# Performance Assessment of an Extremely Challenged Mobile Infrastructure Network over the Oceans

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## ABSTRACT

A novel cost-effective network architecture for providing Internet connectivity to marine fishermen has been successfully prototyped by our research center. A pilot deployment is in progress in a coastal Indian village. This will improve the quality of life of the financially constrained marine fishermen who spend 5-7 days offshore on average for a single fishing trip; it will also help in their safety and security. The architecture employs multiple long range Wi-Fi (LR Wi-Fi) based infrastructure networks stitched together as backhaul. The access network consists of Ethernet and Wi-Fi mesh. The fishermen connect to the on board Wi-Fi access point cum router using their smart phones and are able to use all the apps and services on their smart phone. While the primary infrastructure network uses onshore base stations, the secondary infrastructure networks use boats as mobile base stations. Three field trials were conducted over the ocean using one onshore base station and two mid-sized boats known as trawlers. The performance of both primary and secondary infrastructure networks was assessed during these field trials. This paper describes the impressive results obtained in assessing the performance of the secondary infrastructure network.

## CCS Concepts

•**Networks** → Network experimentation; Network measurement; *Network performance analysis;*

## Keywords

Adaptive Long range Wi-Fi Network; Opportunistic Mobile Infrastructure Network; Point to Multi-Point Network; Smart phone, Marine Internet



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## 1. INTRODUCTION

Marine fishing has been the traditional occupation of fishing communities living along the coasts in many countries of the world for several centuries. India is one such country with a coastline stretching over more than 5000 miles with thousands of fishing villages dotting the coastline [1] [2]. The fishing community consists of boat owners and fishermen who are employed by the boat owners. Some people go fishing in their own boats playing both the roles. Such people tend to own the smaller boats and their fishing trips typically last for a day or two going not too far from the shore (15-20 km). The mid-sized boats known as trawlers have the capacity to store much more fish in onboard cold storage. Up to 10 fishermen go out on a trawler for fishing trips lasting 5-7 days on average. They use special nets and techniques depending on the type of fish they are targeting and could go as far as 120 km away from the shore in search of fish. The fishermen tend to be economically underprivileged especially in developing countries. Currently, they don't have a cost-effective way to communicate with the shore while on a fishing trip. Satellite communication is expensive and not affordable for their income levels. The trawlers are fitted with walkie-talkies for boat to boat communication; however, their range is short and they are not reliable under adverse weather conditions.

Two years ago, our researchers interviewed nearly a hundred of these fishermen in two villages to gain in-depth understanding of the problems faced by them, of the type of equipment that is currently owned by them and of their requirements and skill levels. The interviews revealed that about 67% of fishermen owned smart phones. This number is on the rise with the falling prices and growing popularity of smart phones. Prolonged isolation from their families was felt as a real problem by the fishermen with no viable solution in sight. Most importantly collision with a ship at night was cited as the biggest potential hazard by the fishermen [3]. The fishermen were tech-savvy in general and were willing to try out new solutions, if presented. The interviews also brought out a clear understanding of their fishing behavior. They tend to form clusters of boats in the fishing zones once the zones are located using a combination of their intuition and technology. The trawlers are fitted with echo sounders for under-sea viewing.

Having understood the needs and the behavioral traits of fishermen, our researchers set out to find a suitable solution that would fit their profile. The goal was to use an access network that would enable the use of smart phones already owned by the fishermen and build a backhaul network using the cheapest option available. This approach would ensure that both the capital expenses and the operating expenses are kept low. Several technology options for backhaul such as 2G/3G, LTE, CR, WiMAX and Wi-Fi were evaluated and long range Wi-Fi (LR Wi-Fi) was chosen as the technology of choice for backhaul [4]. The inference was based on a comparative evaluation of several parameters such as (capital and operating) cost, range, availability, data rates, etc. The price of Wi-Fi equipment has been declining especially with the introduction of the next generation 802.11ac technology. Several vendors in the market supplying LR Wi-Fi gear and standard access points (AP) make the technology easily available. The fact that the technology uses unlicensed spectrum helps to keep the costs lower.

