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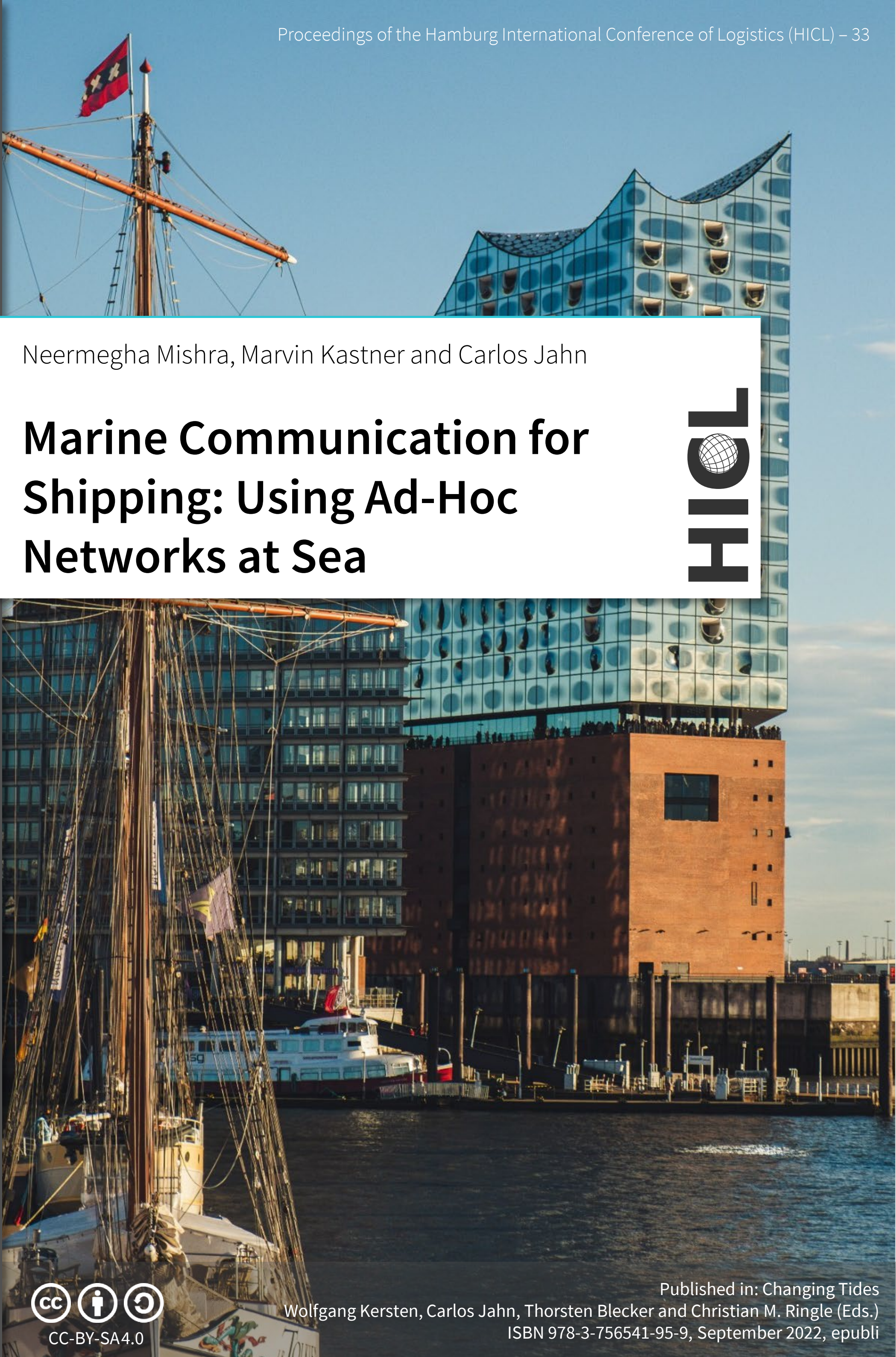

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Marine Communication for Shipping: Using Ad-Hoc Networks at Sea

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Purpose: *Oceans are a dominant means for transport of goods, which in turn has caused a boom in data volumes exchanged at sea. Internet connectivity at sea is heavily reliant on satellites, but it suffers from high cost, low bandwidth and complex regulatory requirements. This acts as an impetus to find alternative means of connection to ease marine communication.*

