# Delay Tolerant Based Warning Message Broadcasting System for Marine Fisheries

**Master of Research**

**Thesis Submitted**

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Statement of Originality

This work has not been submitted for a higher degree to any other university or institution. This thesis refers the contribution of others that are used to implement our ideas.

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# Abstract

Wireless communication has been incredibly successful to make life easier. Despite of such development, many citizens are still far behind from having the benefits of modern communication systems, especially low-income people in developing regions. The marine fishing community of Bangladesh corresponds to such a scenario which as it is suffering a lot due to lack of proper warning system that could broadcast warning messages quickly to every fishing boat when there is extreme sea weather. This project's aim is to develop a warning message broadcasting system for the marine fishing boats. To make this system inexpensive and easily accessible by the fishermen, the Wi-Fi enabled phones available to the fishermen will be exploited with other wireless communication devices. This report presents the challenges and opportunities to implement this system combining Delay Tolerant Networks (DTN) with Mobile Ad-hoc Networks (MANET). The study has focused to find a suitable broadcasting protocol that will ensure fast propagation of warning messages with high reliability in this wide network environment. We have proposed a lightweight broadcasting protocol and conducted an initial evaluation of the network based on this protocol. We have also developed a new mobility model to simulate fishing boats based networks.

***Keywords: Delay Tolerant Network, Mobile Ad-hoc Network, Mobility Models, Broadcasting Protocols, Long Distance Wi-Fi Communication, Smartphones***

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# Chapter 1

# Introduction

## 1.1 Marine Fisheries and Communication

Marine fisheries play important roles in nutrition and economics for many courtiers over the world. This sector has created a significant number of employment opportunities as well. For example, one million people are involved with the marine fisheries in Bangladesh. The fishermen of Bangladesh operate around 27,699 non-mechanised and 30,164 mechanised fishing boats over a 66,440 $km^2$ area in the Bay of Bengal. There are also more than 225 commercial fishing trawlers. However, this industry often suffers from extreme sea weather like tornados, tsunami and cyclones. This causes many deaths of fishermen every year. Lack of flexible and reliable warning system is often addressed as the main reason of death and losing fishermen in the sea when there is extreme weather [1]. Therefore, an efficient early warning system can save many lives of fishermen in Bangladesh.

Very High Frequency (VHF) radios are recommended as communication devices that fishing boats will carry when they do any trips in the sea. Using VHF radio transceivers fishing boats can send distress messages, listen to weather forecasting and warning and get navigation advisory. Fishing boats can communicate using this VHF radio system with onshore base stations that are in 30 km range and 50 km if there is repeater station. They can also communicate with each other up to 10 km distance. But, the fishing boats that go beyond this distance should carry more powerful devices such as (Medium Frequency) MF/(High Frequency) HF based devices [2, 3]. The other more advance communication systems for the marine environment are GMDSS, COSPAS-SARSAT, Telex and INMARSAT etc. These are the satellite based communication systems and provide efficient communication services globally [3].

Unfortunately, fishermen of Bangladesh usually do not take the VHF radio transceivers due to their high cost and the complexity of licensing. Moreover, most of the fishermen who have VHF transceivers cannot operate it properly as they are illiterate. The situation becomes worse with the limited number of repeaters and base stations for VHF communication and some poor monitoring practices of authority. On the other hand, a satellite based system is impractical in the context of Bangladesh as most of the fishermen live under poverty margin.

However, fishing boats regularly travel up to 120 km in the deep sea for catching fish where they do not have any communication options and often fall in danger. Thus, an easily accessible, inexpensive and efficient communication system can significantly improve the marine fishing conditions of Bangladesh.

## 1.2 Motivation

The mobile phones have been a necessary household nowadays and are easily accessible by all kinds of people. Besides, the recent development of smartphone technology provides powerful phones with low cost (with $20). However, general people do not utilise its resources except for talking with others. The communication resources of these devices can be applied to develop potential off-the-self services. Some researchers have already shown its potentiality for developing off-the-self services using Wi-Fi radio of smartphones [4, 5]. Another promising low cost technology for providing Internet services in the rural area is long distance Wi-Fi. As most of the fishermen are familiar and have phones, a communication system combining long distance Wi-Fi and phones would be very flexible and cheaper for them. The authority would be motivated to develop such a system as it is comparatively an inexpensive installation and has low maintenance cost. Therefore, the poor fishermen can be relieved from suffering in the sea just doing extra utilisation of their phones. Secondly, it is significant to explore the use of MANET in the marine environments. Vehicular Ad-hoc Networks (VANETs) have been widely studied for terrestrial environment in the last decades. On the other hand, very little research has been done to leverage the capability of MANET for marine vehicles, although it could provide an effective communication platform for maritime environment combining with the low-cost, short- and long-distance Wi-Fi technology. This research will contribute to further develop the notion of having communication services from anywhere if you have wireless devices, as well as will reduce the “digital divide” among people.

## 1.3 Research Challenges

This research will develop a warning message broadcasting system exploiting Wi-Fi enabled phones available to the fishermen and combining comparatively less expensive wireless network devices such as Wi-Fi Access Points (APs) and Iridium Subscriber Units (ISUs). The network will be implemented integrating Mobile Ad-hoc Network (MANET) and Delay Tolerant Network (DTN) approach. To deploy the network a number of APs will be installed at some harbour locations on the bank of the sea and every fishing trawler will hold an AP. Onshore APs will be connected with the Ethernet and act as gateways and some trawler APs will also be attached with the Iridium Satellite Subscriber Units (satellite phones). When boats and trawlers travel for fishing, the wireless nodes (phones holding by boats and APs) will be intermittently connected due to their movements using DTNs features and will distribute warning messages executing MANET operations.

The network should distribute warning message quickly to every finishing boats. To achieve this goal is quite challenging for the proposed environment. In this network, nodes (on board phones and APs) are frequently connected/disconnected with each other due to the movements of boats and trawlers and short communication range of Wi-Fi, which is 300 meters [6]. Even there might be some nodes or groups of nodes that are totally isolated from others. Therefore, the whole network can be viewed as a collection of large number of separate network segments with one node to a group of nodes over a wide geographical area. These situations make the current MANET based broadcasting protocols unable to work here as these protocols assume that there is an end-to-end path between source and destination nodes at all times [7], and DTNs solutions need to be adapted.

The proposed network becomes highly heterogeneous as the deployed network components are with different communication capabilities and standards, from large trawlers to tiny fishing boats without power. The nodes do not follow specific tracks when they move. The broadcasting protocol should be capable to manage this heterogeneity as well as function using phones that have limited energy, memory and CPU power [8]. While the marine environment also provides some flexibilities as there is no inherent obstacles in the sea, boats are not as fast as cars and do not turn quickly. No MANET protocol considers these issues in their implementations.

Another challenge is to evaluate performance of the proposed network. The performance evaluation of any proposed network is mandatory before a real implementation. The MANET evaluation requires mobility model to reflect the movements of users. The existing mobility models are designed to evaluate terrestrial based MANET applications. None of these models reflects the movement behaviours of fishing boats. The evaluation of required protocols using these models would provide incorrect results as the underlying movements highly affect the network operation. A realistic mobility model is required to study the MANET in the marine environment.

## 1.4 Contributions

In our study, we have addressed the fundamental issues to develop such a system. This thesis contributes to the following issues:

1. We have proposed a heterogeneous network model for the marine fisheries warning system with comparatively inexpensive wireless networking devices. This network is low cost, effective, and flexible for all range of users.
2. We have developed a novel and realistic mobility model for fishing boats movement. This could be used for simulating any fishing boat based communication network. The model can distribute the nodes according to known fishing strategies and can produce traces with large number of nodes.
3. We have developed a lightweight broadcasting protocol for MANET. This protocol is Delay-Tolerant and assumes DTN properties depending on the movement behaviour: either travelling or fishing. This protocol can also retrieve missing warning message and minimal network overhead.
4. We have implemented an initial performance evaluation of the proposed warning system in a simulation environment and analysed important network parameters.

## 1.5 Thesis Organisation

The rest of the thesis is organised in the following ways:

In Chapter 2, a brief description and literature review is presented on the theoretical background and related works. This study provides an insight about the requirements, challenges and opportunities to implement a warning messaging system.

Chapter 3 describes the network modelling and the required components. We present the ways of modifying available technology to implement the network. We also analyse the capacity of the network.

The new boat mobility model is described in Chapter 4. The relevant mathematical models are described first, then proposed mobility model, its implementation, trace generation procedure and our comparative analysis with other models of NS-2 are described.

Chapter 5 presents the proposed lightweight broadcasting protocol. The performance study is presented in this chapter as well. It describes the characteristics of the network in various settings.

In Chapter 6, we provide concluding remarks and discuss future research directions in details.

# Chapter 2

# Background and Review

To design the proposed warning message broadcasting system we are required to use and combine various techniques and methods of communication technology. At the low level, the message broadcasting backbone is created connecting wireless devices carried by fishing vehicles through Mobile Ad-hoc Network (MANET). At the top level, Delay Tolerant Network (DTN) is used to mitigate the effect of disconnection occurred by the movements of fishing vehicles. All these communication strategies are supported by long distance communications to cover the large geographical area of marine fisheries. A proper integration of the above approaches would provide the efficient warning messaging system. The warning message system designing process should go through the following processes: understanding the network environments, finding relevant methods and technologies, designing and implementing the network and evaluating its performance. In this chapter, we present, in brief, the theoretical background and relevant previous works. Through this study we discuss the research challenges and possibilities for implementing the proposed network.

## 2.1 Mobile Ad-hoc Network

Mobile Ad-hoc Network (MANET) is a communication paradigm where several mobile wireless devices can dynamically form a network to exchange information with each other utilising its own networking capability without using any existing fixed network infrastructure. In MANET, the network functionality like routers, switches and servers that are usually provided by the network infrastructure are executed cooperatively by the user's wireless devices. Therefore, a source node can send data to the destination node directly or through intermediate nodes when the destination node is not within the communication range [9]. The MANET can also be connected to infrastructure network using a user as gateway device which has IP based networking services. Due to its infrastructure-less architecture and deployability with user devices, MANET has intensively been studied to implement networks in the extreme environments where network infrastructure building is impossible or traditional networking is cost prohibitive according to application objectives.

The implementation of MANET assumes almost all protocols and networking stack of Internet except some addition in the network layer as shown in Figure 2.1. MANET nodes use an ad-hoc routing protocols to route data. The basic operations of MANET protocols include updating neighbour table continuously, discovering and maintenance of routes [10]. The physical and data link layer use the protocols (IEE 802.11) that are designed for wireless channels. In the transport layer, User Datagram Protocol (UDP) is usually used as it supports both broadcast and unicast. Broadcasting is the fundamental operation of any MANET routing protocol. The Transmission Control Protocol (TCP) is not suitable in MANET as implementation of TCP would require huge networking cost for frequent route changes due to mobility.

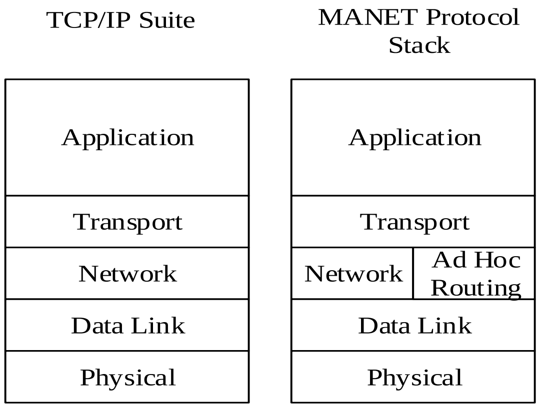



**Figure 2.1**:TCP/IP and MANET suite.

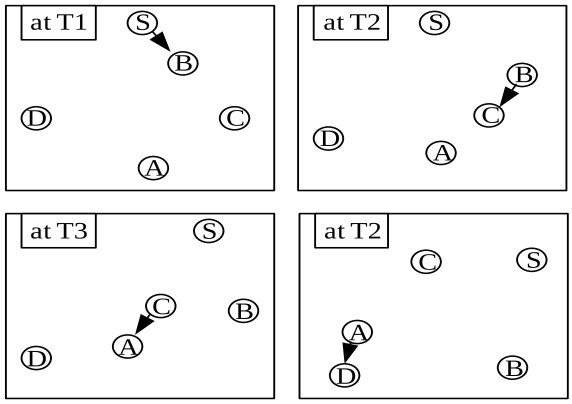



**Figure 2.2:** Packet forwarding in DTN.

## 2.2 Delay Tolerant Network

Delay Tolerant Networking (DTN) is a data forwarding technique where end-to-end paths are not available. In DTN, data is typically forwarded through a special mechanism called store-carry-forward. When a node receives a packet, it takes the decision to forward data further or not. Then it finds whether it has the chosen next hop. If the link is available to the desire node, it forwards the packet. But, if it does not have link to that node, it buffers the packet (instead of dropping it as in MANET) until the link is established to the desire node. The nodes periodically check the connectivity and when available it forwards the packet according to the routing algorithm [11]. The basic mechanism of data routing is shown in Figure-2.2. At time $T_1$ source S has a message m for node D and the message reaches to D at $T_4$ through different meetings and exchanges among the nodes in the network. The DTN routing protocol determines the policy of forwarding to a visited node and erasing the packet. Two basic approaches are widely used in DTN routing: blind distribution (epidemic routing) in which ever node forward packet when met other nodes and limited distribution (Spray and Wait) in which a limited number of forwarding is done through some mechanisms [7].

The DTN works whether independently or as an overlay network of others. As the independent network, DTN follows the bundle protocol which composes of techniques to implement store-carry-forward data propagation. However, when the DTN is applied on top of the other network, the packet forwarding mechanism becomes relevant to the underlying network protocols. The DTN is frequently adopted as an overlay network in the many MANET applications. This makes the MANET to function in the disrupted networking environment as majority of MANET routing protocol assume that end-to-end path exists between source and destination [7]. On the other hand, DTN protocols show poor performance in the dense and large network due to huge duplicate copies of packet. In this case, DTN performance can be improved by adopting MANET approach in its operations.

## 2.3 Long Range Wi-Fi Communication

802.11 Wi-Fi technology is widely used for providing wireless communication services for few hundred meters. However, Wi-Fi also attracted the research community because of its cost-effectiveness for long distance communication. Several factors are helping Wi-Fi being popular for long distance: operating in licence free spectrum, availability of compatible devices and low installation cost. In this case, it is often referred to as **Wi-Fi** over Long **Distance** (**WiLD**). The basic requirement for long distance Wi-Fi is the line of sight between the endpoints. With careful planning and proper antenna, WiLD can communicate up to tens of kilometres for point-to-multipoint links (PtM) and hundreds of kilometres for point-to-point links (PtP) [12].

The MAC 802.11 is modified to implement the long distance Wi-Fi. The MAC protocol usually waits for the acknowledgement after sending the data packet. But, the normal ACK_timeout is smaller than the required time out for long distance. For proper long distance communications it needs to be increased. The slot time is also required to increase as the other terminals in the vicinity get time to understand that other station is transmuting. This is required to configure properly. Otherwise it will produce the underutilisation of system resources. Some modifications are also done at the driver level. The interlink interference is another serious obstacle to implement the WiLD. Modification of generic 802.11 CSMA/CA protocol can provide up to few thousands meter for PtM. But for the hundreds of kilometres TDMA based MAC is recommended [13].

Several projects have been implemented in practical using long distance Wi-Fi. The Village Telco project [14] has developed a VoIP telephony system using long distance Wi-Fi. The mesh potatoes that have long distance Wi-Fi work as terminal for users as well as interconnecting devices to the Ethernet or other mesh potatoes. The author of [15] has implemented communication system for the fishermen using WiLD. Some trawlers have nano base station to connect with on-shore base station. These trawlers have also APs to form mesh network with other trawlers. These APs also connect user's terminal. These projects did not include the user terminals in the network operation.