A novel and unique network architecture for the backhaul network is employed to serve the complex needs of providing connectivity to hundreds of boats as far away as 120 km from the shore in an extremely dynamic and mobile environment. The architecture employs multiple long-range Wi-Fi (LR Wi-Fi) based infrastructure networks stitched together opportunistically as backhaul. The access network consists of Ethernet and Wi-Fi mesh.

The fishermen connect to the on board Wi-Fi access point cum router using their smart phones and are able to use all the apps and services on their smart phone. While the primary infrastructure network has an onshore base station with Internet uplink, the secondary infrastructure networks use boats as mobile base stations. The architecture of the system, named OceanNet, is described in section 2.

Prior work using LR Wi-Fi [5] [6] was done using a mesh network with multiple point-to-point links primarily on land. Our architecture uses point-to-multi-point links as in an infrastructure network. Therefore, while some of the problems that were tackled in these projects such as interference are not so relevant to us, our architecture presents its own challenges due to the complexities of the problem domain such as extreme mobility, instability of the sea surface, very long range, etc.

Triton is a project that attempts to provide high speed and low cost maritime communication [7]. It uses 802.16 wireless mesh nodes equipped with directional antenna arrays. Two hop measurements were done at 5.8 GHz. The range obtained over the first hop (first boat to onshore base station) was 1.3 km and over the second hop (second boat to first boat) was 1 km.

Marcom proposed a Wireless Coastal Area Network (WiCAN) architecture using sub-GHz WiMAX for backhaul and Mobile Multi-hop Relay (MMR) and wireless mesh for range extension [8]. However WiMAX has been superseded by LTE-Advanced technology.

Bluecomplus aims to come up with a proof of concept for a communication solution enabling cost effective broadband internet access at remote ocean areas [9]. The proposed solution is based on standard Wi-Fi access. Several intermediate helikites and ocean platforms are used as relay nodes from the onshore base station into the ocean.

Satellite communication is used only by luxury cruisers and yachts. There are companies like Speedcast [10] and Axxess Marine [11] which offer unlimited internet usage for superyachts. This solution is expensive and therefore not affordable for the fishermen.

In order to validate the assumptions made in the design of our architecture, three field trials were conducted over the Arabian Sea from a coastal village in the state of Kerala in south west India. Both the primary and secondary infrastructure networks were evaluated. The results of the evaluation of primary infrastructure network have been published already [12] [13]. The secondary infrastructure network was evaluated extensively during the third field trial. Section 3 on the validation of the proposed architecture describes the results of the evaluation of secondary infrastructure network in detail. The concluding remarks and future action plan are presented in section 4 .

## 2. OCEANNET ARCHITECTURE

As mentioned before, OceanNet's backhaul network is formed by opportunistic stitching together of multiple LR Wi-Fi infrastructure networks. Figure 1 depicts the OceanNet architecture Each of these infrastructure networks is a point-to-multi-point (P2MP) network wherein multiple client stations connect to a base station. The primary P2MP network has its base station on the shore at a height of 50-60 m from the ground. The onshore base station is connected to the Internet. The client stations, aka Customer Premises Equipment (CPE), are mounted on a pole on the boat at a height of about 8-10 m from the water level. The CPE on the boat is also capable of acting as a base station and can change its role dynamically depending on the location of the boat and the traffic characteristics of the network. For this reason, we refer to it as Adaptive Backhaul Equipment (ABE). The ABE, acting as a mobile base station, can form a secondary P2MP network.