Methodology: *A literature review related to SANET, followed by an analytical and simulation model-based evaluation, along with real-life trace analysis were performed. Three routing protocols (namely, ER, RRS, and S&W) and three communication technologies (VHF, LR-WiFi and WiMax) were inspected based on three use-cases: sending small data in emergency, large data sharing route information, and very large data for insurance purpose.*

Findings*: The evaluation shows that VHF is suitable for distant communication of small data files, whereas WiMax works better for faster transmission of large data files. The performance of the routing protocols is heavily dependent on the deployed scenarios.*

Originality*: To the best of our knowledge, this study is the first to compare the combination of the three communication technologies and routing protocols. The study paves the path for choosing appropriate technologies and routing protocols for the deployment of SANET in maritime logistics.*

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1 Introduction

The world is made up of one portion of land, and three portions of water. Eighty percent of the world's goods are transported through the marine way [42], which is the primary reason for gradual increase of ship traffic at sea with each passing year (ALPHALINER, 2021). In the year 2011, the number of container ships worldwide was 4966, which increased to 5434 by 2021 (Statista, 2021). The sea-based shipping process requires reliable means of communication at sea. Impervious to the growth in market, the communication process at sea has not improved significantly over the years. From ship-to-ship or ship-to-shore, communication has its application province in the maritime logistics sphere varied from exchanging data regarding Search and Rescue (SAR) operations, to business objectives. The communication process at sea is predominantly dependent on using satellites for distant communication and Very High Frequency (VHF) signal for short direct data exchange. High traffic volumes are causing an overload in the connection lines and disrupting communication (Spire, 2020). Over time, satellite communication technologies have been updated but this comes with a massive cost. Satellite-based communication lacks coverage in some places, having the problem of blind spots near high latitude areas, leaving people in undeniable distress, disconnected from the rest of the world during emergency situations (Yau, et al., 2019). Facing these challenges over and over again, the need to find an alternative that could work in time of need, even in the absence of proper infrastructure, has become an unavoidable task. Ad-hoc communication has the potential to be a suitable option to alleviate the above-mentioned problems, while offering additional advantages.

Ad-hoc communication is when two communicating partners come inside each other’s connection range and they exchange information. The information moves around the ad-hoc network based on the mobility of the ships in marine communication, making them the carrier of the data. Because of its infrastructure-less structure, Sea Ad-Hoc Network (SANET) is also suitable to be used in regions where even satellites are unable to provide coverage. In the case of a natural or manmade calamity too, when the existing infrastructure breaks down, it has proven its viability (Dattana, et al., 2020). While being able to work in an adverse situation, and being around for quite some time, SANET is still a relatively unexplored approach. This paper is targeted at providing evidence regarding the feasibility of SANET under different circumstances, and comparing three routing protocols, namely Epidemic Routing Protocol (ER), Randomized Rumor Spreading (RRS) and Spray and Wait (S&W) and three connecting technologies, namely Worldwide Interoperability for Microwave Access (WiMax), VHF and Long Range Wireless Fidelity (LR WiFi). From hereafter, Section 2 explains the state of the art and related terms, Section 3 has methodology explained, Sections 4 and 5 focus on explaining the results and Section 6 concludes the paper.

2 Related work and Literature Background

This section explains the concepts of the terms associated with the marine communication processes and SANET. Searching for the literature focusing on SANET is difficult as compared to the publications available for other ad-hoc processes, for example for Vehicular Ad-Hoc Network (VANET). The scarcity of papers for SANET is evident across various databases, as it can be seen in the following Table 1.

Table 1: Quantitative comparison of publication numbers between SANET and VANET, (without any time limit, in total number) [as accessed on 06.12.2021]

Website name	Number of Hits	
	"Sea Ad-Hoc Network"	"Vehicular Ad-Hoc Network"
Web of Science	85	4651
Scopus	182	15198
Google Scholar	194	56900
Microsoft Academic	44	32738