## 2.4 MANETs using Smartphones

The availability of smartphones to all kinds of people and its flexibility with rich technical resources such as portability, high computing power, versatile user-interface, improved battery powered operation and advanced communication capability etc. has created opportunities to develop potential off-the-self applications to benefit humanity [16]. As the growth of smartphone users are tremendous, phone based MANET applications using peer-to-peer communication is being considered as the future communication endeavours [8]. Although MANET implementation on phones is not new. The project BEDnet [17] developed a Java application to form MANET network among phones using Bluetooth. However, the range and data rate of Bluetooth is very limited. But, recent smartphones are equipped with strong Wi-Fi radio that can transmit data for longer rang with more data speed. With its generic capability, it is also able to work in the ad-hoc mode that allows phones to connect with each other without infrastructure mode. Nokia's Symbian operating system is only OS that have built in ad-hoc support. For the other OS, it is required to modify at the Wi-Fi driver. This modification is possible if the Wi-Fi chip supports Wireless Extension APIs which is used to manipulate wireless networking devices in a standard and uniform way. Android platform supports WEAPI, but not for all chips.

Phone based MANET applications have been demonstrated in practical by some projects. The Serval Project [4] is one of them which implemented a communication system to provide free phone-to-phone local calling, sort messaging and small file sharing using Wi-Fi communication. Another practical demonstration is done by the Terranet [18], a telecom company. In their approach two phones can communicate from few hundred meters. This technology is required a special devices. The SPAN project [19] is also conducted to develop a framework for MANET application on smartphones. The Serval and SPAN projects open their code and can be installed on the supported platform. Another similar project based on peer-to-peer communization is the Firechat [20]. If someone does not have Internet connection, he can share internet connection of other and can talk each other. But, the scalability of these systems is very low. Maximum 20 users can be served by these systems.

## 2.5 Broadcasting in MANET and DTN

Broadcasting is widely used to implement various MANET applications such as instruction distribution in disaster recovery communication system, contents distribution in social networks, and emergency and traffic information dissemination in Vehicular Ad Hoc Networks (VANETs) etc. Broadcasting is also the basic building block for many routing algorithms in MANET where data and control packets are distributed throughout the entire network to establish route to each destination. This network wide broadcast is often done using local broadcasting technique where nodes send messages simultaneously to all their neighbours for further retransmission. The IEEE 802.11 interface has the built-in facility for local broadcasting. However, this approach is highly unreliable for warning message distribution throughout the entire network as messages are not acknowledged and may be lost due to collisions.

Another prominent approach of broadcasting is to forward the message to all neighbours one by one. The simplest way to implement one by one broadcasting is called flooding where nodes re-transmit a received message to its neighbours when it receives message first time. This ensures reliability locally as exchanges are acknowledged and high reach-ability as rebroadcasting process continues until all nodes in the network have received a copy of the packet. However, this mechanism generates a large number of redundant transmissions which will eventually overwhelm the network and consume unnecessary energy [21]. Various techniques have been developed to reduce redundant transmissions. These techniques can be divided into four categories: probabilistic methods, neighbour information based methods, group based methods and hybrid methods. Performances of the broadcasting methods are highly affected by the environment where it is applied. The following paragraphs describe the applicability of present broadcasting protocols in the proposed network environment.

### *2.5.1 Probabilistic Methods*

Probabilistic methods assign a probability of rebroadcasting to every node depending on some metrics. The frequently used metric is neighbour density which is determined using hello messages and duplicate received messages [22]. In these methods, node assumes high probability when it is in sparse regions and low probability when in dense regions. Measuring distance between a receiver and a sender is another way to find rebroadcasting probability where the probability is set to low if the message is received from closest neighbour and high when the sender node is far way [23]. The author of [24] combined duplicate message counting with distance measuring to improve performance. These methods reduce overhead to some extent and the protocol often remains light, but without guarantee that every node gets the message and situations get worse in sparse and dynamic networks.

### *2.5.2 Group Based Methods*

This approach divides nodes into groups. Tree structure is one of the familiar methods where nodes are grouped through parents and children creation. The broadcasting is done through parents to children and the broadcasting is finished when all its children get the message [25]. In another approach called clustering, a cluster head transmits messages to every cluster members and gateway nodes forward from one cluster to another. These schemes reduce retransmission due to its acyclic structures and ensure reachability[26, 27]. Connected Dominating Set (CDS) based broadcasting is another form of grouping where one builds a subset of nodes that have connections to all other nodes of network. Only this subset is responsible to broadcast the messages and this reduces retransmission [28]. As broadcasting in these methods depend on some specific nodes, malfunctioning or inappropriate selection of these nodes might fail the broadcasting process. The maintenance of the group also produces extra overhead. In addition, these methods cannot maintain reliability in sparse and dynamic network.

### *2.5.3 Neighbour Knowledge Based Methods*

In this approach, nodes use neighbours information, collected through “Hello” packets, in the decision of retransmitting messages. The simplest method of this group is the Self-Pruning that combines a list of neighbours with the packet header when rebroadcasting. The receiver node rebroadcasts messages based on this list [29]. The protocol is light, but only reduces a few retransmission and provides poor reliability. Multi-point relays (MPR) is a widely used neighbour-based method which counts 2-hop neighbours and chose a small subset of one-hop neighbours to broadcast to all nodes in the 2-hop. Consequently other one-hop neighbours refrain themselves from rebroadcasting. This scheme reduces retransmissions dramatically, but performance may degrade due to instability of MPR set in dynamic cases and dropping messages when no neighbour exists [30]. The authors of [31] counted 3-hop neighbours and built a two-hop connected dominating set to broadcast messages within the network of 3-hops. The researcher of [32] proposed a K-hop based broadcasting system. These methods generate maintenance overhead that often overlooks the benefits of reducing retransmission.

### *2.5.4 Hybrid Methods*

To improve the performance of broadcasting, some methods have also been developed combining different approaches. The author of [33] has combined clustering and MPR to reduce overhead for TC messages broadcasting in the Optimised Link State Routing protocol (OLSR). They considered each cluster as a node and used the cluster head to represent their cluster. The MPR techniques is applied to broadcast message among cluster heads and cluster heads distribute messages to its cluster member locally. This increases the scalability of the network as well as reduces redundant broadcasting. But, this process requires extra processing for cluster maintenance. The MPR is also applied to find connected dominating set (CDS) in [34]. As MPR based broadcasting approach produces local CDS, they connect the MPR-based CDS to cover the whole network. This approach also reduces the number of retransmission. The author of [35] introduced the idea of gateway MPR in the CDS based broadcasting to minimize redundant retransmission. However, these processes require more maintenance work in dynamic networks.

## 2.6 MANET in the Marine Environment

Vehicular Ad-hoc Network (VANET) is being researched intensively for the last decades. These network adopt MANET and DTN to implement communication system. However, in the literature, we have found that few works have been done to exploit the potentiality of MANET and DTN in the marine environment. The authors of [36] have integrated MANET, cellular mobile gateways and satellite gateways to deploy a mesh network based communication system for ocean fishery vessels. In this network, the on-board phones or laptops can communicate with other ships through mesh access points on ships. However, the users beyond one-hop communication range of APs cannot communicate and the network components are expensive. In [37], the authors have implemented MANET for Maritime Tactical Network (MTN). This network connects mobile ships, submarine, aircraft and shore stations. They have focused on finding the route with less number of hops and considered that the nodes have enough network resources. A MANET based communication system using available VHF devices is developed in [38]. They studied the performance of Ad-hoc On Demand Vector protocol (AODV), AOMDV and DSR in implementing MANET in the maritime environment. In [36], the authors integrated MANET and DTN to address sparse vessel density over large geographical area. However, this is a simulation work only for 100 vessels. These previous works implemented MANET with the nodes having sufficient networking resources and are not applicable for all range of users. They also did not address network disconnections except the work of [38].

## 2.7 Communication using Boats

Some works has also been done to provide data transfer services using movement of boats. In [3], the author has proposed a software defined radio based multi-hop communication system for locating fishing boats, providing weather information and short messaging between boats and mainland stations. They proposed to use their special RF transceivers and used GPS system. The authors of [39] have studied two popular MANET protocols OLSR and AODV forming an ad-hoc network among oil supply boats, oil platforms and onshore stations. Their study revealed that the protocols require modification to be suitable in the maritime environment. These works did not consider the disconnection in the network. Boat based networks were also implemented to exchange data among riparian communities connected by rivers in the Amazon. These networks exploited the trips of boats for implementing DTN based ad-hoc network. Their implementations were relaxed to allow any delay in communication, even one days.

## 2.8 Mobility Models for Network Simulation

A proper performance evaluation through simulation is a prerequisite in any network design. This allows the designer to achieve the best-practice design for the target network environment. In the study of Mobile Ad-hoc Network (MANET), simulation tools require to know the movement patterns of nodes to provide the accurate evaluation of the network performance as the underlying movements of nodes determine the lifetime of links and hence the operation of the network. Therefore, an appropriate mobility model that resembles the movement of users in the real network scenario is required to make an accurate evaluation. Many generic mobility models have been developed to assist the MANET simulation [40]. These models define some rules to generate trajectories of mobile nodes changing the speed and direction with time. Two basic approaches are used in these models to formulate movements of node: traces and synthetic. Trace based mobility models are developed based on the real traces. The parameters of these mobility models are derived and validated using the real trace. Therefore, the models can drive the nodes in the simulation area replicating real movements. However, this approach can only be applied to a limited number of network environments as real traces are not available for all scenarios. On the other hand, synthetic models attempt to realistically reflect the movement behaviours of nodes without the use of traces. With proper mathematical modelling the synthetic model can generate traces for any network scenarios. The underlying mathematics of these models depends on the characteristics of movements. The typical mobility characteristics that mobile nodes show in the real world scenarios are random movements, temporal dependency, spatial dependency and restricted movements [41, 42].

The Random Waypoint is one of the simplest models for generating random movements. This model is frequently implemented in the network simulator such as NS-2. In this model, node randomly selects a location within the simulation area and moves towards it with a speed distributed in the range $[V_{min}, V_{max}]$. Reaching the destination, the node stops for a pause-time period and then repeats the procedures. It is found that the Random Waypoint cannot maintain uniform distribution of nodes as simulation time passes and nodes are finally converged around a specific area [43]. The distribution problem is improved by the Random Direction model [44] which drives the nodes in the same direction until reach to the simulation boundary. These models can not reflect the real scenarios as nodes stop suddenly without considering past movements. In reality, user's movements show some temporal dependency i.e. speeds and directions depend on the previous ones. The Gauss-Markov model was developed by [45] to correlate velocities over time and avoid abrupt behaviours. The model is based on the Gauss-Markov stochastic process. Another temporal mobility model is the Smooth Random (SR) model which drives nodes in a specific direction with fixed velocity until a new direction and speed are imposed [46]. This model is designed based on the Poison process. Beside temporal dependency, nodes also show spatial dependency where nodes speed and direction are influenced by other nodes. This dependency is modelled in the Reference Point Group Mobility Model (RPGM). In RPGM, nodes move in relation to a logical group centre that is created for its group [47]. In the above models nodes are free to move anywhere in the simulation area. However, the user's movements in reality are influenced by some physical factors. The mobility model should consider the geographical structure of network scenarios. The pathway model is the popular model from this category [48]. These models are designed to generate traces for land based users. Thus, it cannot reflect movements of vehicles in the water.

## 2.9 Discussion

In the literature review, we have found very few amount of study for implementing phone based MANET application in the wider context. The work of [4, 18] implemented MANET for a small number of users and they did not consider the disconnectivity in the network. The author of [15] has implemented a network for communication in the marine environment, but it needs special equipment and this is not for all kind of users. In our system, we would like to connect phones of fishermen with the communication system. All of these previous works are not directly applicable to implement our proposed warning system.

The proposed network requires a broadcasting protocol that can forward warning messages to all fishing boats. However, efficiency of broadcasting algorithm not only depends on the novel design of algorithm but also on the network scenarios and networking capabilities of the participating nodes. In the proposed network, links with neighbours are unpredictable as nodes do not follow specific track and move independently during its trips in the sea. The nodes have various communication capabilities (phones and APs) and moving speeds (boats and trawlers). These conditions unable the probabilistic methods to determine appropriate probability of rebroadcasting and will drop reliability. Clustering based broadcasting provides reliability where nodes move with less speed. However, the performance of broadcasting degrades considerably when the cluster heads or gateway nodes fail to do their jobs. The node density is very low in the proposed environment and many nodes are isolated. Therefore, many cluster will be with a single node and benefits of cluster will be lost. This approach also did not address the network partitioning. In the 2-hop neighbour information based Multi-Point Relaying (MPR), a subset of nodes rebroadcasts to all 2-hop nodes and maintenance is more frequent than clustering. These offer more reliability. The Optimized Link State Routing (OLSR) protocol, an enormous successful MANET protocol, has adapted this MPR scheme to broadcast control packets throughout the entire network [49]. However, the MPR is not directly applicable in this frequently partitioned network as it drops rebroadcasting when there is no neighbour.

The authors of [50, 51] have proposed a store-forward technique to address disconnections in the MPR based routing protocols. In his technique, nodes buffer packet when there is no next hop node to forward it to. Whenever the next hop is available for the desired destination, the packet is forwarded. This approach cannot provide fast and reliable broadcasting as there is no guarantee that the nodes buffered packets will travel to the network segments that still have not received the packets. There might be some nodes that could visit the disconnected segment quickly due to their high speed. Finding this kind of nodes and allowing them to carry the message to the nearby network segments will improve the reachability. Besides, MPR based broadcasting method cannot address the isolated nodes that might not be present during diffusion of messages. As the proposed network spans a large geographical area and deals with large number of nodes, there will be a large number of nodes that will miss the warning messages. MPR broadcast does not have the ability to identify who missed the messages and broadcasts messages just once. Therefore, a mechanism is required for a node to retrieve warning message when met other nodes.

The proposed network studied here is a heterogeneous network. Exploiting heterogeneity provides some opportunities to improve the network performance with some complexity. The author of [52] has proposed a DTN overlay network for such a heterogeneous and disconnected network. However, the author applied reactive techniques to handle disruption that depended only on some specific nodes called DTN capable nodes. Non-DTN capable nodes cannot take part in DTN activities. Therefore, the network cannot mitigate the effects of disruption completely. Proper overlay network management is required to leverage the wireless capability of APs. On the other hand, the protocol should be lightweight as most of the nodes in this network are phones with limited memory, battery and CPU power.

As we have seen, the performance of the MANET protocols is highly affected by the underlying mobility of nodes. Therefore, the accuracy of protocols evaluation depends on the mobility models used for simulation. According to our survey presented in section 2.8, existing models provide traces to simulate networks where nodes move on the land. None of them is appropriate to mimic the movements of marine vehicles. The marine vehicles are not restricted to move on the specific tracks like vehicles on land. Turning angle and speed changing conditions are different to movements of terrestrial based vehicles. If the movements are considered for fishing boats, generating traces for network simulation is not possible with the existing models. The movements of fishing boats depends on the fishing strategies and shows characteristics of randomness, temporal dependency, spatial dependency and restricted movements at the different stages of its trajectories. Although mobility models have been developed to mimic these characteristics, no one considers the movements on the water instead of land. Therefore, to study the MANET applications in the marine environment a new mobility model is required to develop. The authors of [53, 54] have studied the trajectories of fishing boats from the data collected by satellite-based Vessel Monitoring Systems (VMS). These references can be used to develop a boat mobility model for network simulation.

# Chapter 3

# Network Modelling

The main goal of our study is to design a flexible and inexpensive warning message broadcasting system for the marine fishing community. The current development of communication technology provides powerful wireless devices such as smartphones and Wi-Fi Access Points (APs) with low cost and these devices are easily accessible. The capability of these devices is not always utilized in their general uses. The research community has focused to utilize the potentiality of these devices for off-the-self services as well. In this chapter, we have presented a warning message broadcasting network model that would be implemented with the user's available resources (smartphones) combining with inexpensive wireless communication devices (APs and Satellite Phones). The proposed network would require little installation cost and easy to access as most of the people are used to with phones these days. At first, we have explained the network architecture for warning system and then we have presented the required modelling of components to implement the warning system.