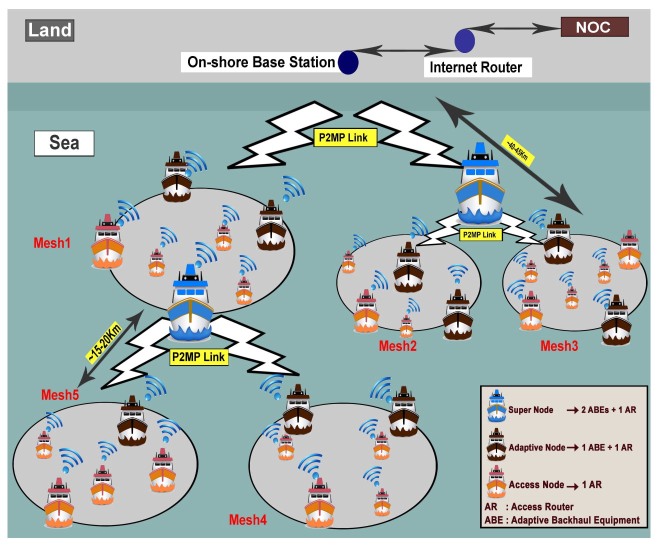


**Figure 1: OceanNet Architecture**

The ABE is connected over Ethernet to a standard Wi-Fi access point (AP) cum router collocated on the boat. We refer to it as Access Router (AR). Fishermen's smart phones, tablets, etc., connect to the AR using their Wi-Fi radio. This enables the end user devices to get internet access and thereby the fishermen can use all the apps and services that they have installed on their smart phones or tablets during their fishing trips.

Boat clusters get formed organically in the fishing zones, sometimes helped by the word spreading within the buddy network of fishermen over walkie-talkies once a fishing zone is detected. Such clusters could be heterogeneous consisting of small boats and mid-sized boats (trawlers). In some cases, a trawler transports one or two small boats to and from the fishing zone along with it. Two small boats can be attached to the sides of a trawler. The small boats will typically have only an AR on board. The trawlers will typically have an AR and one or two ABEs on board.

The ARs within a cluster can form a wireless mesh network for access. This way, the AR on a small boat (or a trawler) can connect to the backhaul network through an ABE on a neighboring trawler. Depending on the traffic needs of the network and the relative positions of the boats, a subset of ABEs within a cluster will act as gateways to the backhaul network. Another subset of ABEs will act as mobile base stations. Some may be turned off or switched to power saver mode, wherein only the receiver may be turned on. A controller running on an AR within the cluster will provide traffic engineering services determining the optimal role of each ABE within a cluster periodically. It will also determine the optimal gateway for each AR in the cluster periodically and notify the ARs of any changes.

The SDN paradigm of separating the control plane from the forwarding plane is applied and the control plane functionality is encapsulated within the controller. The controller is stateless and therefore can relocate itself to a different AR fairly quickly when the need arises due to the extreme mobility of the nodes in the network. This is done by designating a standby controller in each cluster. When the active controller is not reachable, the standby controller takes over as the active controller and designates a new standby controller. When both the active and standby controllers have moved out of range, a new active controller is elected by the cluster members. The new active controller in turn designates a new standby controller.

The onshore Network Operations Center (NOC) is used to monitor and manage the network as well as to provide value-added applications and services such as an early warning system for collision alerts, border crossing alerts, etc., location tracking of fishing vessels and so on [14].

