Mobile Infrastructure for Coastal Region Offshore Communications and Networks

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***Abstract*—Marine fishermen risk their lives when they go as far as 120 km from the shore on a fishing trip lasting 5-7 days. They are completely cut off from the mainland. Cellular coverage exists only up to 12-15 km from the shore. In emergency situations, the fishermen have no way to call for help. Even under normal conditions, prolonged isolation from their family and friends causes mental depression. Since the marine fishermen are not economically well off especially in the developing countries, there has not been much commercial interest in addressing this problem. It is not seen as a profitable business proposition. However, addressing this problem will benefit the marine fishermen community immensely. Our center conducted interviews with several fishermen to understand this problem and came up with a cost-effective solution. The solution enables the fishermen to use the smart phones which they own already to get internet at sea using Wi-Fi. The Access Point (AP) on the boat connects over Ethernet to an onboard gateway to long range Wi-Fi backhaul network. The onshore base station is installed on a tower at a height of 50-60 m. Boats are also used as mobile base stations to extend the range of the network. This solution, when tested over the Arabian Sea, provided a range of 40+ km in the first hop and 20+ km every subsequent hop. This network can be operated on a cooperative community basis by the fishermen community at reasonable per capita CAPEX and OPEX. A pilot deployment is in progress in a coastal village community in Kerala, India, to gain operational experience.**

Keywords—Internet, long range(LR) Wi-Fi, base station, gateway, backhaul network, field trial, point-to-multi-point (P2MP) network

I. Introduction

Marine fishing is a key contributor to the economy of the countries with a long coastline. There are numerous communities of fishermen living along the coastal regions whose livelihood has depended on fishing for generations together. For example, India has a coastline of over 8000 km with 2000 fishing villages inhabited by 7 million people depending solely on fishing for their livelihood. Majority of these people are employed as daily wage earners by the boat owners. Up to 10 fishermen set out in 70 ft long mid-sized boats known as trawlers for marine fishing. These trawlers are equipped with cold storage to preserve the fish. Each fishing trip lasts 5-7 days typically, sometimes even longer, in order to catch enough fish to make it profitable to the boat owners. During these fishing trips, these fishermen are totally isolated from their families and friends. Also, they cannot communicate with the relief and rescue agencies in the case of any emergencies. Collision with a ship is a common problem faced by these fishermen that leads to loss of lives and damage to boats. Inadvertent crossing of the maritime boundary is another common issue that leads to their arrest and confiscation of the boat by the neighboring countries' surveillance personnel. Currently, the fishermen use hand-held radios for communication which have a limited range within the line of sight and do not work reliably under adverse conditions when the sea state is rough.

Researchers at our center conducted extensive interviews with over a hundred fishermen, boat owners and their families based on a questionnaire to gain insight into the problems faced by them, their communication requirements and their behavioral patterns. From their responses, it was evident that they had a real problem for which they didn't have an affordable solution. Any solution proposed should come at almost no cost to them in order for it to be viable. Since the marine fishermen are not economically well off especially in the developing countries, there has not been much commercial interest in addressing this problem. It is not seen as a profitable business proposition. However, addressing this problem will benefit the marine fishermen community immensely. It was also learned that a large percentage of them owned Android based smart phones and that count is rising with smart phones available these days for under $25.

Based on these observations, it was decided that extending the Internet to the sea using the cheapest backhaul technology option would be the best way to develop a viable and cost-effective solution for connecting the marine fishermen to the mainland. A comparative study of various backhaul technology options based on several parameters revealed that long range (LR) Wi-Fi was the most suitable option for the backhaul network [3]. In order to overcome the unique challenges in the marine environment for achieving coverage and connectivity, an innovative backhaul network architecture which opportunistically stitches together several point-to-multi-point (P2MP) networks using Ethernet and Wi-Fi mesh networks was envisaged. The standard Wi-Fi access point (AP) on board the boats will enable the fishermen to connect to the internet using their Wi-Fi enabled smart phones. The Wi-Fi mesh network for access is formed among a cluster of boats in a fishing zone. The on-board access points will be capable of routing the traffic within the Wi-Fi mesh network and also connecting to the backhaul gateway over Ethernet in order to provide internet access. The backhaul network is

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anchored at the base station on the shore at a height of 50-60 m or more which provides the primary P2MP network. The network range is extended opportunistically by forming secondary P2MP networks with the help of boats that act as mobile base stations.