## 3.1 Proposed Network

**Network Description:** The main networking resources for the proposed network are Wi-Fi enabled phones available to the fishermen, Wi-Fi Access Points (APs) with long distance communication capability and Iridium Subscriber Units (ISUs) connected with satellite. The Figure 3.1 depicts the network scenario and possible communication paths in the network.

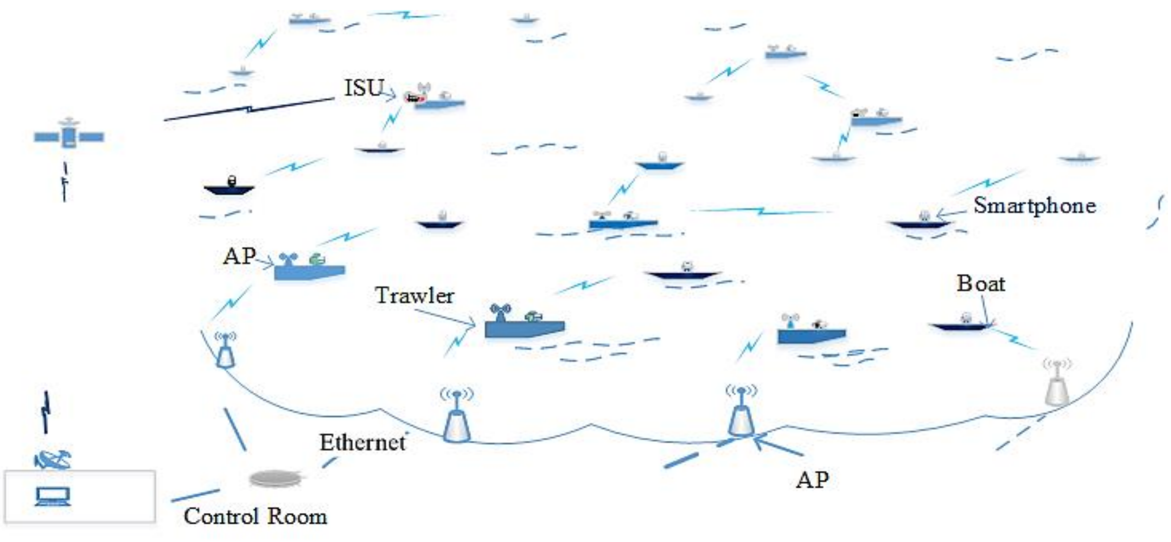



**Figure 3.1:** Network scenario for the marine fisheries.

To deploy the network, several Wi-Fi access points (APs) will be installed on the harbours where trawlers and boats gather to sell and download the catch fish. These APs are equipped with directional antenna to radiate signal toward the sea. The control room is connected with these APs via Ethernet and injects the warning messages into the network through these APs. AP will also be installed on every trawler and some of these APs will be equipped with the ISU. Control room will push the warning messages through these ISUs as well. The ISUs are communicated through satellite communication from the control room.  It is assumed that every boat will have at least one phone participating in the network.

In the network, warning messages are diffused through different APs situated on different regions so that the delivery time to all boats decreases and the number of message recipients increases. Then, the warning messages are distributed through the MANET formed by phones and APs. As the nodes of MANET behave as both user and a router simultaneously, message is relayed by every node and traverse over the network. When the trawlers and boats travel to fishing, the on-board APs and phones come into communication range of each other and exchange messages. As the nodes (phones and APs) frequently change connection, they have the capability through delay tolerant networking (DTN) to buffer data if they do not find nodes to forward data. The network functions as a double layer network composed of a lower MANET and an upper MANET. The lower MANET is formed by phones and APs whereas upper MANET is formed by APs only (see Figure 3.2a and 3.2b). Therefore, the APs communicate with phones and other APs concurrently as well as with Ethernet and ISUs in some cases.

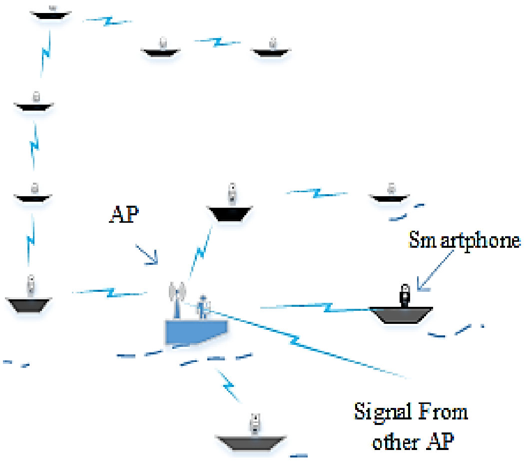



**Figure 3.2a:** Lower MANET operation.

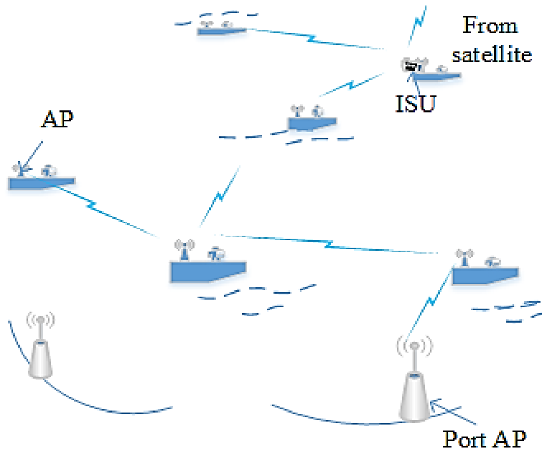



**Figure 3.2b:** Upper MANET operation.

**Warning Message Structure:** The warning messages is forwarded to the fishing boats as soon as possible, when events like Tropical Cyclone, Heavy Rain, Strong Wind and Storm Surge occur. Four levels of warnings are maintained for the marine environment.

**Table 3.1:** Four stages of warning

| Serial No. | Stages of warning | Signals No. |
|---|---|---|
| 01 | Alert Stage | I, II & III |
| 02 | Warning Stage | IV |
| 03 | Disaster Stage | V, VI, VII, VII , IX and X |
| 04 | Post Disaster Stage | Immediately after the cyclone till normalcy is attained. |

The general convention for issuing warning messages in Bangladesh is as follows:

a) Warning Stage: 24 hours in advance.

b) Danger Stage: Minimum 18 hours in advance.

c) Great Danger Stage: Minimum 10 hours in advance

The warning messages will contain information about position and intensity of Cyclone, distance from the coast, past movement and expected future movement over the sea. This also includes information about Wind, Storm surge, inundation and Heavy rainfall [55, 56].

The proposed network will wrap the above information into text messages and distribute to the fishermen. The format of the messages as follows:

| Warning Keyword | Signal no. | Event Name | Speed | Current Position | Destination | Distance from coast |
|---|---|---|---|---|---|---|

The following is the example about a warning message for a Cyclone.

**Warning-II Cyclone 110km/h Andaman Sea Tamilnadu 2000km**

Messaging frequency is every four hours at warning stage, every two hours at danger stage and every hour at great danger stage.

## 3.2 Network Implementation

The proposed network components cannot execute network operation with its usual configuration. The components are usually configured to perform some traditional networking activities. To apply these components in warning system, these should be modelled to work according to proposed network operations when they participate in the network. In this section, we have discussed required modelling and functionalities of these components.

### *3.2.1 MANET Operation on Phones*

The Wi-Fi hardware of smartphone is usually configured to operate in the infrastructure mode (manage mode). In this mode, phone continuously searches for network to attach with an AP and can communicate with other devices on the network through this AP. However, there is no dedicated devices like AP for managing network operation in MANET. Thus, MANET users should be capable to know about the network topology by itself and route data packet intelligently. To participate in MANET, phone's Wi-Fi hardware should be configured to scan the network constantly for any data traffic as well as maintain the neighbour table up to date for routing operation. The others required reconfiguration are: keep reception of UDP packets while phone is in the sleep mode and avoid manage mode operation when participating in MANET [57].

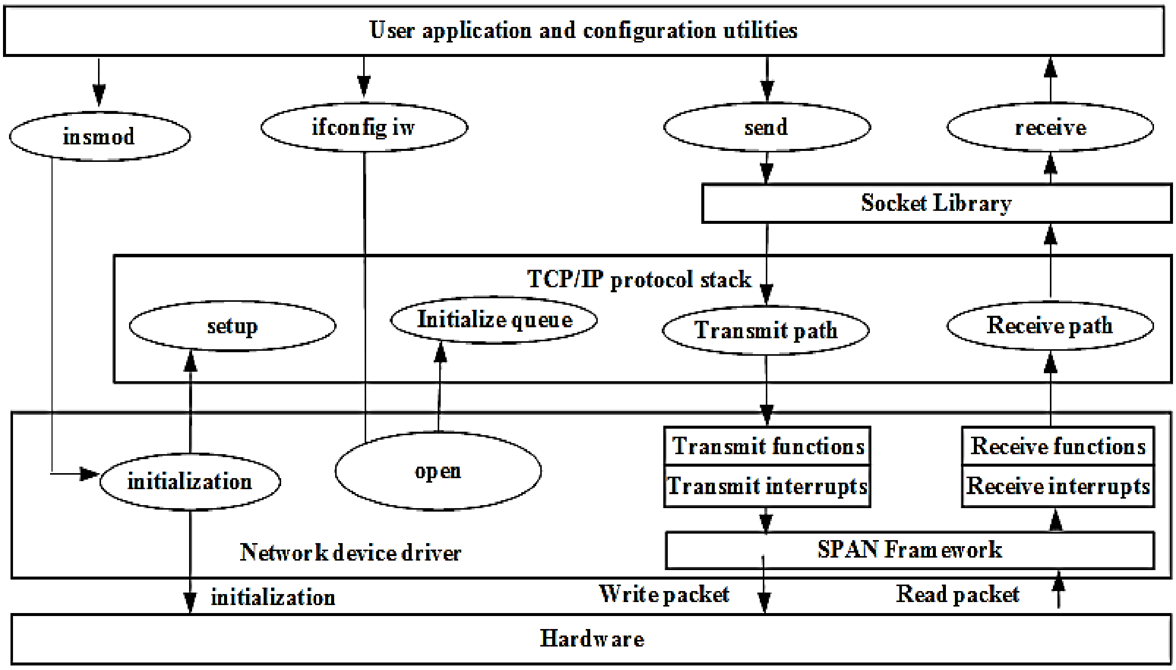



**Figure 3.3** Network stack with SPAN Framework.

The above reconfiguration can be achieved through the modification in wireless driver. The prominent work for MANET implementation on smartphones is done by the SPAN Project. The Figure 3.3 shows the developed framework for MANET mode in android OS. The MANET framework is placed between layers 2 and 3 of the existing Android network stack. Therefore, it becomes completely hidden to the OS and hence all current apps, but it can manipulate all traffics. The application is divided into two parts: MANET Manager and OLSRd. Launching MANET Manager triggers changes of Wi-Fi mode from infrastructure to ad-hoc and allows users to set distinct IP addresses and DNS servers, change default wireless SSID and transmit power of the wireless interface etc. The second part of application accommodates the code of routing algorithm. The default routing algorithm is

OLSRd [58]. However, this code can be replaced with other using NDK toolset that allows importing and utilising some existing codes of Android. Therefore, we can easily integrate our broadcasting protocol instead of OLSRd [59].

### *3.2.2 Increase Communication Range of Phones*

The phones are the main components of the network. As the network is sparse, the communication range of the phone play vital role to up-lift the performance of network. The range is varied by the transmitting power, noise added by propagation path, receiver sensitivity, channel bandwidth and data rates etc. The authors of [60] have found that phone can receive beacon frames from 350 m in the free space. This communication range can be increased further by transmitting signal over the narrow channel bandwidth instead of 20 MHz bandwidth. The authors of [61, 62] have studied the effects of channel bandwidth on range and found that changing bandwidth from 40 MHz to 5 MHz could increase range up to 123.9%. The transmission on narrow channel bandwidth allocates more energy per Hz and gets less noise and signal hence goes furthest distance. The authors have modified at the driver level to manage channel widths of 5, 10, 20, and 40 MHz and respective data rates.

As the Atheros and Broadcom based smartphone Wi-Fi drivers have already been modified to implement MANET mode, smartphones drivers can also be modified to operate the radio with narrow channel bandwidth [61, 62]. Phase Locked Loop (PLL) is used to synthesise the frequency in the most wireless chipsets. The clock frequency for RF transceiver and base-band/MAC processor are derived from the reference frequency applied to PLL using a frequency divider. The reference frequency to PLL also determines the channel bandwidth [60]. The clock frequency and bandwidth are controlled through a hardware register which changes frequency two times for changing value one. Therefore, putting corresponding register value, 5 MHz bandwidth can be set. As the RF transceiver is same to base-band/MAC processor, the symbol duration of OFDM signal is changed and hence the data rate is changed.

### *3.2.3 Long Distance Communication using Access Points (APs)*

**Communication Range Estimation:** The proposed network is required to cover about 62,000 km$^2$. The Figure 3.4 shows the geographical structure of marine economic zone of Bangladesh. About 225 fishing trawlers regularly operate over this area for fishing. All the trawlers will hold Wi-Fi access point (AP) with long range capability and establish MANET among themselves to route data packets. To make a rough estimation of communication range by which APs can cover 62,000 km$^2$, we consider that the 225 trawlers are distributed with 20 columns and 11 rows as shown in Figure 3.4. The port APs will add another row. If we consider that the required communication rang of AP is $X$ kilometre, the coverage area by the above arrangement is,

$$area = (20 - 1) \times (11 - 1) \times X^2$$

Thus for the proposed are of $\quad 62000 = (20 - 1) \times (11 - 1) \times X^2$

We have, $\quad X = 18\ km$


**Figure 3.4** Marine economic zone of Bangladesh.

**APs Installation:** The APs should be capable to work with different networks (Ethernet and ISUs) and communicate up to 18 km. Some manufacturers (EnGenius) provide high power outdoor APs for long range communication. The model EnGenius EOA3630 is multi-functional and can transmit signal with maximum 28 dBm, while the receiver sensitivity is -97 dBm for 1 Mbps. These APs will be installed and upgraded with omni-directional antenna (EAO-2400-15W) of 15 dBi gain and hence can cover more than 18 km (see section-3.3). As the omnidirectional antenna radiates energy in all horizontal direction, installing such antenna at the hub locations will cause some unnecessary interference from urban area. EOC-2610 model of En-genius with 10 dBi directional antenna are chosen for hub to avoid interference from urban side. According to the specification, they can communicate up to 30 km [63].

The antenna is required to install at the appropriate height to achieve the target range. When the radio wave propagates, the energy is spread out forming an elliptical area called Fresnel zone [64]. The signal gets interference when there is any objects or ground contacts within the inner 60% of Fresnel zone. The radius, $R$, for the inner 60% is called "First Fresnel Zone" and is given by

$$R = 5.1 \times \sqrt{D/F} \tag{1}$$

where, D is the distance between the antennas (in kilometres) and F is the frequency in GHz. For the required communication range of 18 km,

$$R = 5.1 \times \sqrt{1\,8/2.4} = 13.96\ m$$

The earth curvature also affects the line of sight distance and antenna should avoid this obstruction as well [22]. The relation for line of sight with antenna height is given by

$$horizon(km) = 3.5 \times \sqrt{height}$$

where, *height* is in meter.

Thus, the additional antenna height will be

$$\frac{linkdistance}{2} = 3.5 \times \sqrt{height}$$

$$height = \left(\frac{linkdistance}{2 \times 3.5}\right)^2$$

$$= 4.5m$$

Therefore, the minimum antenna height would be (13.96 + 4.5) =18.46 meters. The high antenna height also reduces interferences for the phones that establish the lower MANET.