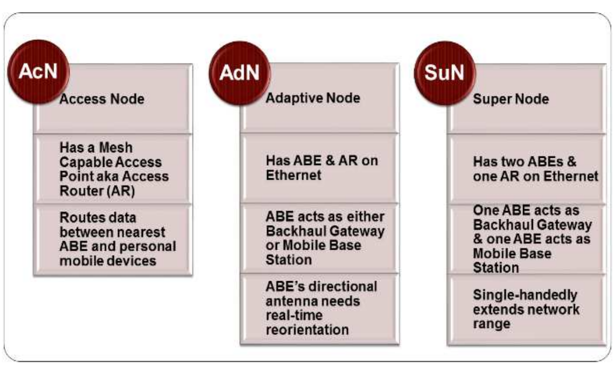


**Figure 2: Node Types - AcN, AdN and SuN**

Note that a trawler with two ABEs and an AR on board can be configured to have one of the ABEs acting as a gateway to the backhaul network and the other ABE as a mobile base station. This way, it can single-handedly extend the range of the network. Such a boat is designated as a Super Node (SuN). A trawler with one ABE and an AR is designated as an Adaptive Node (AdN). The ABE on an AdN can dynamically switch its role between being a gateway to the backhaul network and being a mobile base station. It could also operate in power saver mode if needed. A mobile base station will operate in power saver mode when it has no client stations connected to it. In this mode, it will send out beacons periodically and listen for any incoming connection requests. A boat with only an AR on board is designated as an Access Node (AcN). Figure 2 describes the node types, AcN, AdN and SuN.

Note that the primary infrastructure network has a higher range because the onshore base station can be mounted at a much higher elevation. Also, the coverage within the primary infrastructure network is guaranteed since the onshore base station is fixed and always available. The secondary infrastructure networks, however, are formed opportunistically based on the presence of boats within range to be used as mobile base stations. Due to this reason, there could be temporary loss of connectivity for some boats and the network should be delay tolerant. The nodes should be able to buffer messages until a suitable relay node is found towards the destination.

# 3. VALIDATION OF THE OCEANNET SOLUTION ARCHITECTURE

Three field trials over the Arabian Sea have been conducted from a coastal village in Kerala, India to validate the above network architecture for providing Internet connectivity to marine fishermen. FCC compliant LR Wi-Fi equipment from Ubiquiti Networks was used in the field trials. Rocket M base stations [15] were used onshore and Nano-stations [16]were used as ABEs on boats. The field trial setup is shown in Figure 3.


**Figure 3: Field Trial Setup**

## 3.1 Field Trial 1

The first field trial was conducted using one trawler equipped with a 5 GHz LR Wi-Fi ABE and an AR along with an onshore base station at a height of 56 m. The ABE was mounted on the boat at a height of 9 m from the sea level. The channel bandwidth was set to 5 MHz. The maximum range obtained was only 17 km using the primary infrastructure network. Two factors contributed towards the poor results: (i) The ABE setup was imperfect and was shaking vigorously in the winds. This impacted antenna alignment. (ii) The noise level recorded by the ABE was as high as -83 dBm. In the subsequent trials, it was -98 dBm or lower. The range of 17 km is only slightly better than the 12-15 km range obtained using the onshore cellular network. The results are presented in [12].

## 3.2 Field Trial 2

In the second field trial, 2.4 GHz LR Wi-Fi ABE was used. A trawler fitted with an ABE and an AR was taken to the sea to measure the maximum range from the onshore base station at a height of 56 m (as in the first field trial). The results were far more impressive. Internet connectivity was established as far as 45.6 km away from the shore. Mobile apps such as Whatsapp and Skype were run successfully. The range of the secondary infrastructure network was also measured and found to be 18 km. The second trawler used as the base station of the secondary infrastructure network was anchored on the shore; hence, this was only an approximate assessment of the secondary infrastructure network. The results were quite encouraging and we could expect to get better results over the ocean where there would be much less interference due to multi-path and due to external sources. The detailed analysis of the results of the second field trial is covered in [13].