Field trials were conducted successfully over the Arabian Sea from a coastal village in Kerala, India. FCC compliant long range Wi-Fi equipment and access points were used in the trials performed using two trawlers. The local fishermen were involved in the trials. A range of 45.6 km was achieved in the primary P2MP network with the on-shore base station. The secondary P2MP network using a boat as a mobile base station provided a range of 22 km. The capital expenditure for the on-board equipment on boats to be borne by the boat owners is found to be well within their affordability range. The cost of on-shore equipment is also reasonable making it amenable to community ownership. The monthly subscription fee for the internet service to be borne by the fishermen would be well under \$2. With potential subsidies from the governing bodies, these costs could come down even further. A pilot deployment is in progress in a local village along the coast of Kerala, India, to gain more operational experience. About ten trawlers, instrumented with the necessary equipment, will participate in this pilot deployment program.

The remainder of this paper is organized as follows. Section 2 describes the survey of the fishermen community conducted by the researchers and the inferences drawn from it. Section 3 describes the comparative study of various backhaul technology options and the results obtained. Section 4 describes the unique challenges for providing coverage and connectivity in the marine environment and how the solution architecture addresses them. Section 5 describes the field trials conducted over the Arabian Sea and how they validate the proposed solution. Section 6 shows how the proposed solution is affordable to the marine fishermen community. Finally, section 7 provides the conclusions and also describes the future work planned.

II. Survey of Fishermen's needs and behaviours

The state of Kerala in India stretches along the south western coast of India with several fishing communities living along the coast. Representatives from two of these communities were extensively interviewed by our researchers. The questions asked covered the communication requirements of the community and how they were met currently, the kind of problems they faced due to lack of communication, their affordability, their behavioral patterns in fishing and communication, etc. A comprehensive questionnaire was prepared covering all these aspects to serve as a common framework for these interviews. Close to a hundred fishermen, boat owners and their families were interviewed. Owners and users of both small boats and mid-sized boats known as trawlers were interviewed.

The mid-sized trawlers are typically equipped with a GPS and an echo sounder to observe the sea bed for presence of fish. They use handheld wireless radio to communicate with other boats. Quite often these handhelds are imported illegally. They use the 145 MHz frequency band which is not authorized for marine communications. Their range is limited to line of sight and gets adversely affected during rough sea conditions. The cellular coverage is limited to 15-20 km from the shore. Many fishermen own smart phones. Based on the statistics gathered two years ago, about 65% of the fishermen interviewed owned smart phones. The number of smart phone owners is on the increase with the falling smart phone prices. However, iPhones are not very popular as they are pricey.

There is a marked difference between the fishing behavior of small boat users and trawler users. The small boats are usually fishing within 15-20 km from the shore and they return to the shore within 24 hours. The trawlers on the other hand go as far as 120 km away from the shore and stay at sea for 5-7 days, sometimes even longer. It is quite common for the smaller boats to be attached to the sides of the trawlers and taken to and from the fishing zones. Once a fishing zone is identified, a cluster of boats tends to form in that zone. This is a heterogeneous cluster consisting of small boats and mid-sized trawlers. A cluster may have up to 10 boats. The speed of the trawlers varies between 6 km/h to 15 km/h depending on whether they are cruising or fishing, the load on the boat, the direction of the current, etc.

