Performance Measurement and Analysis of Long Range Wi-Fi Network for Over-the-Sea Communication

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***Abstract*—Currently, Indian fishermen use handheld radios or satellite phones for offshore communication. While the former is based on broadcast communication with its range limited by Line-of-Sight, the latter is expensive. Therefore, lack of connectivity-at-sea is a huge problem for many Indian fishermen. Hence, this work prescribes a hierarchical point-to-multi-point backhaul network using long range (LR) Wi-Fi technology. It is a multi-hop network consisting of base stations and clusters of boats. Each boat-cluster forms a wireless mesh access network. A field-trial was conducted at sea to measure and analyze the coverage and connectivity of the P2mP LR Wi-Fi backhaul network, using commercially available 5 GHz base stations, antennas and customer premises equipment (CPE). Several parameters such as transmission power level, mechanical antenna tilt at the base station and channel bandwidth were fine-tuned to maximize the range. This paper discusses the observations and the results obtained.**

***Index Terms*—Bridge mode, Channel Bandwidth, Mechanical Tilt, Received Signal Strength Index, Link Level Parameters**

I. Introduction

It is apparent that fishing is one of the largest sources of occupation in India. While the revenue generated from fishing is in the order of crores, it involves the fishermen facing threats and putting their lives at risk. Moreover, fishing is performed for distances beyond 100 km. Lack of cellular network coverage at such distances has led to the use of handheld radios and satellite phones [1]. Despite easy installations and delivering good performance, cost factor hinders their usage for fishermen.

Traditional IEEE 802.11 technology does not support long distance communications due to CSMA and small MAC-level AckTimeOut value [2]. A TDMA protocol with modified RTT and ACK times has been introduced in [4] for long distances. This technology termed Long Range Wi-Fi (LR Wi-Fi) has been implemented in [3] [5] for different applications. In this paper, we propose to use LR Wi-Fi and evaluate its efficacy in providing Point to Multi Point (P2MP) connection over long distances in the sea. The P2MP network consists of a base station on shore and clusters of boats offshore. This work primarily sets up a network architecture between the static base station and the mobile boats and evaluates LR Wi-Fi communication link. The network consisted of COTS base station and clients. The proposed architecture consists of clusters of boats connected to the base station at the shore over long-range Wi-Fi backhaul links. LR Wi-Fi is based on 802.11n, however, uses TDMA MAC instead of CSMA/CA. There are several vendors that manufacture long distance 802.11 equipment (Ubiquiti, MikroTik, etc.), with their proprietary MAC protocols. The experiments in this paper are conducted using Ubiquiti equipment. To summarize, the objective of this paper is to measure and analyze network level statistics of a LR Wi-Fi network over the sea consisting of an onshore base station and offshore mobile units. Through our empirical work, we aim to answer some of the key questions such as:

1) What is the maximum range of base station?
2) How does received signal strength vary with the mechanical tilt of antenna?
3) What is the relationship between channel bandwidth and signal strength?
4) How does the quality of wireless link vary with distance?
5) What is the variation of Tx-Rx data rate with distance?

The remainder of this report is structured as follows. In Section 2, the relevant and related work is discussed. Section 3 provides the description of System Design and System Architecture. Section 4 explains the Experimental Setup and Methodology in depth. This is followed by Section 5 which talks about Measurement Analysis and comparison. The work is concluded in Section 6.

II. Related Work

A considerable amount of research has been performed in long distance 802.11 links. However, not much work has been carried out in their implementation over the sea.

One such work is performed in [4] where eight different long distance links were setup, ranging from 1km to 37km. Seven of the links were in the Digital Gangetic Plains (DGP) testbed and one was in the Ashwini Project deployment. The main objectives of this paper was to obtain per-packet information such as Received Signal Strength of the packets received, energy level before packet reception, the modulation used for the packet, MAC packet type and sub-type, and MAC sequence number information.

Another such work is a predecessor of the above work, that has implemented the Digital Gangetic Plains (DGP) testbed

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[5]. The longest link setup between two points in the network is about 80km. The testbed was setup in rural area, with IIT-Kanpur as the center of origin. The authors have discussed the physical layer issues, MAC layer issues, and Routing and Reconfigurability.