## 3.3 Field Trial 3

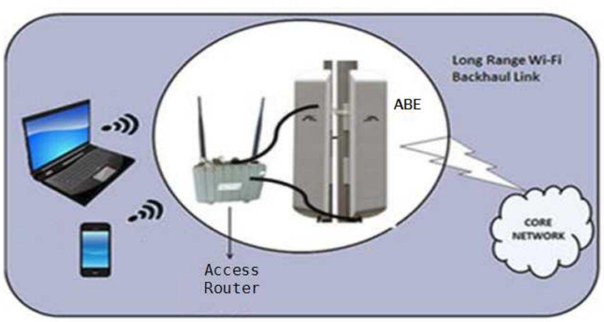


**Figure 4: The Access Network on board a Super Node**

During the third field trial, two trawlers were used. One trawler was a Super Node as it had two ABEs operating at 2.4 GHz with their backs turned towards each other. The two ABEs were facing in opposite directions. The other trawler had two ABEs, one operating at 2.4 GHZ and one at 5 GHz. Therefore, it was acting as two Adaptive Nodes, one at each frequency. Two onshore base stations were mounted side by side at a height of 56 m, one operating at 2.4 GHz and one operating at 5 GHz. Figure 4 shows the access network on board a Super Node. Note that the Adaptive Node will have a similar access network, the only difference being that there will be only one ABE (instead of two) connected over Ethernet to the access router, a range of 43.7 km was achieved in the 2.4 GHz primary infrastructure network. This was comparable with the results obtained in the second field trial using 2.4 GHz gear. The 5 GHz primary infrastructure network recorded a range of 41.1 km, much better than the results obtained in the first field trial using 5 GHz equipment.

By using one of the ABEs on the SuN (trawler #1) as a mobile base station to extend the network range and getting the AdN (trawler #2) to connect to it, a secondary infrastructure network was formed. The maximum range achievable in the secondary infrastructure network was 22.6 km. TCP and UDP performance of the network was measured using iPerf. Even at the farthest distance within range, i.e., at a distance of 22.6 km, TCP throughput of nearly 1 Mbps was obtained.

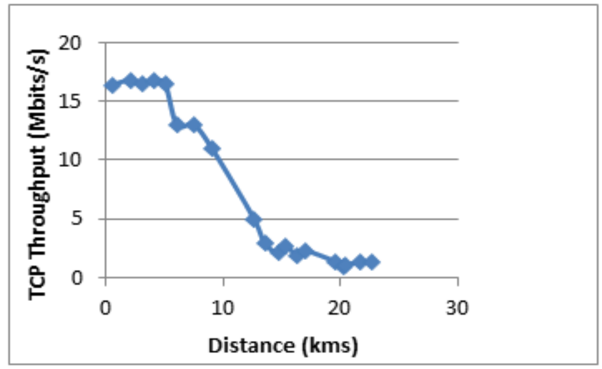


**Figure 5: TCP Throughput versus Distance in the Secondary P2MP network**

Figure 5 depicts the variation of TCP throughput with distance in the secondary infrastructure network. The TCP throughput is > 16 Mbps up to a distance of 5 km. Then it falls steadily to 1 Mbps at a distance of 14 km. Thereafter, the fall is much more gradual and the throughput is about 0.75 Mbps even at a distance of 22.6 km. We measured a good RSSI at 22.2km for boat to boat communication as shown in Figure 6. Table 1 summarizes the configuration parameters and the results obtained during the three field trials.

| # | Configuration | Results | Apps Run |
|---|---|---|---|
| 1 | Freqency: 5.8 GHz, 1 Boat (Adaptive Node), Base Station antenna height: 56 m above the ground, Boat antenna height: 9 m above sea level | Boat <=>Shore connectivity range: 17.7 km | Browser,<br><br>ping |
| 2 | Frequency: 2.4 GHz, 2 Boats (Adaptive Nodes), Same antenna heights as above | Boat <=>Shore connectivity range: 45.6 km,<br><br>Boat <=><br>Boat connectivity range: 16 km | Browser, Whatsapp, Skype audio/video, YouTube, ping |
| 3 | Frequency: 2.4 GHz and 5.8 GHz, 2 Boats (1 Adaptive Node, 1 Super Node), Base Station antenna height: 56 m, Boat antenna height: 8m, 9 m | **2.4GHz**:,<br>Shore <=>Boat: 43.7 km,<br>Boat <=>Boat: 22.6 km.<br><br>**5.8 GHz**:<br>,Shore<=>Boat: 41.1 km,<br>TCP Throughput: 0.75 - 4 Mbps,<br>UDP Packet Loss: 0 - 7 % | Browser,<br><br>Whatsapp, Skype audio/video, ping, iPerf |