The biggest unanimous concern among the fishermen seems to be the threat of getting hit by a ship especially when they have anchored their boat and gone to sleep at night. The fishermen tend to turn off all the lights at night in order to conserve energy and this makes it that much harder for the ships to detect their presence until it is too late.

The fishermen were found to be quite tech savvy and willing to learn and use new equipment. However, they would prefer to have one appliance that combines the functions of GPS navigation, identification of fishing zones and communication. They were willing to share their experiences and needs with us and also willing to participate in testing out new devices provided by us. Low cost and ease of use were their primary criteria for viability of the proposed solution.

III. Comparative Analysis of Backhaul Technology Options

Our challenge was to identify a low cost backhaul technology that would still provide the required performance, range and other features. The technology options considered were 2G/3G, Wi-Fi, Wi-MAX, Cognitive Radio and LTE. These technologies were evaluated based on the following parameters – spectrum licensing cost, capital expenditure, vendor support, communication range, channel bandwidth, supported data rate, latency and mobility. Weights were assigned to the above parameters based on their perceived importance. All technology options were graded based on each of these parameters. A utility function was defined as the normalized weighted sum of the grades for each parameter. Using this function, a utility score (out of 10) was computed for each technology option, similar to a GPA [3]. Table 1 shows the relative weights assigned to the various parameters and Table 2 shows the utility scores obtained for various technology options. It can be seen that Wi-Fi scores much higher than the next best option, Cognitive Radio. Based on this analysis, long range (LR) Wi-Fi is chosen as the backhaul technology of choice. LR Wi-Fi is a variant of standard Wi-Fi which uses directional antennas to increase the transmission range and uses TDMA instead of CSMA/CA for medium access in order to overcome the hidden node problem and to avoid long acknowledgement timeouts. FCC compliant long range Wi-Fi equipment is commercially available.

Table 1: Relative Weights Assigned to Various Parameters

Parameter	Relative Weight
Spectrum licensing cost	3X
CAPEX	3X
Vendor support	2.5X
Transmission range	2X
Supported Data Rate	1.5X
Channel Bandwidth	1.5X
Latency/delay	1.5X
Mobility	X

Table 2: Utility Scores for Various Technology Options

Technology	Utility Score (out of 10)
WiMAX	5.81
LTE	6.19
Cognitive Radio	6.41
2G/3G	5.47
Wi-Fi	8.75

IV. Solution Architecture

There are several challenges unique to this problem domain. Firstly, the proposed solution needs to be extremely low-cost and also needs to be easy to use. In addition, the coverage needs to be over a very long range, as far as 120 km on some occasions. Security is a big concern too since these boats operate close to the maritime boundary. Proper authentication and authorization mechanisms need to be in place. The boats are highly mobile and are also subject to undulating motion due to the waves. This will require regular localization of the nodes and reorientation of the antennas as needed.

The solution architecture stitches together several point-to-multi-point (P2MP) long range Wi-Fi networks together. The primary P2MP network is anchored at the base station on the shore. The client station on the boat connecting to the base station is referred to as Adaptive Backhaul Equipment (ABE). This is because the station can dynamically change its role between being a gateway to the backhaul network and being a mobile base station. The secondary P2MP networks use the ABE on a boat as a mobile base station. The P2MP networks are stitched together over Ethernet and Wi-Fi mesh network. The Wi-Fi mesh network is formed among the boats in a fishing zone. While the expected range of primary P2MP network is 40-45 km, the expected range of secondary P2MP networks is 15-20 km. The required worst case range of 120 km is targeted by stitching together several secondary P2MP networks with the primary P2MP network. The assumption being made is that there will be at least one fishing zone with a boat within the range of each P2MP network. There will be an 802.11 standards compliant Wi-Fi access point on board every boat. Since this access point is also capable of routing the traffic within the Wi-Fi mesh network, it is known as an Access Router (AR). The smart phones, tablets, etc., of the fishermen on board a boat will connect to the local AR over Wi-Fi.