M. Zennaro, C. Fonda, et al., 2008 [6] proposed the implementation of a 162km wireless link in Malawi, Africa. Their objective was to provide a long wireless link for rural telemedicine. The link connects the University of Malawi College of Medicine in Blantyre with the Mangochi Hospital as research institutions in the cities of Blantyre, Zomba and Mangochi.

Rob Flickenger, et al., 2008 [7] have presented a successful 279km wireless link in Venezeula, and a permanent 133km test network in northern Italy for research purposes. The 279km link runs from Pico del Aguila to El Baul and provides line-of-sight communication. The authors used Linksys WRT54G wireless router and an assembled high gain directional antenna.

Our work includes a novel architecture of over the sea communication network to provide seamless and reliable communication to the fishermen when they are in sea over long distance. The next section describes the system design and system architecture.

III. System Design

This section provides a description of the design of the system and explains its architecture. The work presented in this paper is practically implemented by use of long range transceiver equipment from a vendor named Ubiquiti. Three different devices are used, namely, Ubiquiti Rocket M5, Ubiquiti airMAX Sector Antenna AM-5G19-120, and Ubiquiti NanoStation M5. The technical information of these devices is given in Fig. 1.

Hardware Tools	Specifications
Ubiquiti Rocket M5 Base Station	• Operating Frequency: 5170MHz to 5875MHz • IEEE 802.11n • Power Supply: 24V, 1A Power-over-Ethernet Adapter • Weight: 0.5 kg • Max. Power Consumption: 8W • Operating Temperature: -30^{0}C to 75^{0}C
Ubiquiti airMAX Sector Antenna 5G19-120	• Frequency Range: 5.15 GHz to 5.85 GHz • Gain: 18.6 to 19.1 dBi • HPOL Beamwidth: 123^0(6 dB) • VPOL Beamwidth: 123^0(6 dB) • Max. VSWR: 1.5:1 • Cross-pol Isolation: 28dB min. • Wind Survivability: 125mph • Weight: 5.9 kg • Mounting: Pole Mount
Ubiquiti NanoStation M5	• Operating Frequency: 5170 MHz to 5875 MHz • Gain: 14.6 to 16.1 dBi • HPOL Beamwidth: 43^0 • VPOL Beamwidth: 41^0 • Cross-pol Isolation: 22 dB min. • Max. VSWR: 1.6:1 • Power Supply:24V, 0.5A Power-over-Ethernet Supply • Weight: 0.4 kg • Mounting: Pole Mount

Fig. 1. Technical Information of the devices used

Fig. 2. (a). Ubiquiti Rocket M5 Base Station. (b). Ubiquiti airMAX Sector Antenna AM-5G19-120. (c). Ubiquiti NanoStation M5 CPE

The Sector Antenna utilizes airMAX technology. Unlike standard Wi-Fi protocol, Ubiquiti's TDMA airMAX protocol allows each client to send and receive data using pre-designated time slots scheduled by an intelligent AP controller, which is the Rocket M5. The antenna can support up to 100 clients (CPEs). In the experiments conducted, the wireless mode of Rocket M5 is set as Access Point, and that of NanoStation M5 is set as Station. The devices run on airOS, a configuration interface provided by Ubiquiti Networks.

Ubiquiti airOS and Ubiquiti airView are the software tools used in this network. The airOS is the configuration interface/operating system running on the Ubiquiti Rocket M5 and Ubiquiti NanoStation M5. Various parameters such as Output power, Antenna Gain, Frequency, Channel to be used, Channel Width to name a few, can be varied using airOS. In the main screen of airOS, information such as Device Name, airOS version, Wireless Mode, Network SSID, Frequency that is being used currently, channel width, channel number and MAC ID of the device are displayed. The airView Spectrum Analyzer is used to analyze the noise environment of radio spectrum and intelligently select the optimal frequency to install a Point-to-Point airMAX link.