CSMA/CA is used as the MAC protocol for this network. The MAC protocol specified in the IEEE 802.11 standard cannot operate properly for long distance Wi-Fi communication as the CSMA/CA was designed for nodes communicating from few hundred meters. The basic parameters of CSMA/CA are SIFS, DIFS, Back-off time and ACK-timeout that are determined by the slot time. The slot time should be greater than the propagation time of radio waves from one station to another station so that they can avoid collisions [65]. The estimated communication range is 18 km for the stations who will receive packets. Therefore, there should be 2 km more range so that nodes can understand that someone is transmitting. Thus, the minimum slot time is

$$slot - time = \frac{(18 + 2)km}{3 \times 10^5 km} = 60\ \mu s$$

### *3.2.4 Iridium Subscriber Units*

The Iridium System provides communication services to virtually any place on the earth. This communication system is based on sixty six Low-Earth Orbiting (LEO) satellites that are arranged in such a way that every location on the earth is covered by at least one satellite at all time. These satellites form mesh networking and each satellite is cross-linked with other four satellites to provide robust services. The Iridium satellite network is connected to terrestrial data networks through System Control Segments (ground centres and gateways). The users can connect to the network through Iridium subscriber products (phones and pagers etc.). The data is relayed from one satellite to another until they reach the satellite above the Iridium Subscriber Unit (ISU) [66].

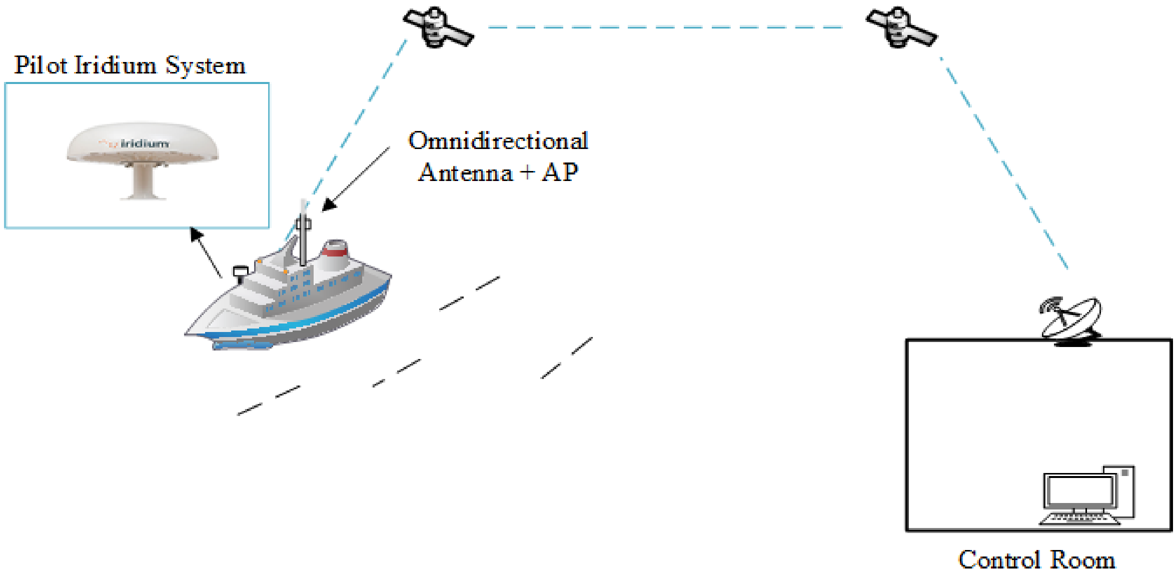



**Figure 3.5** Data communication using Iridium Subscriber Unit.

The Iridium Pilot system is the suitable subscriber product that can be connected to some of the trawlers' APs to work as gateways. This has two basic components: Above Decks Equipment (ADE) and Below Decks Equipment (BDE). ADE has the transceivers and digital base-band processor as well as a solid state antenna array for locating and tracking overhead Iridium satellites to establish communication. The BDE is the equipment through which phones and computers connect to the Iridium system. The BDE has Ethernet port that can be connected with the APs easily. The Iridium Pilot system requires a SIM card from the Iridium authority to run the system. The Iridium system can support data up to 2400 bit/sec. The data can be received as UDP packets through Ethernet port to the APs [67].

### *3.2.5 Heterogeneous Networking with APs*

In the proposed network, phones and APs are required to exchange data to execute network operations. However, they have different communication capabilities and need some procedures to interact with each other. This is usually done installing two interfaces with the single AP (e.g. mesh networking). The interfaces are configured to operate with different configurations. However, this solution is expensive. In the wireless networking, network interface virtualization is one of the promising approaches that can allow heterogeneous devices to connect to a WLAN through a common access point [68]. The potentiality of network interface virtualization will be used to handle the proposed double layer MANET through single AP. This will reduce the implementation cost of warning system.

The author of [69] has proposed a model for MAC virtualization where the generic MAC firmware is modified to implement a MAC virtualization architecture. This architecture has two parts: MAC Engine and Virtual MAC Monitor. The architecture is shown in Figure 3.6. There is a virtual engine correspond to each virtual MAC. The virtual MAC monitor exposes the appropriate virtual engine and relevant upper level network applications to the clients for this VAP through MAC engine. The MAC engine fetches the MAC program from the virtual MACs and runs the hardware according to the configuration (data rates, channel, slot time etc.) of this VAP. The hardware is shared through TDMA. The consumption duration is specified in the MAC configuration.

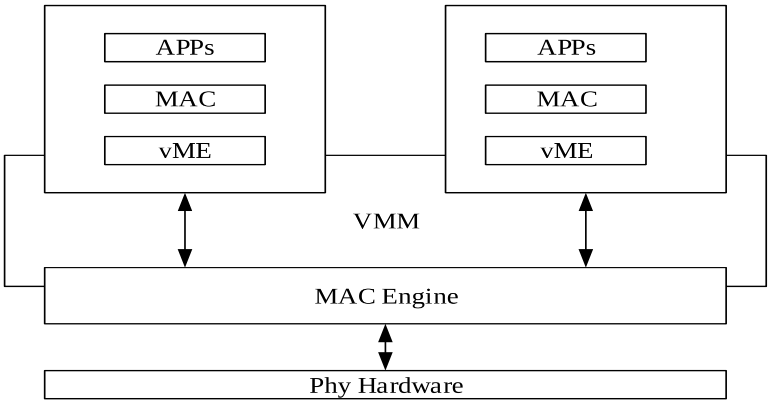



**Figure 3.6:** MAC virtualization on AP.


**Figure 3.7:** Time schedule for two layers.

In the proposed network, every AP will have two virtual MACs with two configurations: long range and short range. A common routing agent will be used for both VMAC. Long range MAC will operate on channel 1 with the maximum transmitting power of 27 dBm and modulation and coding scheme for 5 MHz bandwidth. The short range VMAC will operate on channel 3 with the transmitting power of 1 dBm to make compatibility with phones and modulation and coding scheme for 5 MHz bandwidth. The hardware scheduling sequence by VMACs is shown in Figure 3.7. According to this time slot corresponding nodes will exchange hello messages and data. The nodes of lower layer MANET cannot communicate any time with the AP nodes. This situation will be handled by instructing the one-hop phones of APs to send the hello messages during the slot time specified for lower MANET and buffering the data packet destined to AP until a threshold time is expired. This threshold time will be set to two time slots.

As the selected APs support IEEE 802.11b/g, the phones will be configured to operate on IEEE 802.11g when they take part in the MANET operations [63]. The APs which are connected with the Ethernet and ISUs will be configured to receive data via Ethernet port as they do in their general use. But, the Wi-Fi interface will be configured to operate MANET operations. The ISUs can work as modem and connect to other devices through the Ethernet port of AP. Therefore, the client can get satellite based data services using ISU connected AP. The broadcasting protocol will be designed to consider the Ethernet connected devices as neighbours. The warning messages are forwarded and received from these devices. These configurations can be implanted using MadWiFi which is open source AP software [81].

## 3.3 Network Capacity

The performance of the above model varies by some networking parameters. In this section, we have analysed the possible communication range of phones and APs and the maximum throughput. [63]

### *3.3.1 Link Budget for Phones*

The minimum required signal for considering a packet as valid depends on the strength of noise components in the signal. The noise that significantly affects RF signal is thermal noise, noise figure and device noise that is produced at the receiver circuits [5]. The following equation (2) measures the total noise called noise floor where $\Delta f$ is the bandwidth of channel.

$$P_{dBm} = -174\ dBm + 10\ log_{10}\,\Delta f \qquad (2)$$

As the signal is transmitted over the channel of 5 MHz bandwidth,

$$P_{dBm} = -174\ dBm + 10\ log_{10}\,(5 \times 10^{6})$$
$$= -174\ dBm + 67$$
$$= -107\ dBm$$

For acceptable BER, the minimum SNR at the receiver is 4 dB. Phones also require 4 dB as marginal energy. Therefore, the minimum required signal strength for 5 MHz channel is

$$-107\ dBm + 4\ dBm + 4\ dBm = -99\ dBm.$$

The transmitted energy becomes weaken as the signal travels and the nodes who get the packets more than -99 dBm can only receive the packets. There are many factors which determine the signal strength at the receiver end such as antenna gains, loss to feed the antennas and multi-path fading etc. The free-space path loss is given by equation (3).

$$link - loss = 20\ log_{10}\ (f_c) + 40\ log_{10}\ (d) - 20\ log_{10}\ (h_{rx} \times h_{tx}) \quad (3)$$

where, $f_c$ is the carrier frequency in GHz and d is the travel distance in meter, $h_{tx}$ is the height of the transmitter and $h_{rx}$ is the height of the receiver in meter [10].

In the proposed environment, the devices will be always at the height of boats plus 1/2 meter on board (Figure 3.9). The average height is around 2.5 meter. If the carrier frequency is 2.4 GHz, then the link loss

$$link - loss = 20\ log_{10}\ (2.4) + 40\ log_{10}\ (d) - 20\ log_{10}\ (2.5 \times 2.5)$$
$$= 7.7 + 40\ log_d\ (d) - 15.91$$

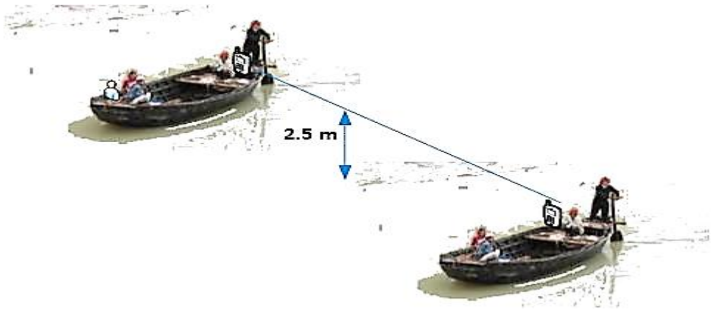



**Figure 3.8** Height of the phones from water surface.

According to the study of [70], the feeder and connector of smart phone consume energy is around 10 dB. Therefore, the total losses become

$$\text{Total power loss} = 10 + 7.7 - 15.91 + 40\ log_{10}\ d$$

The maximum transmitting power of a popular smartphone model Symphony that the fishermen use in Bangladesh is 15 dBm [71]. For the transmitting power of 15 dBm and the receiver sensitivity -99 dBm, the total power loss could be

$$15 + 99 = 1.79 + 40\ log_{10}\ d$$
$$log_{10}\ d = 112.21/40$$
$$d = 638\ m$$

Considering the practical characteristics derived by the study of [60] and maximum boundary of energy losses, the above calculation shows that the communication range of Wi-Fi for smartphones could be 638 meters in the free space.

As the waves in the normal ocean varies up to 2m [82]. Therefore, the receiver and transmitter antenna heights change frequently and the path loss varies. This decreases the estimate communication range 638 m for sometimes. According to the study of [83], a variation of 1 m in antenna height for both receiver and transmitter can make 13 dB in path loss. Thus, the range will be d = 298 m that is the about half of the estimated range. Besides, this range can be affected for attenuation happened when phones are hidden by human bodies or by other trawlers and boats. Besides, antenna orientation among phones also affects range [5]. As the phones will form MANET in the free space, these effects can be neglected in some cases. This is because the phone has a chance to connect with several other phones and can perform in MANET mode.

### *3.3.2 Link Budget for APs*

In the long distance Wi-Fi, it is required to have sufficient higher SNR (margin SNR) at the receiver than the receiver sensitivity for acceptable bit error rate (BER). This margin ensures high quality radio link during rough weather in the sea. The author of [15] has found that the good margin is 10-15 dB. The connector cables also consume a significant amount of power that is around 4 dB. The maximum transmitting power of selected APs is 27 dBm and the antenna gain is 15 dBi. Therefore, the maximum available power is 27+2x15=57 dBm. As the receiver sensitivity is -97 dBm and SNR margin is 15 dB, the received signal should be above -97+15=-72. Thus, the maximum path loss can be,

$$Lmax = 57 + 72 - 4 = 125\ dB$$

The link loss is given by

$$link - loss = 20\ log_{10}\,(f_c) + 40\ log_{10}\,(d) - 20\ log_{10}\,(h_{rx} \times h_{tx}) \quad (3)$$

$$= 40\ log_{10}\,(d) - 43.4$$

As the maximum loss could be 125 dB,

$$125 = 40\ log_{10}\,(d) - 43.4$$

$$d = 15.3\ km$$

If the channel is operated on 5 MHz bandwidth, according to experiment of [6] the receiver can detect signal with 3 dB less than 20 MHz bandwidth.

Therefore,

$$128 = 40\ log_{10}\,(d) - 43.4$$

$$d = 19.2\ km$$

### *3.3.3 Throughput Calculation*

According to the 802.11n specification, the data rate varies from 6 Mbps to 54 Mbps depending on the link condition [72]. However, in this network fixed rate will be used and the rate is reduced as the channel is narrowed down. In 802.11n, OFDM signal use 64 sub-carriers to transmit data. Among them, 48 are used to carry data, 4 carry synchronisation information, 11 are used as guard carriers and one is a not-active carrier that indicates the centre of channel. The sub-carrier bandwidth is 312.5 Khz. Based on this information, maximum data rate can be found easily for the 5 MHz channel.

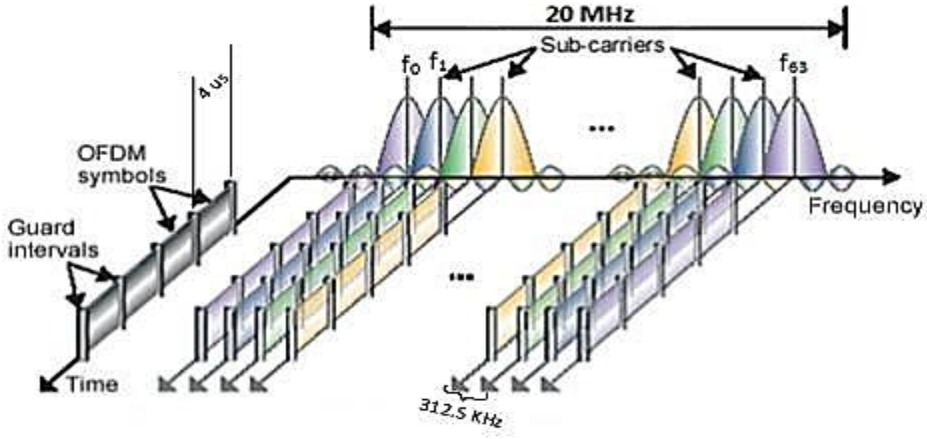



**Figure 3.9** OFDM modulation technique.

For 5 MHz, the number of carriers are 5000/312.5=16. Among these 16 channels, 4 channels are required as the pilot sub-carriers, one is used as central no-active sub-carrier and other three will be used as guard sub-carriers. Thus, only 8 channels are available for data transmission. In 802.11n, the duration of modulation symbol is 4 $\mu$s. But, for configuring the channel width to 5 MHz the reference clock to the Phase Locked Loop (PLL) that determines the centre frequency and channel width is changed to the 5 MHz. This reference clock is also connected with the base-band/MAC processor that will increase symbol length to 16 µs [6]. Therefore,

total number of symbols per second =1/16 x$10^{-6}$ =62500 or 62.5 K symbols

For 8 sub-carriers, total number of symbols=8 x 62.5 K=0.5 M symbols.