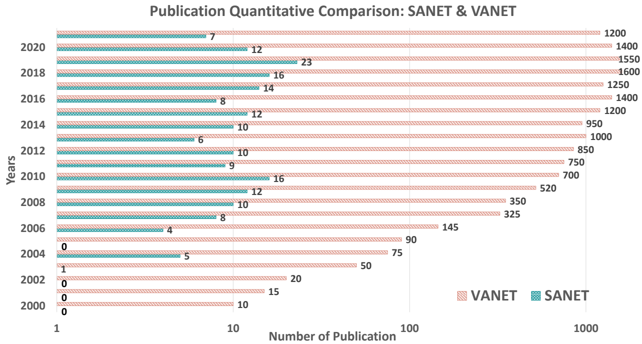


Figure 1: Number of Publication comparison between SANET and VANET in Scopus

The shortage of the papers concerning SANET, in comparison to VANET (Table 1) shows the limited amount of work done in the field, though recently there is a growth in the number of publications for SANET too, as it is in VANET, accessing the growth in publication number focusing only from the year 2000 onwards in Scopus (Figure 1). Starting from the beginning on how SANET is established at sea and how the communication process can take place (Laarhuis, 2010; Zhou & Harada, 2012), the work moves forward to explore how advantageous the infrastructure independence is for data transmission from remote offshore areas (Xu, et al., 2019). Some papers focuses on the prospects and the problems associated with SANET from a general perspective (Taher, 2018), while some explained SANET along with the other types of ad-hoc networks, describing its functionality and the application areas (Al-Absi, et al., 2021; Chauhan, et al., 2020; Yau, et al., 2019). Work has been done to explore the usability of SANET in various fields, such as, for real-time Voice over Internet Protocol functions (Lambrinos & Djouvas, 2011), or for marine data acquisition and cartography (Al-Zaidi, et al., 2017). Publications are also exploring the effect of parameters on the efficiency of the communication process (Mohsin, et al., 2015). Different routing protocol performances are also evaluated in this regard (Mohsin & Woods, 2014), some proposing new routing protocols to be explored and explaining their advantages over the available ones (Yun, et al., 2012). Few of the publications focuses on exploring SANET on the basis of case studies (Xin, et al., 2015), investigating the utilization of SANET for the underwater data exchange process (Garcia-Pineda, et al., 2011; Kong, et al., 2005). Work is also in progress to increase the efficiency of the communication process following the principles of SANET (Shi, et al., 2016).

Due to the insufficiency of available papers associated with the topic of SANET (see Table 1), information is also extracted from the published papers on the topics of communication over other types of ad-hoc networks, as VANET, Mobile Ad-Hoc Network (MANET), to develop the literature background for the paper, as explained below.

2.1 Satellite Communication (SATCOM)

The marine communication in the process of transferring goods through the sea way, includes communication between the ships, as well as with the shore. The main requirement is to ensure a proper uninterrupted communication system between the ships for tracking or monitoring, updating information when on route, and providing safety or security alerts. Establishing communication and entertainment for the crew members is another requirement for communication at sea. Since 1964, satellites are being used as the medium of communication for marine purposes (Ilcev, 2019). To communicate with a ship from the shore, the data is sent to the satellite, which then forwards the data to the intended ship. The opposite way communication too happens the same way, having the satellite in between to forward the information back to shore (Figure 2). With time, the number of satellites have increased, starting from geosynchronous equatorial orbit, then including highly elliptical orbit, low earth orbit satellites in the process, to ensure better efficiency in the data exchanging process.

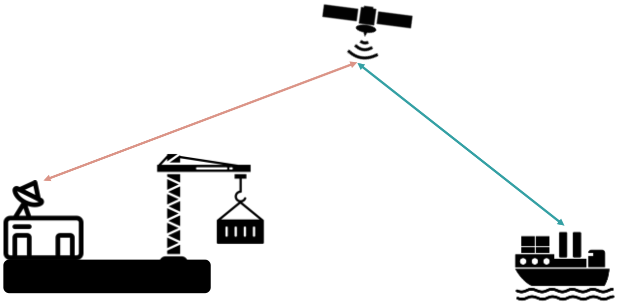


Figure 2: Satellite Communication process (Own work)

2.2 Ad-Hoc Networks

Ad-hoc networks are opportunistic, dynamic, wireless, infrastructure-less network with unavoidable delays associated with the process (Kaur & Mathur, 2016). The connection between nodes is limited by their range of communication, and their movement, which occurs in irregular intervals. The process can be described as "store-move-forward" (Nguyen, et al., 2015). A node receives information, stores it within, moves from place to place, finds another node inside its range to communicate, and forwards the message. In ad-hoc communication, there remains a possibility that the source and destination might never come directly into contact (Kaur & Mathur, 2016), the source tries to find out the shortest path and either sends copies of messages to all its neighbors or directly transmits the message itself forward, depending on the requirement. By choosing the hop count, memory allocation, and routing protocols appropriately, the efficiency of the ad-hoc networks can be increased.