**Table 1: Summary of Field Trials & Results**

Note that as more ABEs join the network, the throughput per ABE will be lower. This is because the ABEs use TDMA for medium access. The effect of more ABEs join-

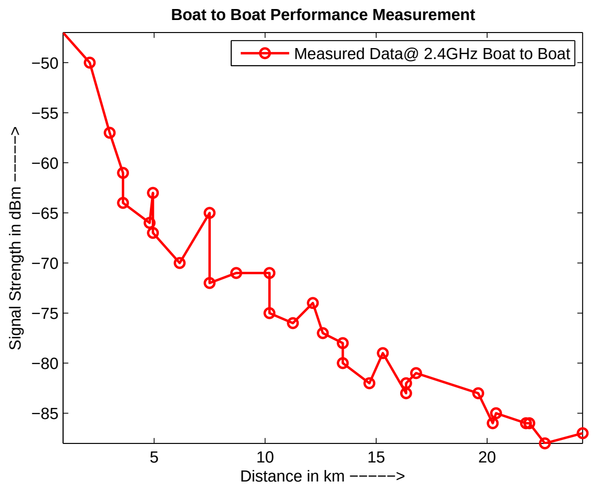


**Figure 6: RSSI vs Distance between trawler#1 and trawler#2-Secondary P2MP network**

ing the network on the TCP throughput was studied across the backwaters spanning 500 m. The same base station at a height of 56 m was turned towards the land and connectivity was established with ABEs mounted at about the same height of 9m (as on the boat) on the other shore of the backwaters. The results of this study are shown in Figure 7.

The throughput can be increased by increasing the channel bandwidth. By increasing the channel bandwidth to 20 MHz, we achieved an average TCP throughput of 10.3 Mbits/sec for the 10 ABEs scenario over the backwaters. During our sea trials, we observed that increasing the channel bandwidth results in a slight increase in the path loss thereby resulting in somewhat shorter range. This observation was also confirmed in our tests over the backwaters using the same LR Wi-Fi equipment. We observed a 10 dB drop in signal strength as the channel bandwidth was increased from 5 MHz to 40 MHz. We also observed that the noise floor value went higher as we increased the channel bandwidth. The noise floor value went up from -98 dBm to -89 dBm as the channel bandwidth was increased from 5 MHz to 40 MHz.

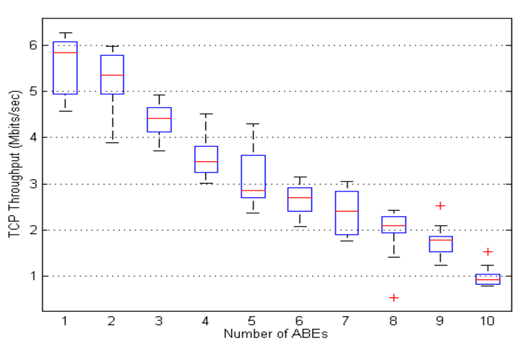


**Figure 7: TCP Throughput versus Number of ABEs**

Packet loss and jitter were also measured in the secondary P2MP network using iPerf and UDP traffic. The results are