In the proposed system, the BPSK modulation with ½ coding will be considered. Therefore, the maximum throughput is 0.5/2 or 0.25 Mbps. This is possible only for lower MANET. As the upper MANET can operate only half of the air time, the maximum throughput will be 125 Kbps.

# Chapter 4

# Mobility Modelling for Fishing Boats

Modelling the movement patterns of users who will take part in the MANET plays vital role to design the appropriate network for the target scenario. The performance of MANET network stacks and protocols are highly affected by these movements. However, the existing mobility models cannot mimic the movement behaviour of the fishing boats that constitute the communication backbone for the proposed network. The fishing boats move following some specific strategies, different to the behaviour of any entities. According to the control and management of fishing over the sea [53, 73] the fishing activities are distributed over the sea according to the species stock and changed over the seasons in a given year. The fishing activities happen at the different times of the day. Most of the fishing is done during the night, yet some fishing is done in the day time. This is because of the fishing regulation for a specific region and behaviour of the target species. In the evening, the fishing boats start travelling for a fishing trip and return in the morning time after finishing their fishing trips. The fishing boats show three behavioural states for any fishing trip: *fishing*, *streaming* and *stopping*. Streaming and trawling speeds depend on the various factors like engine power of fishing boats, currents and tides, weather, size of net, type of gear, target species etc. The others activities for which the speed is affected are emptying nets, turning, sorting catch, etc. Besides these characteristics, the boats have some other strategies like boats do not start fishing in the crowded fishing zone and makes group for trawling activities etc.

The dynamics of fishing boats are intensively studied to understand the trawling efforts at very fine spatial and temporal scales [29, 74, 75]. The researchers have modelled the trajectories of fishing boats to retrieve the fishing activities. These movement models reconstruct the sequence of fishing behaviours using statistical model and data collected from the Vessel Monitoring Systems (VMS). According to the fishing strategies and these models, fishing boats show all the movement characteristics (randomness, temporal dependency, spatial dependency and restricted movements) in their journey. These models cannot produce traces for network simulation directly. In this chapter, we present a new mobility model for fishing boats based on the description of movements derived by these models. The developed model can drive the nodes in the network simulation mimicking the movement's behaviours of fishing boats. This model is simple and can produces traces for large scale heterogeneous network. To our knowledge, this is the first network simulation mobility model for fishing boats. The scalability is increased significantly by applying a simple technique for GOD (General Operation Director) information generation. The relevant mathematical models have been described in the section 4.1 and the proposed model is presented in the section 4.2. The trace generation engine is described in the section 4.3 and the GOD processing method is explained in the section 4.4. The section 4.5 presents the comparison and analysis of our developed models with other simple models used in NS-2.

## 4.1 Fishing Boat Movement Models

In the literature, several models have been proposed to represent the behavioural states and movements of fishing boats. The authors of [29] have applied Markov Process (MP) with discrete time to describe the succession of behavioural states in a trajectory of a boat. The boat movements and behaviours over the path can be considered as the first order homogeneous Markov chain and can be viewed at any discrete time step $t$ =1, 2 …. . . $n$. The process stays in the state $i$ before moving to other state $j$ for a time period $T_i = k.\Delta t$, where $k$ is the random values of discrete time steps and $\Delta t$ is the difference between two time steps. The process can be entirely defined by the $m\ x\ m$ stochastic matrix $P = (P_{ij})$, where $P_{ij}$ is the probability to shift from state $i$ to state $j$ between two discrete times $t$ and $t + \Delta t$. As the number of states are fixed, the probabilities should be $\sum_{j=1}^{k} P_{ij}$ and $P_{ij}$ can be non-null as the system could stay in the same state $i$ between two instants $t$ and $t + \Delta t$.

The speed and direction of movement depend on the behavioural states and can also be defined with the discrete time steps. The equation (1) defines the location of a boat over regular time intervals that are based on the previous state and location and the current behavioural mode. If the process stays in the state $S_t$ and the current location $X_t$ at the time $t$, the location $X_{t+\Delta t}$ at the next time step $t + \Delta t$ is defined as follows.

$$X_{t+\Delta t} = X_t + D_{t+\Delta t} + \varepsilon_{t+\Delta t} \quad (1)$$

where, $D_{t+\Delta t}$ is the straight displacement from location $X_t$ to $X_{t+\Delta t}$ which is calculated from the speed and turning angle associated with the current behavioural state $S_t$ and $\varepsilon_{t+\Delta t}$ is the process error. The process error is the bivariate Normal with a variance-covariance matrix $\sigma^2$ and is defined with

$$\varepsilon_{t+\Delta t} \sim N(0, \sigma^2) \quad (2)$$

The displacement vector $D_{t+\Delta t}$ is defined as

$$D_{t+\Delta t} = V_t T_t U_t \Delta t \quad (3)$$

In the equation (3), $U_t = \frac{D_t}{|D_t|}$ is the unit vector that indicates the direction of previous movement and $V_t$ is the speed of boat that varies with the states and is drawn in a prior with unknown mean that depends upon the current behavioural state. $V_t$ is derived with the following equation

$$V_t|S_t = (\mu_{s=s_t}, \sigma_{s=s_t}) \tag{4}$$

In case of mode "Stopping", the speed $V_t$ is assigned to zero so that no displacement is made. In equation (3), $T_t$ is the transition matrix at time $t$ with mean turning angle $\theta_t$ that defines the rotational component of the movement, such that $T_t U_t$ is the new direction after turning. The transition matrix for $T_t$ is given bellow.

$$T_t = \begin{bmatrix} \cos(\theta_t) & -\sin(\theta_t) \\ \sin(\theta_t) & \cos(\theta_t) \end{bmatrix} \tag{5}$$

Turning angles are distributed a priori as a Wrapped-Cauchy distribution (Fisher, 1993). W-Cauchy distributions are embedded within a hierarchical structure such that at each time step $t$, $\theta_t$ is drawn in W- Cauchy distribution with concentration parameter that depends upon the current behavioural state $S_t$. If location parameters of W-Cauchy were set to 0 ($\theta_t = 0$)

$$\theta_t|\, S_t \sim Wrapped - Cauchy\ (\, S_t, \mu_{\theta_t} = 0) \tag{6}$$

When the boat is at behavioural mode "Stopping" a directional vector $U_t$ is built randomly to be able to compute the next displacement.

This model considers the strait path between two succeeding time steps. However, this is not straight for the real case [75, 76]. There is always deviation from the straight line connecting two successive positions. The author of [75] has computed the extent of deviation using ellipse. The maximum deviation is measured based on the maximum speed found between these two positions. The maximum distance for the maximum speed will be the half perimeter of ellipse formed with the radius of straight displacement. All movements will be within the ellipse area.

## 4.2 Proposed Mobility Model

The above models are designed to extract the trajectories of fishing boats from VMS data. In our model, we would like to generate these paths without VMS data. Therefore, we have utilized some concepts and parameter from these models to generate traces mimicking the fishing boats movements. The movements in our model are derived hierarchically through long flights and small flights. The author of [29] has estimated the state transition matrix (equ.7) with real VMS data. We have adopted this matrix to generate behavioural sequence of fishing boats in our modelling.

### *4.2.1 Zone Creation*

The fishing activities are distributed spatially and correspond with species stock. To reflect the spatial distribution of fishing boats, a number of fishing zones are created over the simulation area. For the simplicity, these zone shapes are kept square. The number of zones, size of these zones and the minimum distance between two consecutive zones are given by the user. The x-coordination of the zones are fixed and determined by dividing the x-axis with the number of zones, but the y-coordination is randomly chosen keeping the minimum distance among nearest zones and no-fishing zone from the land. The no-fishing zone is maintained as the boats usually do not do netting around its harbour area. The random selection of y-coordination creates different distribution of fishing zones over simulation area for every trace generation. This will allow to study network performance for every fishing stock that might be created in different seasons of a year.

### *4.2.2 Nodes Distribution at Harbours*

The fishing boats are anchored at harbours over the coast line. The model will uniformly distribute the given number of nodes to the given number of harbours. Although, some small boats are arbitrarily distributed over the coastal area in real scenario as the fishermen often anchor boats around their habitats. For simplicity, we neglect this costal distribution of boats in our model. The trawler nodes are also distributed homogeneously for every harbour. Besides these vehicle nodes, model places some nodes as fixed nodes if the network has base station at the harbours. The nodes from these ports are distributed non-uniformly over the fishing zones.

### *4.2.3 Path Creation and Zones Selection*

Before starting fishing trip by a boat, a sequence of behavioural states is created following the Markov Process. A behavioural generator creates a sequence of states following the transition matrix.

$$P=\begin{bmatrix} 0.7 & 0.2 & 0.1 \\ 0.6 & 0.4 & 0 \\ 0.5 & 0 & 0.5 \end{bmatrix} \tag{7}$$

Every boat is also assigned a zone where it will travel first. The first fishing zone selection strategy is that the nearest zone has more probability to be selected by a node as fishermen have tendency to start fishing at the nearest zone. The probability from a port $i$ to zone $j$ is determined by

$$P_{ij} = \frac{1}{D_{ij} \sum_{j=1}^{k} \frac{1}{D_{ij}}} \qquad (8)$$

where, $D_{ij}$ is the distance from port to zone.

However, the trawler nodes tend to select the furthest zones. Thus, a trawler is assigned the zone that has the smallest probability from the port. After finishing netting for the time period specified by the behavioural state generator, it goes to streaming state to travel the next fishing zone. The next fishing zone is assigned based on the time specified for this streaming. A distance is estimated for this streaming time period and a zone is selected from the zones situated within this range. The selected zone is verified whether it has ability to accommodate one more fishing boat as a fishing zone has a maximum number of boats allowed. In reality, crowded zones are not chosen by the boats in reality. Besides, the zone will be on the upper coordination if the current trip time is below 75% of maximum trip time and lower coordination if the current trip time is above 75%: a boat goes furthest distance for a certain time and then tends to return and chose fishing zones along the returning path.

### *4.2.4 Streaming*

Three types of streaming are done in our mobility model: harbour to zone, zone to zone and zone to harbour. To reach any target destination, the boat makes several long flights for every two consecutive time steps and each long flight consist of small flights. The long flight is done following the model described in the equation of (1) and with some modifications. As the boats do not move straight, movements is made through small flights to reflect the real tracks. The streaming strategies implemented in our model are shown in Figure 4.1.

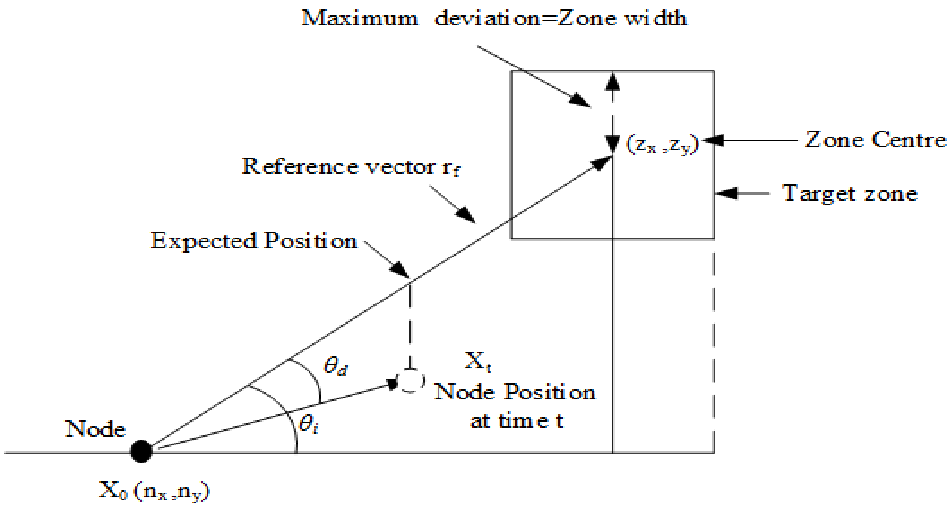



**Figure 4.1:** Streaming strategies and long flight creation.

**Long Flight Creation:** The nodes construct a directional unit vector $r_d$ and an initial angle $\theta_i$ to begin flight creation.

$$r_d = m.i + n.j \tag{9}$$

where, m= $\begin{cases} 1 & if\ n_x < z_x \\ -1 & if\ n_x > z_x \end{cases}$ , n= $\begin{cases} 1 & if\ n_y < z_y \\ -1 & if\ n_y > z_y \end{cases}$

$$\theta_i = \tan^{-1} \left|\frac{n_y - z_y}{n_x - z_x}\right|$$

The unit vector for the first flight is given by the following equation

$$r_t = \ r_d\ (\cos(\theta_c + \theta_t)i + \sin(\theta_c + \theta_t)\, j) \tag{10}$$

where, $\theta_c$ is the current angle, for the first flight $\theta_c = \theta_i$, and $\theta_t$ is the turning angle added with $\theta_c$ to create next flight. Therefore, the first flight can be given by

$$D_t = V_t\, r_t \Delta t \tag{11}$$

where, $V_t$ is the speed chosen this flight which is determined through normal distribution (equ-12) with mean $\mu = V_s$ that is assigned for streaming state and maximum speed deviation $\sigma = v_d$.

$$P(x|\mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{12}$$

The author of [75] has presented that the changes in turning angles for fishing boat follows mean deviation angle. To make the model simple and the future locations are often deterministic, the direction angle is also derived from normal distribution (12) with mean $\mu = 0$ and the deviation angle $\sigma = \theta_d$ instead of W-cauchy distribution. The maximum deviation angle $\theta_d$ is determined at the beginning of streaming using zone width and the maximum speed $V_s$ set for the streaming state. With the initial angle and mean speed, the displacement in the x-axis could be

$$D_x = V_s\, \Delta t\ \cos(\theta_i)$$

With the maximum deviation angle $\theta_d$, the x-component could be

$$D_x(d) = V_s\, \Delta t\ \ \cos(\theta_i - \theta_d)$$

The maximum allowed displacement in any axis is the zone width as this will ensure that the node reach the target zone, therefore we get

$$zn_{width} = D_x(d) - D_x$$

$$\cos(\theta_i - \theta_d) = \frac{V_s\, \Delta t\ \ \cos(\theta_i) - zn\_width}{V_s\, \Delta \mathrm{t}} \tag{13}$$

To make the model stable, the movements are coordinated according to the streaming strategies and with a reference unit vector $r_f$ from zone to the initial position of node.

$$R_i = (n_x - z_x)\, i + (n_y - z_y)\, j$$

$$r_f = \frac{R_i}{|R_i|} = r_x\, i + r_y\, j$$

where, $r_x = \frac{n_x - z_x}{\sqrt{(n_x - z_y)^2 + (n_y - z_y)^2}}$, $r_y = \frac{n_y - z_y}{\sqrt{(n_x - z_y)^2 + (n_y - z_y)^2}}$

Each construction of long flights is verified before node moves. For the chosen location there is one expected position of node for reaching to the target zone (Fig 4.1). The conditions for valid flight are determined by the equations (14 and 15). The difference between expected positions and chosen positions should be below the zone width

$$\left| \frac{(n_x(t) - z_x) * r_y}{r_x} - n_y(t) \right| < \text{zn\_width} \tag{14}$$

$$\left| \frac{(n_y(t) - z_y) * r_x}{r_y} - n_x(t) \right| < \text{zn\_width} \tag{15}$$

**Small Flight Creation:** For the small flights, the displacement is made for 10 seconds period with the following equation.

$$d_t = 10\, v_t\, r'_t \tag{16}$$

$$r'_t = r_d\ (\cos(\theta'_c + \theta'_t) i + \sin(\theta'_c + \theta'_t)\, j)$$

where, $\theta'_c$ is the current angle and $\theta'_t$ is the new turning angle for small flight. For the first small flight $\theta'_c = \theta_c + \theta_t$ and $\theta'_t$ is calculated by the normal distribution with mean angle $\mu = \theta_c + \theta_t$ and maximum deviation angle $\sigma = \theta_t - \theta_d$. The speed $v_t$ for small flights are chosen depending on the speed phases. The speed selection is divided into three phases: *exiting* phase, *steady* phase and *entering* phase as the boats increase speed when they start to move toward a zone and decrease speed when they enter the zone. We have used exponential increase of speed until to reach $V_t$ for the exiting phase and inverse exponential is used to decrease the speed from $V_t$ to fishing speed $V_f$ for entering phase. At the steady phase, the speed for small flight is determined by the normal distribution with mean $\mu = V_t$ and deviation of $\sigma = v'_d$.