A. Network Topology

Fig. 3 shows the topology for over the sea network. The

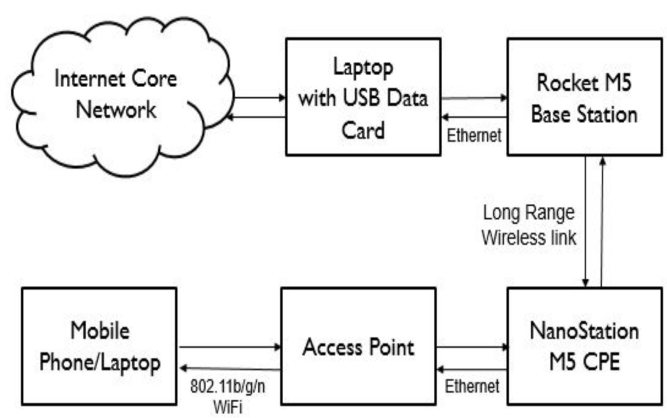

Fig. 3. Topology of the proposed network

Internet Core Network, Laptop with USB Data Card, and Ubiquiti Rocket M5 Base Station with Sector Antenna are on the shore. Ubiquiti NanoStation M5 CPE, Access Point, and Mobile Phone/Laptop are on the boat side (fishing trawler). A Cisco Linksys E2500 Access Point was used.

At every component, both uplink and downlink transmission takes place. Hence the two sided arrows. From the experiments we conducted, it was found that the link between BS and CPE is approximately 18 km (subject to environmental conditions and sources of interference). It means the fishermen can get internet connectivity up to 18 km into the sea. However the range is not limited to 18 km. Our research continues with the prime objective being the range extension of wireless link that we deployed.

B. Network Architecture

The proposed architecture consists of clusters of boats connected to the base station at the shore over LR Wi-Fi backhaul links. Long-range Wi-Fi is based on 802.11n, however, uses TDMA MAC instead of CSMA/CA. Several vendors have FCC compliant products based on this technology with several real world deployments. Most of the deployments are Fixed Wireless deployments (WISP) on land though. Both point-to-point and point-to-multi-point links have been deployed.

The base station at the shore would provide a point-to-multipoint network to the customer premises equipment (CPE) on the boats. The CPE will be connected to an access node, say, a wireless access point (AP), which will provide the access network to the user equipment (UE) such as smart phones, tablets, laptops, etc. that are wireless enabled. The boats within each cluster will be interconnected as a wireless mesh network. While the backhaul Wi-Fi network operates at 5.8 GHz, the access Wi-Fi networks could operate at 2.4 GHz. In order to increase the range, one of the boats at the edge of a cluster could in turn provide yet another point to multipoint long-range Wi-Fi link by acting as a base station. Fig. 4 shows the network architecture. The next section describes the practical

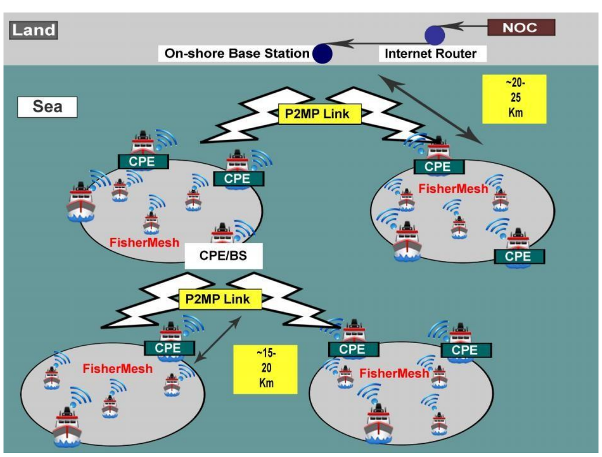

Fig. 4. Architecture of the proposed network

implementation of the system architecture, experimental setup and methodology.

IV. Experimental Setup and Methodology

In this section, the experimental setup of over the sea communication network is discussed in detail. The experiment was conducted from Parayakadavu beach, a fishing village in the Kollam district, in Kerala. The experimental setup is shown in Fig. 5. The Rocket M5 base station along with the sector antenna was installed on the terrace of a 16 storey building situated on the beach at a height of approximately 56 metres. The Nanostation M5 CPE with the integrated antenna was mounted at a height of about 9 metres from the water surface on the boat's deck. The back end connection of the base station