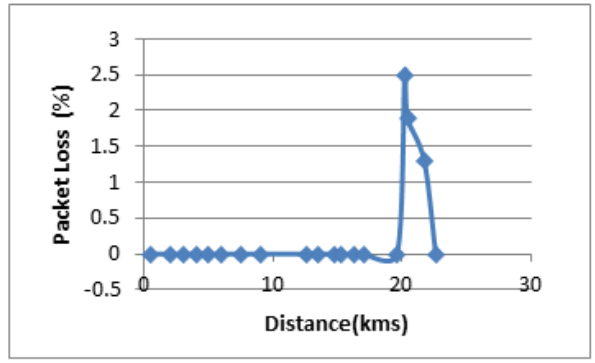


**Figure 8: UDP Packet Loss versus Distance**

shown Figure 8 and Figure 9. No packet loss was observed up to a distance of 20 km. Thereafter, it went up to 2.5% at a distance of 22 km. The rise was quite steep but was still a fairly small percentage at 2.5%. The jitter values were below 10 ms up to a distance of 14 km and then went up fairly steeply to 30-50 ms at 20 km and beyond.

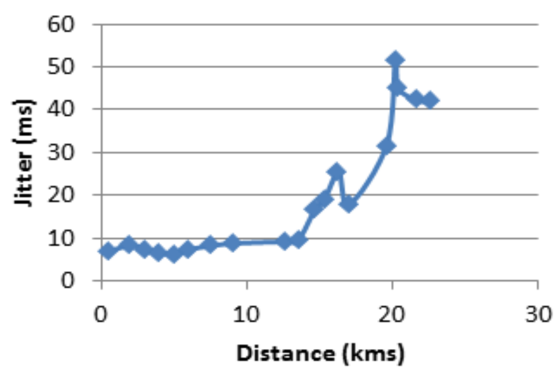


**Figure 9: UDP Jitter versus Distance**

Note that all the field trials were carried out by setting the channel bandwidth at 5 MHz. By increasing this to 20 MHz, the throughput can be increased at the cost of slightly reduced network range. The channel bandwidth can be varied dynamically based on the demands of the network and the number of stations connected to the base station. However, this needs to be done in a controlled fashion in order to ensure that all stations are in sync.

The ABE used in the field trial has a directional antenna, which is a built-in sector antenna with a sector angle of 40-50 degrees. This means that the ABE needs to be reoriented periodically to align with the base station. In addition, it needs to be stabilized against the rocking movements of the boat due to the waves in the ocean. If it is not stabilized, it could lead to transient link loss.

During the field trials, the reorientation was done manually and the sea state was fairly calm and hence the rocking of the boat was not a big problem. Work is underway to build a mechanical automatic reorientation and stabilization system. In the long term, this will be done electrically with beam forming using antenna arrays. The goal is to develop this indigenously in order to make it cost-effective.

Other marine networking solutions field tested in the past [17] [8] [7] have used older technology and also a mesh network architecture. For these reasons, the results obtained by them have not been as impressive. They achieved a maximum range of 11-15 km only.

## 4. CONCLUSIONS

Tremendous progress has been made towards realizing a cost-effective solution for the vexing problem of isolation of marine fishermen for several days together from the mainland during their fishing trips. Our field trials over the Arabian Sea have demonstrated that by using a multi-level hierarchy of extremely mobile infrastructure networks, it is possible to achieve Internet coverage over a wide range from the shores, as far away as 120 km. While the primary P2MP network can provide a range of 40-45 km, the secondary P2MP networks using boats opportunistically as mobile base stations can extend the range by an additional 15-20 km. Since the fishing zones tend to be uniformly distributed, it is reasonable to assume that there will be boats available 15-20 km apart to extend the network range to the desired 120+ km.

This is a classic example of scientific research resulting in a tangible benefit to an underprivileged section of the society. A pilot deployment of the proposed solution is currently in progress among the fishing community in a coastal village in Kerala, India. This will help us to further validate the solution and gain some valuable operational experience. It will also help in testing the durability and ease of use of the proposed solution. Once the pilot deployment is successfully completed, we will partner with an appropriate entity - an enterprise, an NGO or a governing body, to roll out this solution on a larger scale.

## 5. ACKNOWLEDGMENTS

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