According to [75], boats movement between two consecutive time steps i.e. for a long flight is constrained within an ellipse formed with major radius equal to flight length $D_t$. The other radius of ellipse is determined by the maximum distance that boat could move for a maximum speed for this flight. This maximum distance is the half perimeter of ellipse.

Therefore, for the ellipse of Figure 4.2, $a = D_t$ and the maximum distance with maximum speed is,

$D_{max}$ =($V_t + v'_d$) $x$ $\Delta t$ and according to the perimeter formula of ellipse

$$2D_{max} \approx 2\pi\sqrt{\frac{a^2+b^2}{2}}$$

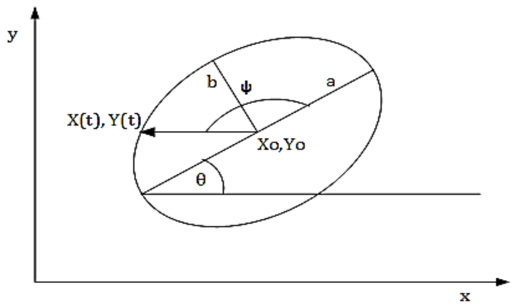



**Figure 4.2:** Path for small flights.

If the displacement form an angle $\theta$ with the x-axis, any locations on the perimeter are defined by the following equations

$$r'_t = r_d \ (\cos(\theta'_c + \theta'_t)i + \sin(\theta'_c + \theta'_t)\,j)$$

$$x(t) = X_0 + a \cos\varphi \cos\theta - b \sin\varphi \sin\theta \quad (17)$$

$$y(t) = Y_o + a \cos\varphi \cos\theta + b \sin\varphi \sin\theta \quad (18)$$

where, $X_0, Y_o$ is the coordinate at the half point of displacement and $\varphi$ is the angle created at the node position. Every small flight will be validated with these equations (17, 18).

### *4.2.5 Fishing at Zones*

After reaching the fishing zone, the boat will move creating the long and small flights as well. But the speed, $V_f$, is fixed for long flights. The fishing boats movement often model with Levy random walk [77]. When the boats move in the fishing zone, flight creation will be done with some randomness. The direction for the first long flight is chosen randomly. The turning angle $\theta_t$ for the next flight will be chosen using normal distribution with the mean angle $\mu = 0$ and maximum deviation angle $\sigma = 45$ degrees. This turning angle is added with the previous angle $\theta_c$. This approach is adopted as the boats tend to forward with netting. The next flight is defined by the following equations.

$$r_t = r_d \ (\cos(\theta_c + \theta_t)i + \sin(\theta_c + \theta_t)\,j)$$

$$D_t = V_f \ r_t \Delta t \quad (19)$$

This process continues until the boats reaches the border of fishing zone. At this stage, the next flight is created and an angle $\pi$ is added with the turning angle to move the boat in the opposite direction. All flights are checked so that it maintains certain distance from the previous two flight destinations. The small flight is made in the same process and fulfilling the same condition of ellipse. The speed is chosen from normal distribution with mean $V_f$ and maximum deviation 0.5 m/s and the angle is chosen form normal distribution as well with the mean angle equal to the angle for long flight and the deviation angle is 60 degree. At the fishing state the nodes turn frequently for small flight [75].

### 4.3 Trace Generation

The trace generator engine coordinates all the functionalities of developed model. The working principal of trace generation is described in the Figure 4.3. At the beginning of trace generation, procedures zone creation, node distribution and leave time are invoked to initialize different parameters. The leave times are usually chosen from a period of two hours as the boats do not leave ports together. Based on the leave time, nodes are shorted in ascending order. The scheduler picks up that node that will create flight first and consequently. If the trajectory is not created for that node, a sequence of behavioural states is generated. Then the scheduler sends it to the appropriate methods to create flight according to the behavioural state. The scheduler also extracts the next state if the time period for the current state is over. But, fishing zone method is allowed to invoke the new set zone procedure when node finishes the fishing and initiates for the streaming state. For each small flight, the trace is saved to an output file. The trace generator also triggers the GOD generation method periodically. If the simulation time is over the trace generation is stopped.

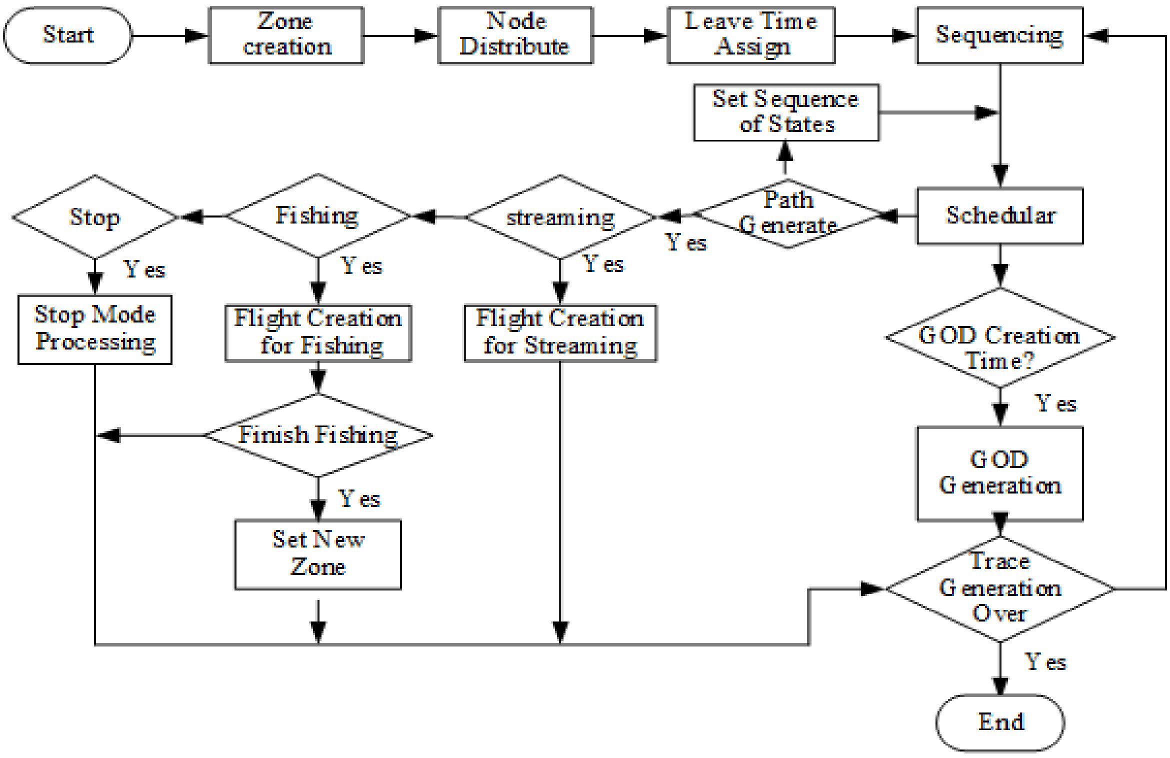



**Figure 4.3:** Functional description of the mobility model

## 4.4 GOD Generation

The Network Simulator-2 (NS-2) creates an object GOD (General Operation Director) for any wireless network simulation. This stores the connection status among all nodes in the simulation. For the large network simulation, GOD should be calculated before simulation starts as calculating this during run time is quite time consuming. Thus, mobility model usually generates GOD information for simulation. In general, the connection for a node with others is checked sequentially one by one. But, this makes the system complex and consumes much time for large network. In our model, we have integrated a short cut mechanism to find the neighbours of a node. The Figure 4.4 shows the basic principal of our method.

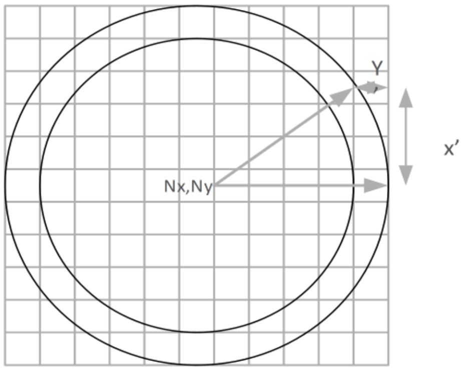
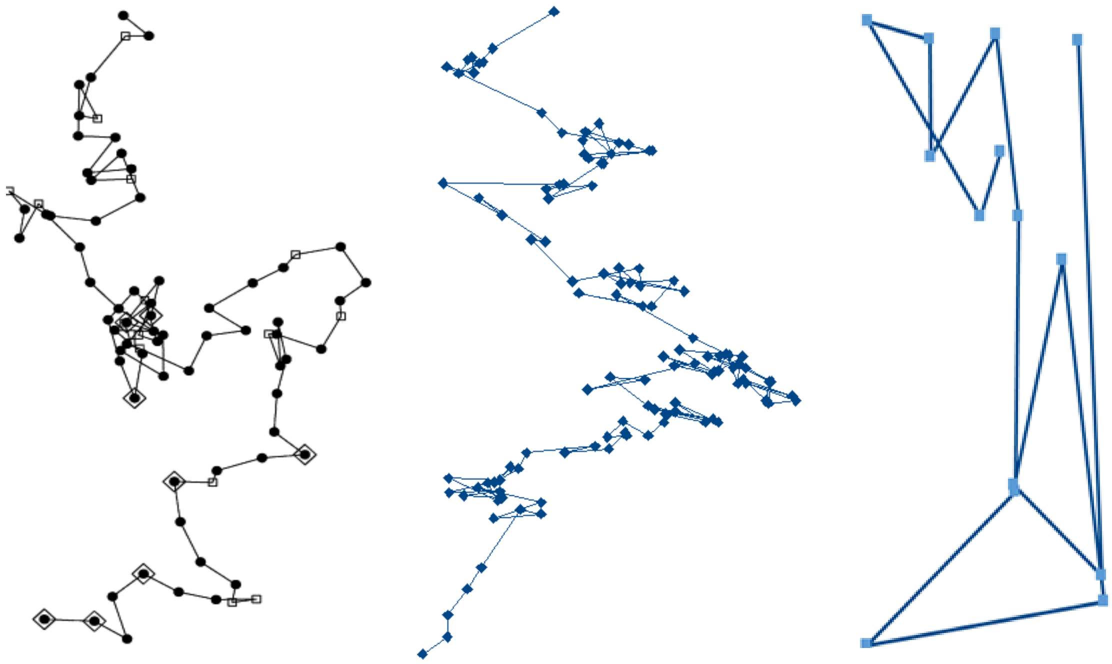



**Figure 4.4:** Mechanism for neighbour searching.

In our approach, the simulation area is divided into grids of square area with 100 m length. Each grid keeps track of the nodes who are within. Grid contents are updated when any small flight is created. At the initial state, a node searches all the grids within its communication range and add nodes to its neighbour list. Only the boundary grids need special care. In the Figure 4.4, the node position is indicated with ($N_x$, $N_y$) and the grids which are 500 m apart from its own grid will be intersected by the perimeter of a circle with radius of 500 m. These grids might have some nodes which are within communication range and some of them are out of communication range. Only distances to the nodes of boundary grids are measured and added to the neighbour list if they are within communication range. The other nodes from the grids that within this circle are added to the neighbour list. At the beginning of GOD generation, a list of nodes which are on the grids of 400 m circle are preserved. Further, this list is used to determine whether the boundary grids nodes are closing to the nodes or going outs from these nodes. In neighbour update, only fifth boundary grids are searched and calculated distance. If any node which was in the fifth boundary grid is not available now, then it is searched in the fourth grids. If it is not found, the connection is consider as lost. Therefore, nodes only require to search in the fifth grid and this reduces computation complexity. This makes our model more scalable.

## 4.5. Comparison and Analysis

We compare the path generated by our model with the path generated by the VMS data and the path generated by Random Waypoint Model. The Figure 4.5a shows the trajectory of a fishing boat. This path is generated by the model of [53] which uses the VMS data. The trajectory generated by the proposed model is shown in Figure 4.5b. The crowded squares mean that the boat is at fishing mode or at the stopping mode. The straight line connected by squares mean the boat are traveling. These graphs only show the straight line between two VMS data collection points. In the Figure 4.5c, we have presented a path generated by Random Waypoint (RWP) included in the NS-2. This is clearly understood that this cannot reflect the movements of fishing boats.



(a) (b) (c)

**Figure 4.5:** Trajectories generated by (a) VMS, (b) proposed model and (c) RWP

This mobility model can be validated more deeply using statistical methods. From the VMS data, we can find the distribution of fishing activities and this distribution can be compared with the distribution of fishing activities found in the generated traces by this model. The node distribution is another way to validate mobility model which can be compared and found from the VMS and generated traces [84]. The stability of model will be analysed through studying the randomness of direction changes in the generated trace and VMS data [85].

# Chapter 5

# Broadcasting Techniques and Simulation

In the proposed warning system, a mechanism is required to forward the warning messages to the nodes situated far away from the nodes that receive message from the control room (Ethernet and ISU connected). Message flooding is done to distribute the warning messages throughout the network in many MANET applications but this approach consumes much energy due to redundant broadcasting. As most of the users in the proposed network are mobile phones, some energy efficient mechanism is required. The popular MANET protocol called Optimised Link State Routing Protocol (OLSR) uses Multipoint Relay (MPR) based flooding to disseminate its Topology Control (TC) messages over the network. This mechanism reduces the unnecessary rebroadcasting significantly. This protocol is highly efficient to broadcast messages in the distributed communication systems where peer-to-peer transmission is the underlying mechanism. We have customised and modified the MPR of UM-OLSR [78] to adopt in the warning system. In this chapter, we discuss the broadcasting techniques and the network performance with this broadcasting approach. We also present a performance comparison of our broadcasting protocol. The evaluation has been conducted using Network Simulator-2.

## 5.1 Multipoint Relay Based Broadcasting

The basic principal of MPR is that every node selects a subset of its neighbours that are able to forward packets to all two hop neighbours. The other one hop neighbours only receive the message and refrain themselves to rebroadcast the message. This selection is done independently. The selected subset of one-hop neighbours is called MPR. Each node maintains another set of nodes which have selected it as MPR, and this is called the MPR selector set. If the node gets any broadcasting message from the members of MPR selector set, it rebroadcasts the message. As a selected number of nodes only rebroadcast packets, the redundant broadcasting is reduced considerably [79].

The basic procedure of MPR is shown in Figure 5.1. In the traditional flooding, each node retransmits the received message while here only MPR nodes retransmit the received messages. In the MPR broadcasting, each node collects link information for the neighbours through periodic hello messages. The hello messages include the list of neighbours that nodes have heard from and the status of these links. Initially, the hello message is only received by the one hop neighbours. Based on these information node determines the relationship with the neighbours. If node finds its address to the hello message forwarded by neighbour, the link is considered as symmetric, i.e. the both way communication is possible. Otherwise, the links is considered as asymmetric where only the source node can send messages. If the hello message is not received for a specific time period, the link is considered lost [80].

