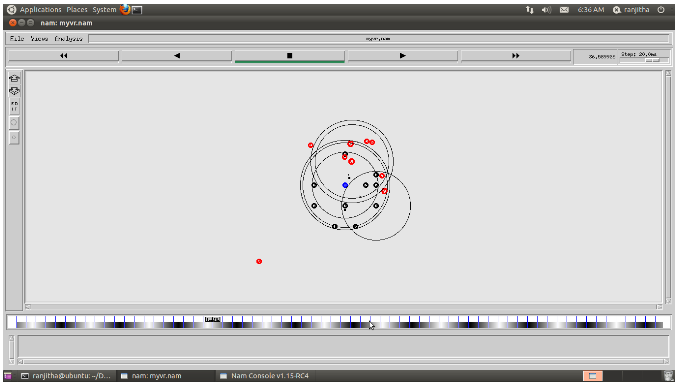

Fig. 10. Simulation in ns2

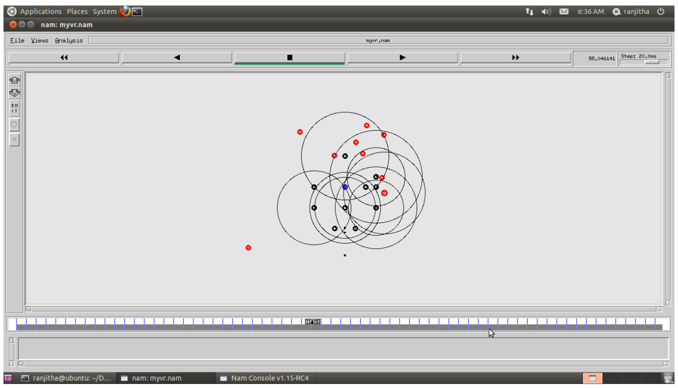

Fig. 11. Simulation in ns2

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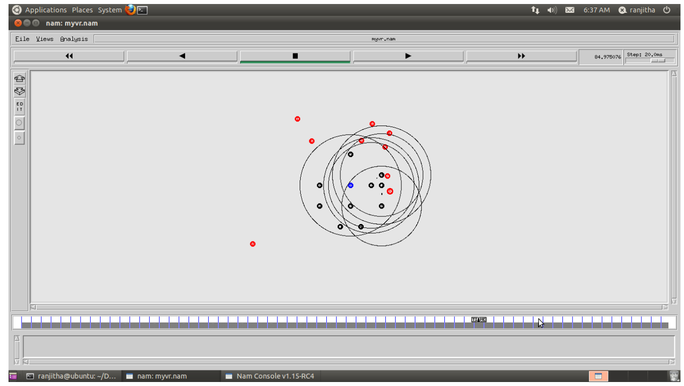

Fig. 12. Simulation in ns2

Biography

Swarnalatha Srinivas, born in Bangalore on 22nd October, 1964. Obtained Bachelors Degree in Electrical Engineering from University Visvesvaraya College of Engg., Bangalore, Karnataka, India in 1988. Obtained Masters degree in Power Systems, University Visvesvaraya College of Engg., Bangalore, Karnataka, India in 1992.
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