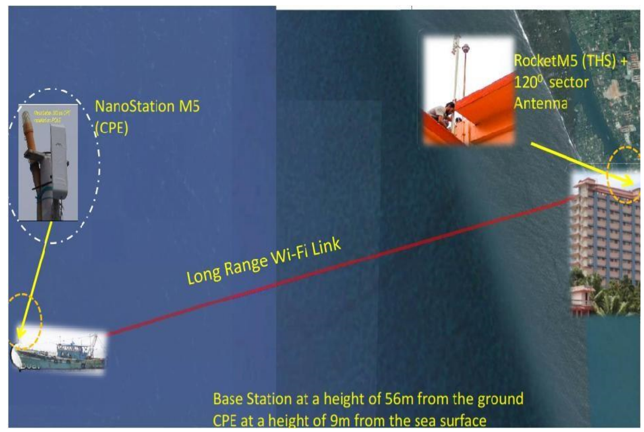

Fig. 5. Experimental Setup

is the laptop that is connected to internet via D-Link USB Data Card. The long distance wireless link is between Sector Antenna connected to Rocket M5 and NanoStations, which forms a Point-to-multiPoint link (PtmP). The distance of the link specified by the vendor is around 20 km. It is subject to change with the environmental conditions and interference levels. It is not necessary that all boats have to be equipped with a NanoStation. If the boats travel in a cluster, one of the boats can be installed with NanoStation and access point, and the nearby boats will get signal reception from the access point. It should be reminded that "by boats getting signals", it means the phones possessed by fishermen in the boats get signals through Wi-Fi network of the access point. The cluster based network can also be named as Ad hoc Mesh network.

A. Hardware and Software Setup

The Ubiquiti Rocket M5 Base Station with Sector Antenna is pole mounted on top of the building. In the boat side, the Ubiquiti NanoStation M5 CPE is pole mounted. It is ensured that a clear line-of-sight path always exists between BS and CPE, so as to provide seamless and reliable communication to fishermen. On the shore, a laptop is connected to D-Link USB Data Card to provide internet access to the laptop. The laptop is connected to a Power-over-Ethernet (PoE) adapter by an ethernet cable. The Rocket M5 cannot be connected directly to the laptop since the power required by Rocket M5 is different from that provided by the ethernet port of laptop. Rocket M5 requires a current of 1A which is provided by the PoE adapter.

The PoE adapter has to RJ-45 ports: one for connecting to laptop, another for connecting to Rocket M5. Rocket M5 itself does not have any antenna. It is externally connected to Sector Antenna through two Coaxial cables, one for transmission, another for reception. The internet access provided by the D-Link Data Card is shared with the ethernet port of laptop. Therefore the Rocket M5 transmits internet packets to sector antenna which wirelessly transmits the same. The NanoStation M5 which has established a wireless connection with Rocket M5, receives internet packets from Rocket M5, and forwards the packets to the Cisco LinkSys E2500 Access Point (AP). This AP provides 802.11 b/g/n 2.4 GHz Wi-Fi network on the boat. The fishermen, using their mobile phones equipped with Wi-Fi, connect to AP, thereby getting access to internet. Fig. 6 shows the devices that will be installed in the boat, and their connections.

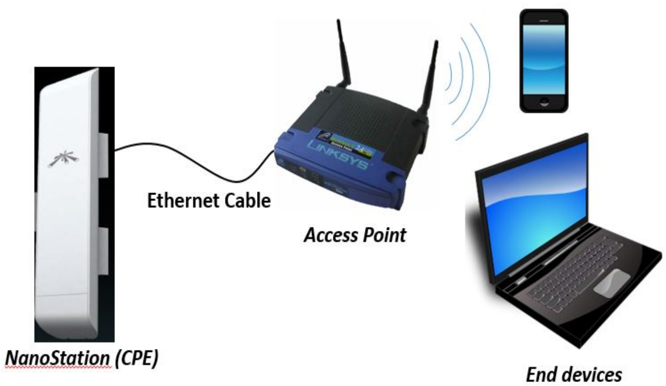

Fig. 6. The devices installed in the boat and their connections

B. Real-time Network Setup

In our practical deployment of over the sea scenario, a Point-to-multiPoint link is setup. We traveled along Arabian Sea on a fishing boat in which the CPE was installed. As we sailed across the ocean we had to frequently align the CPE in order to maintain a Line-Of-Sight path between the sector antenna and CPE. A 20m Cat6 UTP ethernet cable was connected to the CPE, and its other end ran all the way inside the wheel house (cabin) of the boat. It was connected to the PoE which supplies an output current of 0.5A to the CPE. The other RJ-45 port of the PoE was connected to the Cisco LinkSys E2500 Access Point, which provided 2.4 GHz 802.11 b/g/n Wi-Fi. Any Wi-Fi supported mobile phone or laptop could be connected to AP.