Boats which have only an AR are known as Access Nodes (AcN). Boat with an AR and an ABE are known as Adaptive Nodes (AdN). The ABE on board can act as either a gateway to the backhaul network or as a mobile base station. Its role will depend on the location of the boat within a cluster and can change dynamically as the boat moves around. Some boats will have an AR and two ABEs, one acting as a gateway and the other as a mobile base station. Such boats can extend the range of the network single-handedly. These are known as Super Nodes (SuN). Note that the AR and the ABEs aboard a boat are connected over Ethernet. Figure 1 illustrates the network architecture.

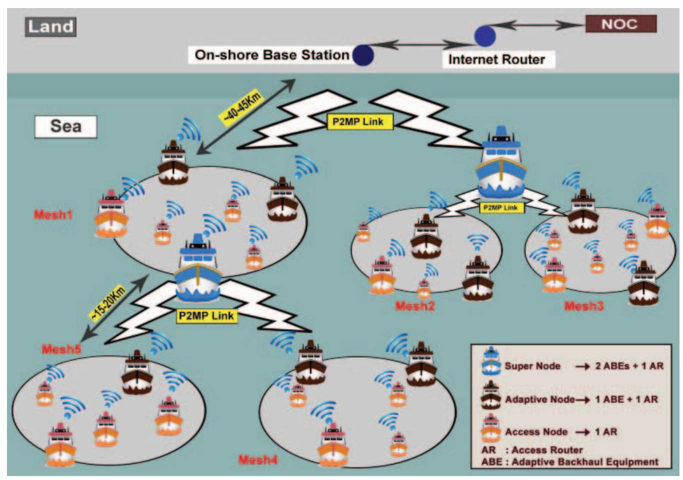

Figure 1: Network Architecture

802.1X based authentication and authorization will be used to address the security requirements. In addition, standard WPA2 based 802.11i security protocol will be used.

Prior work done using long range Wi-Fi [4] [5] was based on point-to-point (P2P) links. This meant that there could be multiple radios at one node and the problem of interference had to be dealt with. In this architecture using P2MP links, there will at most be two radios at one node and non-overlapping channels can be used to avoid interference. Also, the backhaul and access networks can operate in different spectrum (2.4 GHz versus 5 GHz) in order to avoid interference.

Long range Wi-Fi relies heavily on directional antennas for range extension. Therefore, in this highly mobile environment, constant tracking of the location of the base station and reorientation of the client station (ABE) antenna towards the base station is a requirement. This is achieved by mounting the ABE antenna over a rotary platform and using a micro-controller to periodically reorient the antenna towards the base station. The client stations should somehow localize the base station and then reorient their antenna accordingly to always face the base station. In addition, a suitable stabilization mechanism such as a gyroscope or a steady cam can be used for mounting the antenna in order to counter the rocking movement of the boats due to the ocean waves.

A Network Operations Center (NOC) [10] will be deployed onshore to monitor and manage the network. The NOC will also host custom-built apps for fishermen's use such as an early warning system for collision detection alert, maritime border crossing alert, underwater hazard alert, rough weather alert, etc., mobile app for auction of daily catch, search and rescue portal, etc.

V. Field Trials

FCC compliant long range Wi-Fi equipment from Ubiquiti Networks [6] was used in the field trial along with Cisco Linksys access routers. Three field trials were conducted - one with the 5.8 GHz gear, one with the 2.4 GHz gear and one with both gear side by side. In the first two trials, one trawler (AdN) was used while in the third trial, two trawlers were used – one AdN and one SuN. Therefore, in the third trial, in addition to assessing the range of the primary P2MP network anchored at the base station on the shore, we also assessed the range of the secondary P2MP network using the ABE on the boat as a mobile base station. The results with 2.4 GHz gear were better than the results using 5.8 GHz gear.