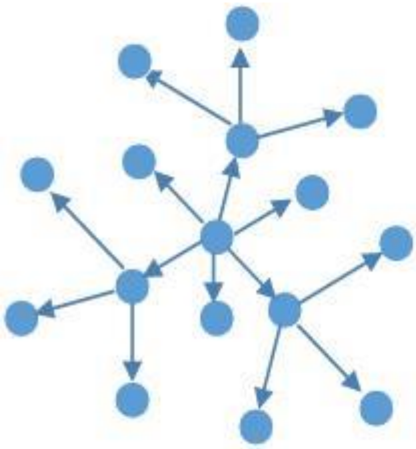


**Figure 5.1a:** Traditional flooding.

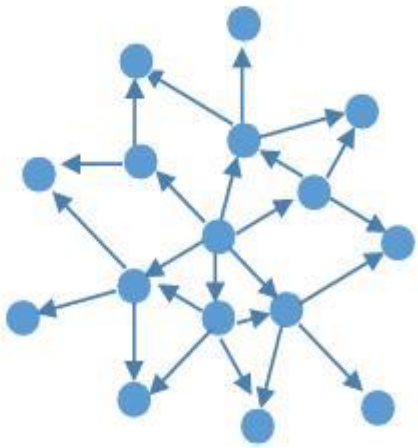


**Figure 5.1b:** MPR flooding.

Based on this neighbour information, the MPR set is computed by the node independently. The MPR is selected from only symmetric neighbours. After any change in link information, MPRs are recomputed. A smaller size of MPR is expected to reduce the overhearing efficiently. However, MPR finding is an NP hard problem. The original MPR computation algorithm used a greedy approach to calculate the MPR set. In this algorithm, the 1-hop neighbour of node x is defined by N(x) and 2-hop neighbour as $N_2(x)$. For each 1-hop neighbour, the out-degree D(y) is also calculated that counts the number of 2-hop nodes connected to this neighbour. Then, the MPR of node x is MPR(x) that is found in the following ways.

1. Begin with empty MPR(x), MPR(x) =Φ
2. Count D(y) for each node y in N(x).
3. Find and add to MPR(x) the nodes of N(x) that is only node which can reach some nodes in $N_2(x)$; that is $N(y) \cap N(x) = \Phi$. Then remove nodes from $N_2(x)$ which are covered by MPR nodes.
4. $N_2(x)$ have some nodes which are not yet covered by the nodes in MPR(x). For each node y in N(x) which is not in MPR(x), recompute D(y) for the remaining $N_2(x)$ and select the node which has maximum D(y) and remove the covered nodes from $N_2(x)$. Repeat the procedure until all nodes of $N_2(x)$ are covered.

## 5.2 Warning Message Wrapping

In the Optimized Links State Routing Protocol (OLSR) [49], Topology Control (TC) messages are distributed using MPR thought the network. The TC messages are inserted as data to the OLSR packet. The structure of OLSR packet is shown in the Figure 5.2. For broadcasting TC messages, the message type is set to OLSR_TC_MSG and Time to Live is set to maximum value. This adds an Advertised Neighbour Sequence Number (ANSN) and a link set which is the links to all nodes of its MPR selector at least. For distributing warning message, a new message Warning Message (WM), will be added to MPR that is similar to the TC message. The structure of WM message is shown in the Figure 5.3.  It has Warning Message Sequence Number (WMSN), Reserved and Code fields. The message type for OLSR packet will be OLSR_W_MSG.

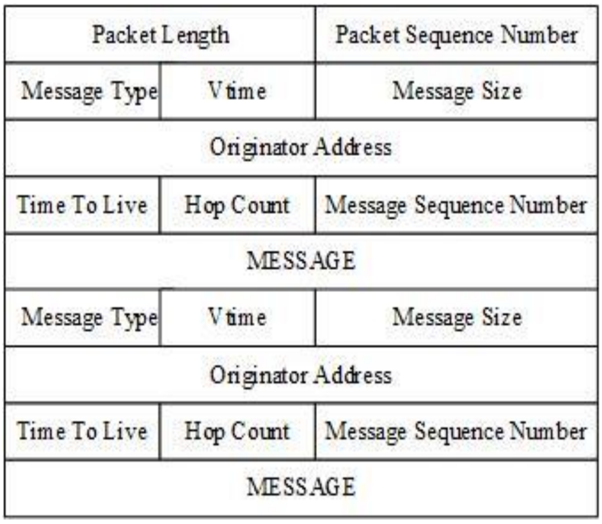



**Figure 5.2:** Format of OLSR packet.

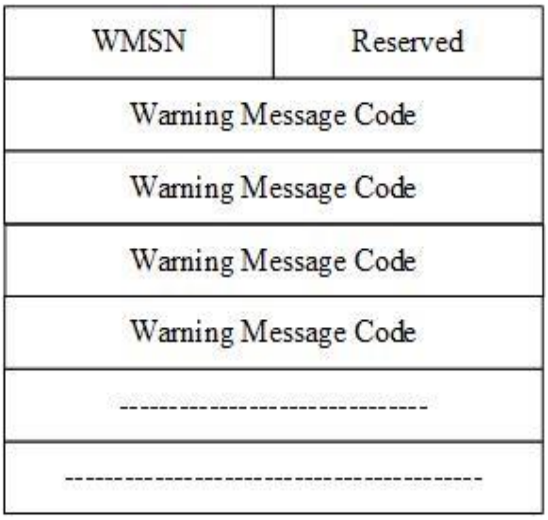



**Figure 5.3:** Format of WM packet.

UM-OLSR [78] allows to send maximum 90 addresses on a message. If the address size is 4 bytes (IPv4), the maximum size of bytes are 360. The structure of our warning messages is shown in the Table 5.1. An equivalent code for the prepared message can be accommodated as a WM message into the OLSR packet. In the warning message, seven types information is distributed. The current position, destination and event name fields require comparatively more bits to code the corresponding information, but other fields need very few bits to represent them. Therefore, the normal messaging structure of OLSR is enough to broadcast proposed WM. Besides, OLSR message size can be varied according to the networking demand.

**Table 5.1:** Warning message structure

| Warning Keyword | Signal no. | Event Name | Speed | Current Position | Destination | Distance from coast |
|---|---|---|---|---|---|---|

## 5.3 Enhancement of MPR

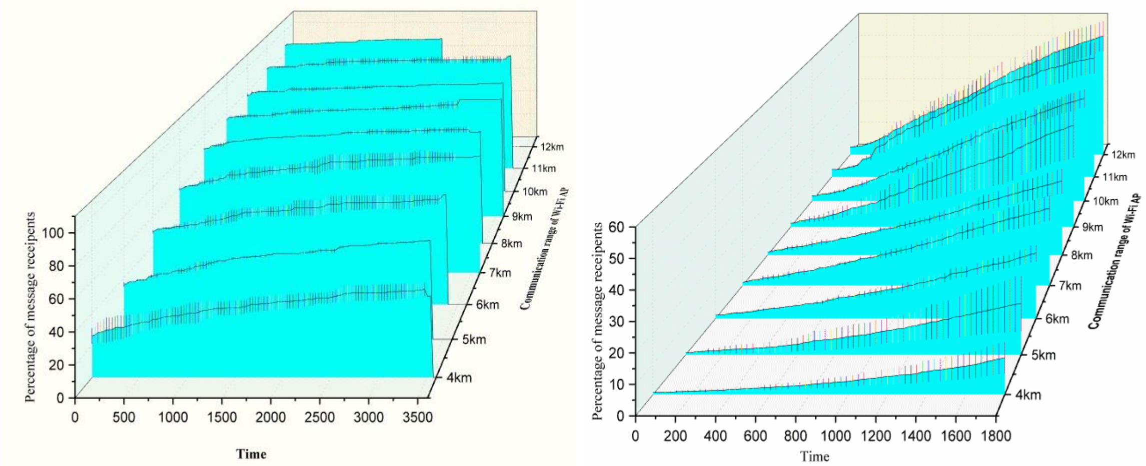
The MPR drops the packets if it does not have neighbour. This is not suitable for the proposed network as the nodes connected/disconnected frequently with other nodes. Thus, the DTN property is added with the MPR where every node buffers the packet for implementing the proposed warning message distribution operations. The restricted forwarding approaches for DTN [6], where some specific nodes only rebroadcast copy of messages as required, is applied to maintain DTN operations. When a node receives warning message, it rebroadcasts warning messages according to MPR protocol if it is only selected as MPR node. Further, the node advertises the WMSN of the received WM message via the periodic hello messages. This is done putting the WMSN to the register "Reserved" of OLSR hello packet. When a node processes the received hello messages, it compares the WMSN of its last received warning message with the WMSN receiving from its neighbours. If it finds that the neighbour did not receive its last warning message, it verifies whether it has the smaller address among the neighbours of message missing node. If its own address is the smaller then it rebroadcasts a copy of last WM. Thus, the node which was not present in the broadcasted area during the warning message distribution can retrieve the message later. This process controls the redundant broadcasting as a specific node rebroadcast only. However, the DTN nodes rebroadcast the message quickly when it meets the new nodes and notices that the area was not covered by the broadcast. The DTN nodes understand whether the area is broadcasted or not by checking the WMSN of newly added neighbours. If the DTN node finds that a threshold number of nodes did not receive last WM, the area is considered as unbroadcasted. The DTN node does not consider its address status in rebroadcasting as there might not be other nodes that can forward the message in this area. These DTN properties are assigned to the nodes which are in the traveling mode. We have added an information repository function to keep track of how long a node (boat) stays in contact with other or how frequently it revisits a specific node. The neighbour list is periodically checked to determine how long a node stays as neighbour. After losing a neighbour, it is checked whether the node has been neighbour again within a certain period. If it happens, a revisit counter is activated for that node. When a boat is in fishing mode, it is possible to be in contact with other boats for long time or frequently meet with each other due to the netting strategies. Therefore, it will not assume DTN capability while other assumes DTN capability.

## 5.4 Network Performance Evaluation

The overall objective of our simulation is to study the proposed network model and observe its performance for different networking conditions. We have used our modified version of MPR as broadcasting protocol. The developed mobility model is used to generate movement traces. The simulation is conducted in NS-2. The AP nodes of network have the capability to work with both other APs and phones. To reflect this, we add multiple interfaces multiple channel capabilities to NS-2. The modification is also capable of assigning different MAC parameters for each channel. This allows NS-2 to simulate heterogeneous networking. However, the proposed time scheduling technique for APs is not making the simulation simple and is avoided at this stage. The function of Ethernet and ISUs are provided by designing an App that generates the warning messages as TC messages. Some nodes are always kept static to mimic the port AP. NS-2 is also modified to neither receive nor transmit packets when nodes are at port (as the fishermen leave the port after returning from a trip). For the trace generation, we run the trace generator of our mobility model at least for the time equivalent to one day. After that snapshot of scenarios (GOD file) are taken for simulation. The GOD information is generated for every 10s. The time used in the experiments are real time. We have conducted the following experiments to characterize the proposed warning system and every experiment is run for 5-10 times.

**Experiment-1: Effects of Communication Range Provided by APs**

In our network model, we have applied some long distance Wi-Fi to distribute the warning messages quickly to trawler nodes so that the messages can be diffused concurrently from a large number of points in the sea as well as with the port APs. This will reduce the required time to reach every node in the network. Therefore, it is very significant to understand the effects of communication range for these long distance capable Wi-Fi APs. In this experiment, we first study only the longer range APs. We have done simulation for 225 nodes at sea over 300 Km X 200 Km area. All the nodes are distributed on the harbour points homogeneously. The coastline is considered to be 300 Km long and the nodes travel to 200Km in the sea. The trace generator ran for the time of equivalent two days and traces were taken. Then, we conduct another simulation for both type of nodes (phones and APs) in the network. This will provide information on how the longer range nodes impact the performance for short range nodes. We chose the area of 100 Km X 100 Km to keep the simulation simple, but it reveals the influence of range. We put 9000 nodes (according to real density of nodes) with 500 metre range and 45 longer range nodes. These simulations are run for a short period of 30 minutes. The simulation results are shown in Figure 5.4a and 5.4b.




(a) (b)

**Figure 5.4:** Network performance with communication range of APs: (a) Long distance node only and (b) proposed network.

At the simulation of longer range, we find that the message recipients at the instant of diffusion goes up significantly for changes from 4 km to 8 Km. Further, the improvement is very slow with further increase. In the proposed network the growth rate improved rapidly up to 7 km of communication range. Above 7 km, there are similar changes in every two kilometres. Therefore, more communication range increase is needed to get significant growth rates after 8 km. In the proposed network, the longer range nodes capable to forward message more nodes as range increase as well as speed up further distribution significantly. This is because the longer range node can easily retransmit messages to other nodes which are 10 km apart, while the smaller range nodes take much more time (10 km/4 $ms^{-1}$=2,500 s) to travel this area. Thus, the message propagation speed is affected by these nodes with longer-range at a later time as well. The experiment-3 also reveals the impact of longer ranges.

**Experiment -2: Warning Message Broadcasting at Different Time of the Day**

The fishing activities are different over the time of a day. The movement behaviours, speeds and density of nodes vary over the day. Therefore, the network cannot provide the same performance for all the time of a day. Understanding the network behaviour over time will provide information about the possible message propagation speed which is important to understand the delay for message flooding to guarantee that messages can reach every node. This experiment is conducted every 2 hours in a 24 h window and in each case the simulation is run for one hour.

We consider 3000 nodes (with real density) for the area of 3500 $Km^2$. When nodes are in the sea they take part in the network operation. However, the nodes that returned to the port after fishing do not take part in the network operation as the fishermen do not stay at the port. We also considered that majority of fishermen leave the port for making trip within 4 PM to 7 PM in the evening and return to the port in the morning within 7 AM. Very few fishermen leave or return to the port on the other time of the day. We keep around 40% of nodes at the see for all the time as most of the boats do trip for more than one day. The simulation result is shown in Figure 5.6.

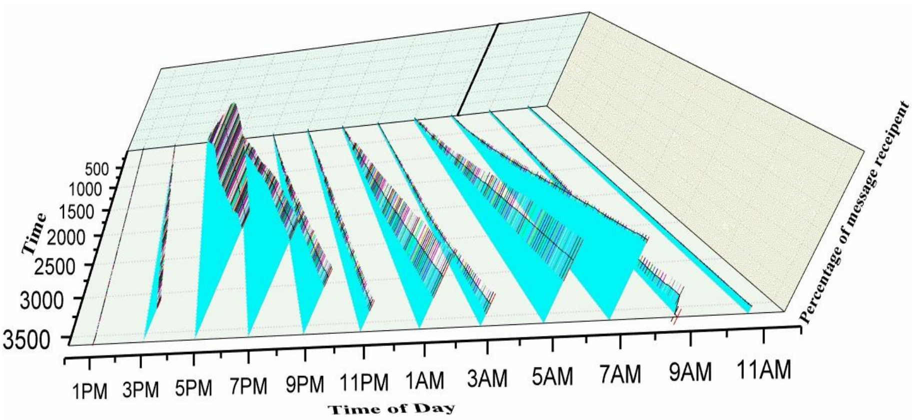


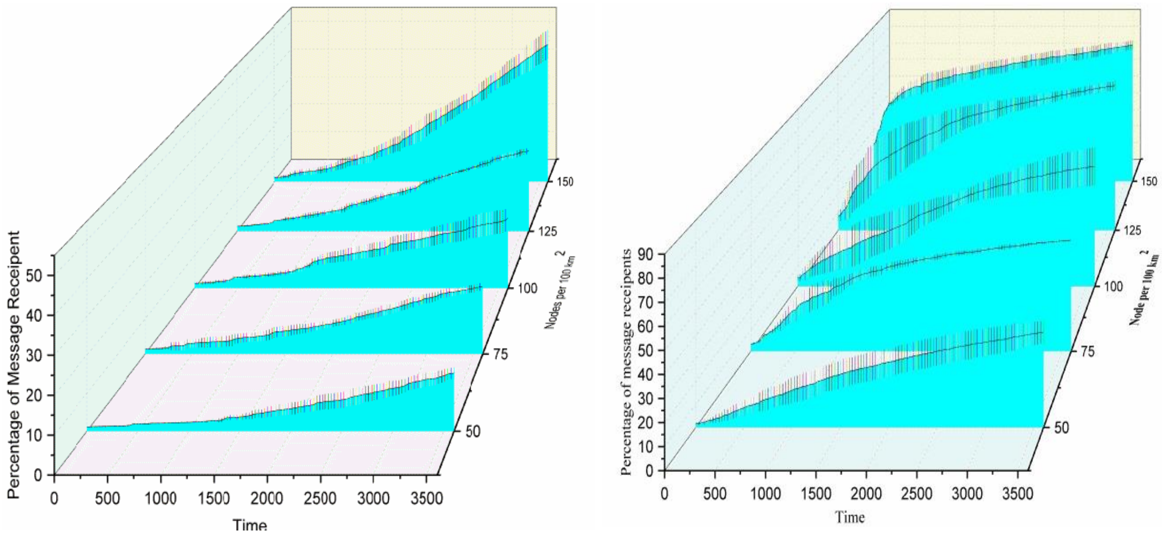

**Figure 5.6:** Network performance at the different time of a day.

The simulation results presented in the Figure 5.6 give a picture of message propagation speeds. The messages propagate with high speed from 5 PM to 7 PM. At this time fishing boats are moving to their target zones and few do fishing. Therefore, many of them assume DTN properties according to our protocol and carry warning messages for other nodes. From 9 PM to 5 AM the message propagation was almost similar as the boats was doing fishing at these time periods. However, the growth rate goes up at the time 5 AM to 7 AM for retuning of boats. Although, this is significantly lower than the traveling to fishing zones. The reason is that boats do no longer take part in the networking upon their return. As a result they could not transfer messages for others then. Another factor accelerating this situation is that every boat that leaves a port gets message from port AP and carries it. However the returned boats which got a message cannot carry for others in the sea. During daytime from 9 AM to 3 PM, the propagation speed fall much as the number of nodes decrease in the sea as well as few boats return and travel to fishing.