For our experimental purposes we connected two mobile phones and two laptops to the AP via Wi-Fi. Internet data packets were transmitted from BS to CPE, thereby providing internet access to the mobile phones and laptops connected to AP. In the laptop, we monitored the performance using the airOS configuration interface. We recorded the screen using a third-party software called Corel Screen Capture and recorded the laptop screen while we were noting down the readings. Our entire attention revolved around the received signal strength of CPE; the variation of signal strength with distance, how it varies- is it a steep variation due to some interference or gradual variation with distance, and the effect of varying signal strength in Tx/Rx rate of CPE. We were able to obtain successful connectivity till 17.7 km in the sea. The signal strength at 17.7 km was -91 dBm. The noise floor was -93 dBm. At -91 dBm, the Tx/Rx rate was 1.7/1.625 Mbps. This results in around 400 KBps of total data transfer rate, which is more than adequate to stream a video seamlessly.

C. Measurement Methodology

There are two broad metrics we took into consideration for our experiments:

1) Received Signal Strength
2) Distance

Based on these metrics, the following parameters were observed:

- The relationship of mechanical tilt of sector antenna and signal strength for various distances: We conducted experiments by varying the mechanical tilt of sector antenna at tilt degrees of 2^0 to -2.5^0. We found that at a tilt of -1.5^0, the received signal strength of CPE was higher than that at the remaining tilt degrees. The analysis is carried out in the next section.
- The relationship of wireless link quality and Client Connection Quality (CCQ) with distance: We found that the link quality and CCQ were pretty good till connectivity was lost.
- The relationship of channel bandwidth of the propagated signal and signal strength at different distances: We conducted experiments of varying channel bandwidth of the signals at 5 MHz, 10 MHz and 20 MHz. We found that for signals with bandwidth of 5MHz, the received signal strength of CPE was higher than other bandwidths, for the same distance.
- The relationship of Tx-Rx Data Rate with distance: We had just over 1 Mbps Tx/Rx data rate till we lost connectivity.

Detailed analysis and graphs of the above measurements are discussed in the following section.

V. Measurement Analysis

This section covers the measurements taken in the experiments and their analysis. As discussed in the previous section, five different relationships are made from the experiments. They are:

- Received Signal Strength of NSM5 CPE (RSS) vs Distance at Antenna Tilts
- Air Quality and CCQ vs Distance
- Received Signal Strength of NSM5 CPE (RSS) vs Antenna Tilt at 5 MHz
- Received Signal Strength of NSM5 CPE (RSS) vs Channel Bandwidth
- Tx-Rx data rate vs Distance

1) *Received Signal Strength of NSM5 CPE (RSS) vs Distance at Antenna Tilts*: Fig. 7 shows the graph of RSSI vs