Figure 2 shows the field trial setup. The trials were conducted from a coastal village in Kerala, India. One of the campuses of our multi-campus university is located in this village. The on-shore base station was installed on top of a 16 story building along the sea shore at a height of 56 m. The ABEs were mounted on top of a pole fitted to the trawler at a height of 9 m from the sea level. The on-shore base station has an external sector antenna with a beam width of 120◦ whereas the ABE has a built in sector antenna with a beam width of 42◦ (5.8 GHz) or 54◦ (2.4 GHz).

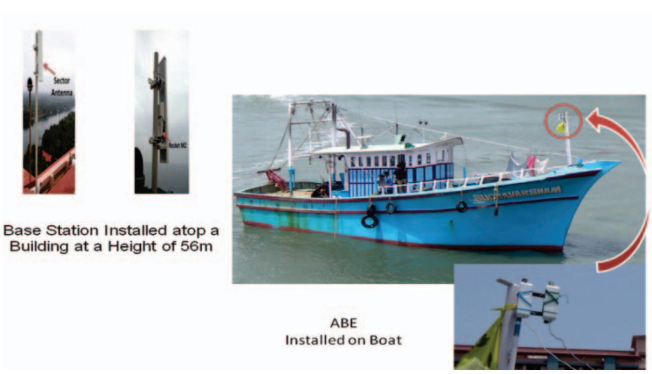

Figure 2: Field Trial Setup

The results from the first field trial using 5.8 GHz gear were very poor. The maximum range obtained was only 17 km. However, there were some issues with the setup and the noise floor was also found to be higher than normal at -90 to -95 dBm. The third field trial provided a much better range of 40+ km for the 5.8 GHz gear. The 2.4 GHz gear provided a range of 45+ km in both the second and third field trials. All these results are for the primary P2MP network anchored at the base station on the shore. The range of the secondary P2MP network using the boat as a mobile base station was measured using the 2.4 GHz gear only during the third field trial. The range obtained was 22 km. Even at the farthest distance within range, a TCP throughput of at least 750 kb/s was obtainable using iPerf. Applications such as Whatsapp and Skype could be run seamlessly. The parameters and results are summarized in Table 3. Overall, the results obtained from the field trials at sea served to validate the viability of our network architecture. Figure 3 shows the variation of signal strength with distance using the 2.4 GHz gear. [1] & [2] cover the field trials in greater detail.

Table 3: Field Trial Parameters & Results

Operating Frequency	5.8 GHz	2.4 GHz
Base Station Antenna Gain	18.6 - 19.1 dBi	15.0 - 16.0 dBi
Base Station Beam Width	120◦	120◦
Base Station Antenna Height	56 m	56 m
ABE Antenna Gain	14.6 - 16.1 dBi	10.4 - 11.2 dBi
ABE Beam Width	42◦	54◦
ABE Antenna Height	9 m	9 m
Primary P2MP Network Range	40+ km	45+ km
Secondary P2MP Network Range	NA	20+ km

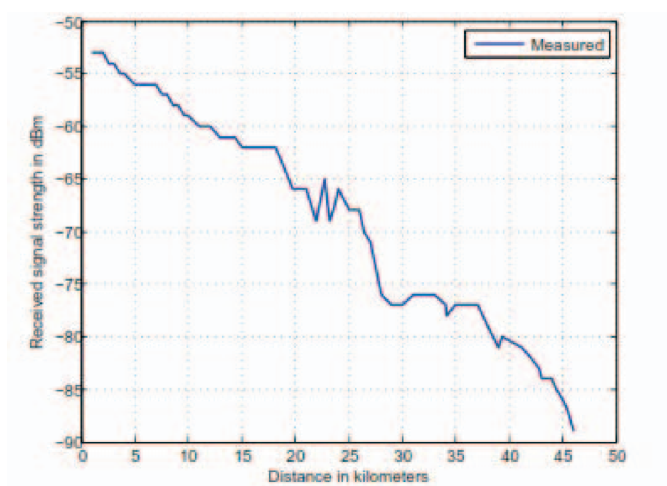

Figure 3: Received Signal Strength versus Distance (2.4 GHz)

During the field trials, the ABEs were manually reoriented when needed in order to align their directional antennas in the direction of the base station. Work is currently in progress to develop a rotary platform to mount the ABE. This rotary platform will be automatically adjusted using a micro-controller to align the ABE in the direction of the base station. The mounting will also have a steady cam like mechanism to stabilize the ABE against the rocking movements of the boat due to the ocean waves.