**Experiment -3: Effects of Node Density on Network Performance**

In the disconnected MANET, the node density is the key factor for routing data packets. Reduction in the node density degrades the network performance sharply. In the proposed network, user movements are not controlled as the node moves independently and follow their fishing strategies. Therefore, it is common to have the area where nodes are sparsely distributed. To understand the behaviour of the network with different densities, we have conducted several simulations over an area of 5,000 $km^2$ with various numbers of nodes:

from 50 to 150 nodes per 100 km$^2$. This experiment is done for two different network configurations. In the first configuration the estimated range 500m for phones are used for all nodes, while the network has some nodes with longer range in the second configuration (the proposed network model). The simulation is run for one hour. The message distribution time is taken at the evening time. The simulation results are shown in Figure 5.7a and 5.7b.




(a) (b)

**Figure 5.7:** Effects of node density on network performance: (a) normal MANET and (b) heterogeneous MANET.

At the beginning of message diffusion, the message recipients are more in the heterogeneous network than the normal MANET. The reason is that the nodes with longer range get messages instantly through the upper MANET. As a result, the message diffusion starts at a large number of points and a significant number of nodes (5 %) get the message at the beginning of the propagation. While in the normal MANET, the message is propagated from the message originator points (5 ISU connected nodes) only and only a few nodes (1 %) get the messages at the beginning. These recipients are the nodes that would get the message if DTN were not applied. Further, messages are received through the DTN procedures and the growth rate of recipients depends on the node density (in the Figure 5.6a and 5.6b). The growth rate is high in the proposed MANET. As this is covering wide area by longer range nodes, larger number of MPR groups are formed than in the normal MANET and the message propagates quickly. In the normal network, the growth is gradual as the larger number of message recipients participate by forwarding messages to missing nodes and more areas are covered by them. However, both networks reach a threshold value after which the growth is low. At this point, no MPR broadcasting or DTN process operate frequently. Only missing message retrieval procedure of our algorithm works. This phenomenon is observed in the experiment-5.

**Experiment-4: Requires Hello Period for Making Effective Networking**

Most of the users are mobile phones in the network. The energy is the main constrained for them. The periodic Hello Message emission consumes most energy for this network. In term of speed, the network environment is different than other MANET applications like VANET. The maximum speed in the streaming mode is about 4m/s and below 2m/s in the fishing modes. Therefore, the network maintenance does not require much frequent hello emission. In this experiment, we consider an area of 3,500 $km^2$ and the number of nodes is 3,000 corresponding to the available node density. The hello period is set from 50s to 400s with the step of 50s. The simulation is run for 1 hour period and traces are taken at the evening time when boats are moving as hello messages are important for the management of the mobility. For each selected hello period we have applied the same traces. The simulation results are shown in the Figure 5.8.

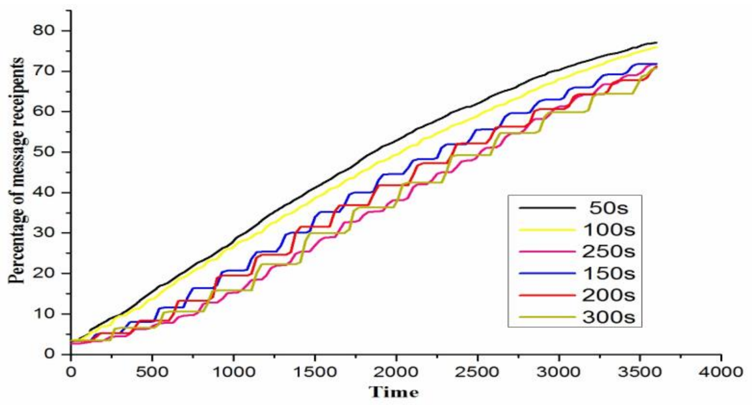



**Figure 5.8:** Growth rates of message recipients for different hello periods

At the initial state the growth rate is almost similar as the broadcasting is governed by MPR. For 50s to 150s the growth rates are similar. From 200s the growth rates decreases significantly and the difference increases as time goes. According to the protocol, this is expected when missing message's retrieval procedure works. For longer period of hello message, the process stops for long time and the possibility to trigger retrieval process by other delayed. Therefore the overall propagation speed decreases. Looking to Figure 5.8, the system can work smoothly up to 150s and this shows an important characteristic of this network environment.

**Experiments-5: Requirements for maximal reachability**

The warning message should reach every boat. The above studies provided the behaviour of the network for different networking conditions. We however need to assess if the system can forward the messages to every boat. In this experiment, we will study how the network can forward messages to every boat. For the first case, we run a simulation for a longer period of two hours. Then, we run another simulation with a larger number of long range APs (larger than what is available). We chose 90 nodes with longer range instead of 45 nodes (in the case of the actual density). Finally, we also consider increasing the node density (although it is not possible to increase the node density in reality). But, this shows the capability of our network to reach everyone. We add 25% more nodes than with a real density. The simulation area is 100 km X 100 km. The simulation results are shown in Figure 5.9.

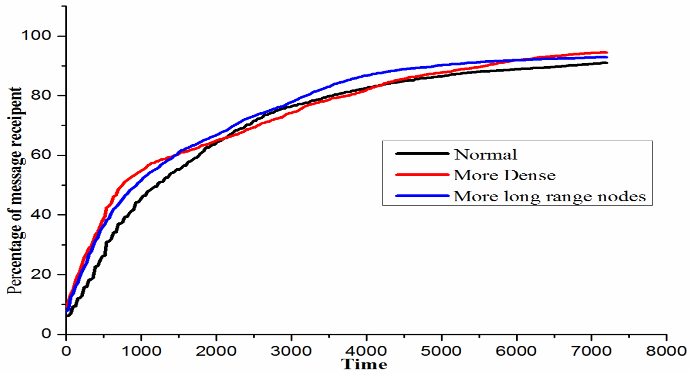



**Figure 5.9:** Propagation behaviour for different networking parameters.

The different configurations show different behaviours. At the beginning the dense network reaches to 50% of nodes quickly. This is expected as a dense network forms more MPR-based operations. Furthermore, networks with longer range are the fastest to reach 90% of the nodes. Due to the larger number of long range nodes, the area which was not originally reached, now receives the broadcast message faster. When 90% of the nodes are reached, the behaviour becomes similar for all configurations as at this stage only retrieval process works and the remaining few nodes need to retrieve the messages, but the remaining growth rate is low. After 2 hours, networks can deliver messages to 94% boats. The percentage is acceptable as some nodes that are at port do not take part in the network operation.

### 5.5 Broadcasting Protocol Evaluation

In the previous section, we have analysed the characteristics of the proposed network. In the literature review, we have found that no broadcasting protocol consider the marine vehicle movements characteristics. In our protocol, we integrate the movement behaviours of marine vehicles in broadcasting decision. The suitability of our algorithm has already found in the previous experiments. In this section, we have analysed the efficiency of proposed broadcasting protocol in comparison with others. At first, we compare the performance with normal MPR where we remove our enhancement (DTN and missing message retrieval procedures). Secondly, we configure the protocol in such a way so that each node can retransmit at least to one node. This is done in many flooding based broadcasting protocols. If a node does not have new neighbours it buffers the packet and retransmits blindly when it finds a new node. We have used the same traces for these two configurations as well as our protocol. We have chosen an area of 3,500 Km$^2$ (50 km X 70 Km) and 3,000 nodes. We have considered three metrics: delivery ability, redundant message generation and propagation speed. The simulation results are shown in Table 5.1 and Figure 5.10.

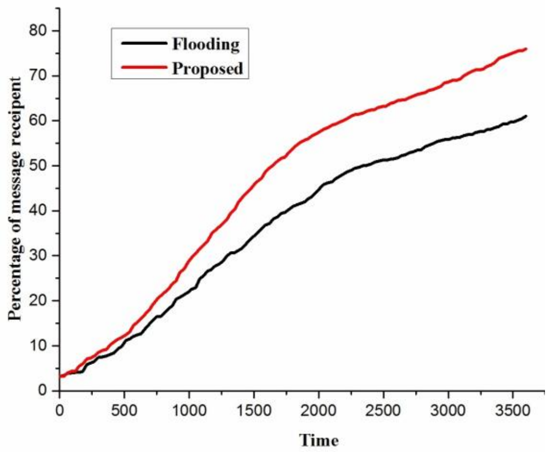



**Table 5.2:** Message delivery efficiency and redundant cost of protocols

| Protocol Name | Individual Message Recipients | | Total Received Messages | |
|---|---|---|---|---|
| MPR | 98 | 3.22% | 240 | 2.44 times |
| Flooding | 1856 | 61.5% | 41826 | 22.53 times |
| Proposed | 2311 | 76.02% | 11028 | 4.77 times |

**Figure 5.10:** Performance comparison of proposed broadcasting protocol with simple flooding and MPR.

The simulation results show the efficiency of our broadcasting protocol. This is faster than the normal flooding as well as delivers message to more individual nodes. With MPR, only 98 nodes get the message among 3,000 nodes and 1,856 nodes get through flooding while our protocol can forward message to 2,311 nodes (see Table 5.2). Among the protocols, the redundant message generation is minimum for MPR, with 2.44 times. However, the MPR stops broadcasting at the time of message diffusion. The redundant message generation by flooding is 22.53 times while our algorithm produces only 4.77 times as well as transfer messages to more nodes quickly. The comparison is shown in Table 5.2.

# Chapter 6

# Discussion and Future Works

In this chapter we make some observations on the possibilities of this research, discuss the limitation of our work and highlight future directions.

## 6.1 Discussion

Communication technology is changing rapidly and provides flexibility of access to all range of people. New technology is replacing old technology or improving them along with introducing new improvement. The marine fishing community of Bangladesh depends on the VHF radio for communication form the sea. However, it is not possible to bring the majority of the fishermen under this network for economic reasons. In this research, we have explored an alternative for communication using cheap networking devices. Wi-Fi radio is licence free and very inexpensive and almost all adult people nowadays have mobile phones. Therefore, mobile phone based communication system is easily accessible for these people. If the fishermen do not have phones, they can buy it with $20 only and get the free messaging services just installing an App. From the users point view, this is cost free that is the main goal of this research. The installation cost is very low for the authority. Many trawlers have ISUs or they can be instructed to buy it. The ISU will provide data services to the fishermen of trawlers as well since the warning system only uses it to push the warning messages. For deploying the network, the authority is mainly required to install high power APs. The selected model of AP costs $200. If some APs do not work when they are in operations, the services do not break due to feature of MANET operations. The faulty AP can be replaced at suitable time with new one. Therefore, the authority requires small operation and maintenance cost comparatively with other system like VHF system.

This research carries both academic and practical implications. We have found that the available resources can be applied to develop off-the-shelves services beyond their typical uses. On the other hand, the marine environment provides some flexibility to implement MANET and DTN based applications combining Long Distance Wi-Fi technology. However, with a wide geographical area, sparse density of nodes and trackless movements pose challenges for the current approaches. Thus, a wide range of research is still needed to deploy a complete communication system based on MANET and DTN. The proposed approach of communication has the potential to be applicable in other countries as well. The developed algorithms also provide insights into the implementation of MANET applications in the sparse environment.

In our study, we have addressed some issues that need to be resolved to implement MANET in the marine environment. First, we have proposed a network model exploiting user resources phones and inexpensive wireless components Wi-Fi and ISUs. Then, we have developed a new mobility model as none of the current mobility models are suitable to evaluate the communication network in the marine environment. We have also proposed a lightweight broadcasting protocol for this network. As an initial evaluation, we have analysed the behaviour of this network using various networking conditions. The evaluation shows that using some long range communication is very effective to help propagate the message quickly over the large geographical area. The message propagation was studied at different times of day. We have observed that there are some time periods when broadcasting messages could reach almost every boat. A decay in node density increase delay in message distribution. However, the developed broadcasting protocol is efficient to handle this situation through its DTN properties and its missing message retrieval feature. As the phones are energy constrained, it needs energy saving protocol. We have compared our protocol with other approach and found that it generates low redundancy in messages. The study of hello periods shows that the network can work with longer hello period. Therefore, broadcasting hello message less frequently could save significant energy. Finally we show how the reachability can be improved by increasing the number of longer range nodes.

Due to time constraints, the initial evaluation was done running simulation 5-10 times only. This only provides a rough observation of the network behaviour. A rigorous simulation is required to reveal the real behaviour of the network accurately. Theses simulation did not account for the marine features, such as effects of waves on the communication ranges. We did not consider the interference effect either, but a robust method is required to handle the interference as the nodes communicate in the free space. For sake of simplicity, the time scheduling to operate APs for upper and lower MANET was left out. Improper timing may drop many packets which would decrease the message propagation speed. The mobility model is not verified by a real trace. Verification through real trace would help us tuning its parameters and would enhance the model. The current model drives all nodes from the port. However, this is not realistic as some boats start trips from some locations and return to different locations. This would impact the network performances. In reality, the long distance communication is not correlated to the perfect settings. It should require some evaluation to setup Contention Window and Slot Time. As the simulation area considered for the conducted experiments are smaller, the small range of communication still cover this area easily and could shift the network scenario away from reality. If the simulation is run for larger area, then more realistic effects can be found.

## 6.2 Future Works

In this study, we have done a preliminary evaluation to implement a warning message system for the marine fisheries. As this study is done within a time frame of nine months, leading us to be limited in our study. Although the outcome of this study has shown the potential of the applied methods and techniques for such a system, there are lot of remaining issues that need to be investigated to make the system realistic and applicable. The mobility model is not verified with real traces. As the Vessel Monitoring System (VMS) provides traces of fishing boats, various parameters can be tuned to make the mobility model more realistic. In the developed model, the boat cannot sense each other so that they can be very close to each other. However, the boats always maintain certain distance from each other in real scenario. This property is required to be included in the mobility model. The broadcasting protocol should include a mechanism to implement the proposed TDM. A technique will be developed extending hello message to make synchronisation with neighbour. The broadcasting protocol should also be improved to forward warning messages quickly. The current version takes two hours for reaching everyone. However, this should reach everyone within short time before storm coming even in a low density environment. This should be more energy efficient although we could not measure the energy consumption of current version. As the communication is in the free space, the boat movement can be measured through packet energy. This technique can control the period of hello emission and hence save energy. Network services are required to improve as well. As the marine fishing communications system it should be capable to send distress messages and exchange messages among each other that is common feature of VHF radio system. As the APs has enough power, AP based algorithm can be developed to route messages coming from phones or from their family. Besides these improvements, the network evaluation would be done more deeply running rigorous simulation for large number of users over wide area and ocean behaviours such as waves.

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