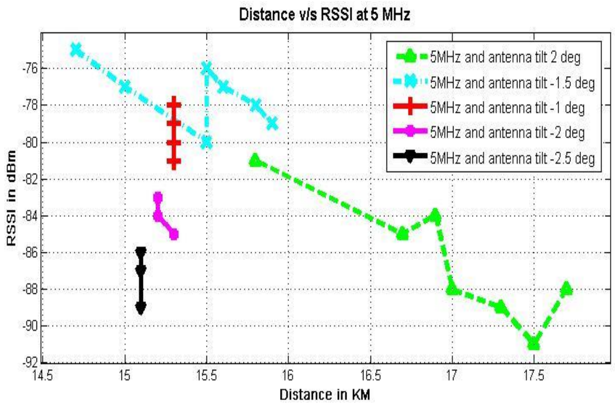

Fig. 7. RSSI vs Distance at various Antenna Tilts

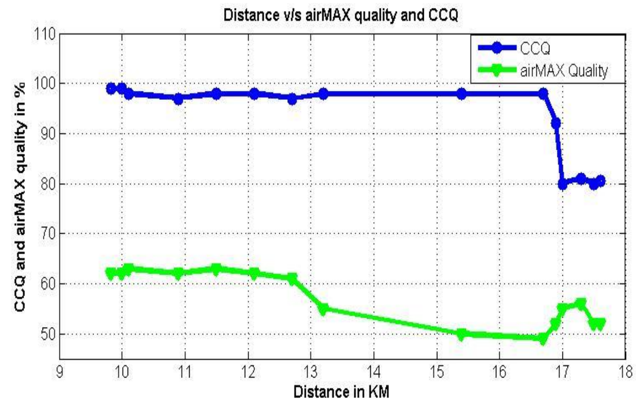

Fig. 8. airMAX Quality and CCQ vs Distance

Distance at various antenna tilts. It is a known fact that as channel width decreases the throughput decreases and communication range increases. Since our emphasis was on determining the maximum range of the network, we set the channel bandwidth to the lowest possible value, i.e., 5 MHz. The graph shows different lines which are channel bandwidths, and its impact on RSSI of CPE at varied distances. At -1.5^0, the RSSI was found to be the highest, among other tilt degrees. This means that at -1.5^0, the CPE is exactly in the sector of the BS sector antenna. We further observed that even for a slight change of $\pm 0.5^0$ there is a significant decrease in RSSI. Initially, the base station antenna was set up with a mechanical up-tilt of 2^0. This was to compensate for the built-in electrical down-tilt of 2^0. We wanted to optimize for a distance of 10 km from the base station. With the antenna at a height of 56 metres, this gave us an angle of incidence of

$$\tan^{-1}(56/10000) = 0.321^0 \quad (1)$$

Since this is close to zero, we wanted to start with an initial mechanical up-tilt of 2^0 and then vary it in increments or decrements of 0.5^0. The maximum distance we could get the signal was 17.7 km at tilt degrees of -1.5^0, and -2^0.

2) *airMAX Quality and CCQ vs Distance*:
CCQ- Wireless Client Connection Quality: The level is based on a percentage value for which 100% corresponds to a perfect link state. *airMAX Quality (AMQ)* is based on the number of retries and the quality of the physical link. Fig. 8 shows the relationship of airMAX quality and CCQ with distance. We observed that the CCQ remained unchanged irrespective of increased distance, upto 17 km. The quality of connection was good throughout, and deteriorated slightly towards the end. The behavior of airMAX link quality is as expected; it reduced as distance increased.

3) *Received Signal Strength of NSM5 CPE (RSS) vs Antenna Tilt at 5 MHz*: Since we took most of the

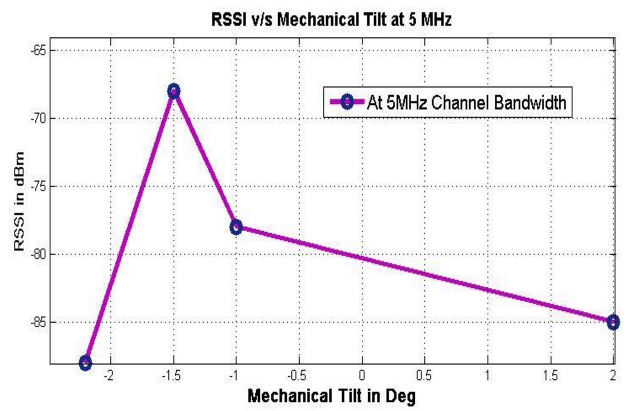

Fig. 9. RSSI vs Antenna Tilt at 5 MHz

readings keeping the channel bandwidth at 5 MHz, we decided to draw a relationship between RSSI and Antenna Tilt at 5 MHz channel bandwidth. This set of readings were taken at approximately 15 km from BS. The graph is as explained earlier. We observed a maximum RSSI of -68 dBm at -1.5^0. It started to decline as we changed the tilt degrees to -1^0, 0^0, 1^0 and 2^0. This means that at -1.5^0, the CPE is exactly in the sector of the BS sector antenna.