It is to be noted that the trawlers of the local fishermen were rented for the field trials and the local fishermen were also actively involved in the trials. They were curious to see and understand the working of the proposed system.

VI. Affordability of the Proposed Solution

One of the fundamental requirements of any proposed solution is that it needs to be affordable to the financially challenged fishermen community. This was one of the major considerations in selecting the appropriate technology to solve this problem. Wi-Fi gear has become a lot more affordable with the prices coming down especially when the next generation technology (802.11ac) entered the market. Based on the equipment used in our field trials, the approximate cost of equipment for different types of boats are as shown in Table 4.

Node Type	Equipment Cost
Access Node (AcN)	$100
Adaptive Node (AdN)	$250
Super Node (SuN)	$350
On-shore Base Station	$500

Table 4: Equipment Cost for Various Node Types

The cost of on-board equipment on the boat will be a capital expense to the boat owner. The cost associated with setting up a base station on the shore can be shared among a community of boat owners. The on-shore base station can support up to 100 client stations per the data sheet. However, with as little of 10 boats sharing an on-shore base station, if the cost of setting up the base station were to be amortized over two years, the cost per boat owner would be about $2 per month. Setting up a tall tower on the shore may be expensive; however, this can be avoided by making use of the existing tall structures such as cellular and other communication towers, light houses, tall buildings, etc. The monthly subscription rates for mobile data service have been declining in all parts of the world. A community of fishermen should be able to get good data plans under $100 per month and this can be shared among the members of the community. This cost can be either borne by the boat owners or the fishermen themselves or a combination of the two. It is quite possible to get government subsidies for both the capital expenses and the operating expenses and this will further bring down the costs. Based on the coverage range obtained, the base stations can be located at least 50 km apart along the shore. This allows for multiple communities to share the same base station also. We could also have multiple base stations co-located and operating in non-overlapping channels in order to increase the overall capacity.

VII. Conclusion and Future Work

Marine fishermen community all over the world face a real problem when they have to spend 5-7 days or more at a time in the middle of the ocean with no cost-effective means of contacting the mainland. This is more so in the developing countries where the financial constraints of this community are even more acute. Our researchers can rightfully claim to have found a viable economical solution to this problem using an innovative and unique network architecture that uses long range Wi-Fi for backhaul. By extending internet to the seas seamlessly, we make all the smart phone based apps and services available to the fishermen while they go fishing over the seas for days together. This has the potential to substantially improve the quality of life of the marine fishermen community and also provide them with better safety and security.

A pilot deployment is currently in progress in the Arabian Sea near a coastal village in Kerala, India, in order to gain more operational experience with the novel network architecture. Once this is successful, we will look for partners to roll this out on a larger scale. The potential partners will include a combination of government organizations, private enterprises and NGOs. The statutory corporate social responsibility (CSR) commitment of private enterprises in some countries may also be leveraged for this purpose. Indigenous development of equipment for cost reduction will also be investigated. Overall, we have successfully taken the first steps in realizing a cost-effective technology solution to provide marine infrastructure for coastal offshore communications for fishermen.

Acknowledgment

We sincerely acknowledge the tremendous motivation and support provided by our beloved Chancellor and a world renowned humanitarian leader, Dr. Mata Amritanandamayi Devi, popularly known as Amma, for addressing this real life problem which directly affects the local fishing community. She was also instrumental in raising our awareness to this global problem. We are also thankful to the local fishermen who helped us with the field trials enthusiastically.

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