4) *Received Signal Strength of NSM5 CPE (RSS) vs Channel Bandwidth*: Fig. 10 shows the variation of RSSI with different channel bandwidths of 5 MHz, 10 MHz and 20 MHz. We could not measure the RSSI for all the channel bandwidths for all distances due to logistics issues. We stopped the boat at 11 km and 15 km, changed the channel bandwidth and plotted the observation. At 11 km, the result is as expected. As channel bandwidth increases, RSSI decreases. At 15 km, when we increased the bandwidth from 10 MHz to 20 MHz, to our surprise, the RSSI value increased by

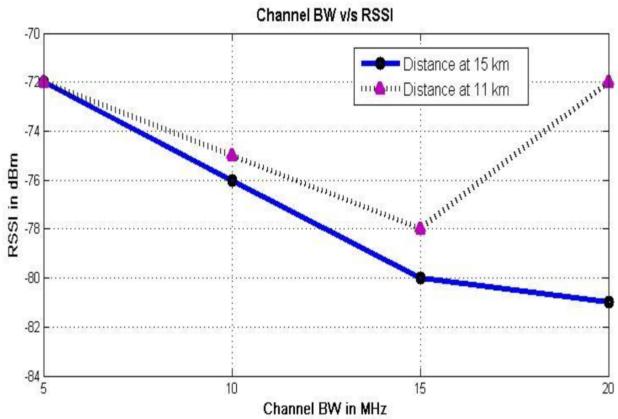

Fig. 10. RSSI vs Channel Bandwidth

about 5 dBm. This observation is still unexplained. It is unclear if it is the result of some technical glitch or a sudden variation in signal characteristics. To answer this question, we have to conduct more field trials and analyze the behavior of signal with varying channel bandwidth.

5) *Tx-Rx data rate vs Distance*: Fig. 11 shows the variation of Tx and Rx data rate with distance. We could not collect the Tx-Rx data rate values for the entire 18 kms due to logistics issues. The plot of the readings we could take, is shown in Fig. 11. At 2^{0} antenna tilt, the highest Tx data rate was around 3.25 Mbps at 16.9 km. The highest Rx data rate was around 4.25 Mbps at 16.9 km. After that the Tx and Rx data rate were pretty much the same for the remaining distances.

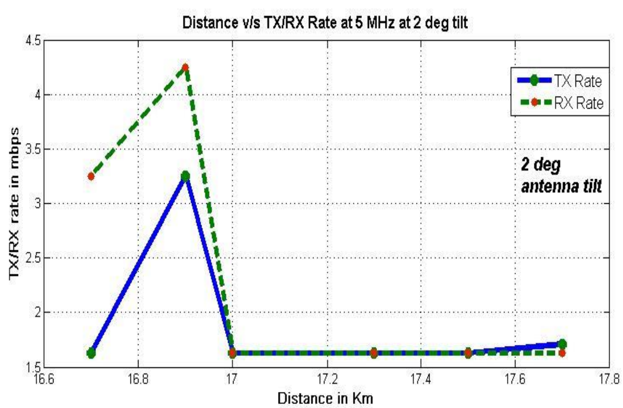

Fig. 11. Tx-Rx data rate vs Distance

Modeling the link using Ubiquiti airLink

airLink Outdoor Wireless Link Calculator, a proprietary tool provided by Ubiquiti Networks for modeling wireless links, estimates a signal strength of -72 dBm at a distance of 16 km at 5.8 GHz. The measured signal strength at 16 km was -80 dBm to -82 dBm.

VI. Conclusion and Future Work

In this research, an over the sea network architecture was designed to provide seamless and reliable long distance communication to the fishermen when they are at sea. To determine the characteristics of long distance link, various measurements were taken by conducting different experiments at different distances in the sea. We observed that to obtain the best performance at the longest link, i.e., at 17.7 km, the channel width of the transmitted signal should be set to 5 MHz and mechanical downtilt of sector antenna should be set to -1.5^{0}.

After conducting further experiments and setting up stable links, fishermen can access internet using their Wi-Fi equipped mobile phones, through which they can obtain information about weather forecast, GPS coordinates, current market rates of fishing, broadcast emergency SOS in case of boat collision or medical emergency, and contact border officials while crossing borders.

As for the future work, automatic alignment of the antennas using micro-controller driven rotary platform can be implemented. For detailed analysis of link characteristics, the similar experiments can be conducted using 2.4 GHz equipment, consequently, a comparative study can be performed with the 5 GHz experiments. Also, to answer the question of range extension, a BS can be installed in the boat, which essentially forms a multihop network.

VII. Acknowledgement

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