2.3 Routing Protocols

The nature of the routing protocol being used for communication, decides the delay and resource consumption in the network. They can be divided broadly into two categories based on the data transmission characteristics (Figure 3), namely *forwarding-based approach* and *flooding-based approach*. For this paper, protocols are chosen from both flooding-based (ER & RRS) and forwarding-based (S&W) types, respectively following the principle of *epidemic* and *direct transmission*. Their performance and the effect of data dissemination principle on the efficiency of SANET are evaluated based on the chosen routing protocol under similar circumstances.

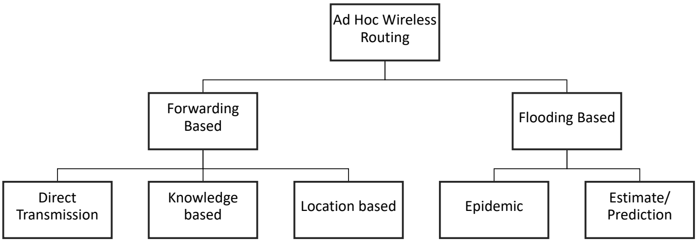


Figure 3: Classification of Routing Protocols based on data dissemination [adapted from (Kaur & Mathur, 2016)]

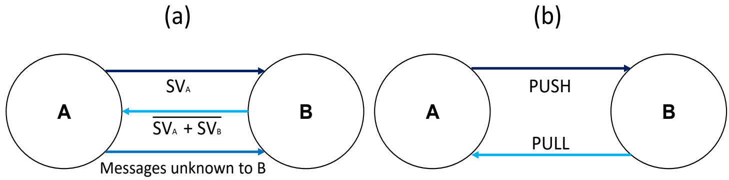
2.3.1 Epidemic Routing Protocol

ER is a type of flooding-based, direction-less approach (Kuppusamy, et al., 2019), so it forwards the message to every node coming inside its range, and before sending the information, it creates an *anti-entropy session* between the node pair and after that only data sending takes place as shown in Figure 4.a. It does not keep track of meeting nodes after a certain period of time, if all messages are found to be the same for both nodes, no data transmission takes place. So there is always some overhead present, however, the data is never sent twice to the same node. There are two factors deciding the performance efficiency of the routing protocol- *hop count and buffer size*, which control the data delivery process and the communication in ER (Amin & Becker, 2000).

2.3.2 Randomized Rumor Spreading

RRS is an existing, gossip-spread-based algorithm used to disseminate data in a large network. The algorithm is used to distribute copies of a recent update or the *hot rumor* among the nodes of the network (Karp, et al., 2000). It uses simple and random communication for robustness, without creating any anti-entropy session (Figure 4.b).

When a node receives any new update, it becomes the hot rumor for that specific node. Until it receives any new update, it keeps on spreading the update among its neighbors, calling them randomly, to spread the message in the whole network. RRS offers the advantage of spreading the news in the whole network with a minimum amount of rounds. The key advantage of this algorithm is its simplicity and robustness as it can be seen in Figure 4.b, its self-organizing nature and its scalability (Doerr, et al., 2014).



[SV_A =Summary vector from A, SV_B=Summary vector from B; having the list of messages, $\overline{SV_A + SV_B}$= unique messages' list to B]

A & B are two communicating partners inside each others connection range

Figure 4: Data transfer process through ER (a) and RRS (b)

2.3.3 Spray and Wait Routing Protocol

S&W is a direction oriented forwarding routing protocol that follows two phases in the data exchange process, as:

- Spray phase: The originating node produces L copies of the message and sprays the message to $L-1$ nodes coming to contact.
- Wait phase: After spreading the message, and having left with only one copy of the message, the source goes into the wait phase for a certain amount of time, while the nodes that received the message copies in spray phase, does direct transmission to the destination.

The S&W routing protocol follows the principle of the ER protocol, being similar with the speed and simplicity for direct transmission, while differing in keeping a limit on the number of copies of the message being available in the network, thus being better on the basis of the number of transmissions (Dhurandher, et al., 2015).

2.4 OMNET++ and OPS simulator

OMNET++ is an expandable, modular, well structured, C++ simulation framework, referred to as the 'Objective Modular NETwork testbed', offering flexibility for parallel execution of simulation, large ranged library for various modules, graphical representation of results and support for both event and process based simulations (Dorathy & Chandrasekaran, 2018).

Utilizing the advantages offered by OMNET++, the Opportunistic Protocol Simulator (OPS) is built on its framework, which is the used simulator in the scope of this paper (ComNets, 2017).

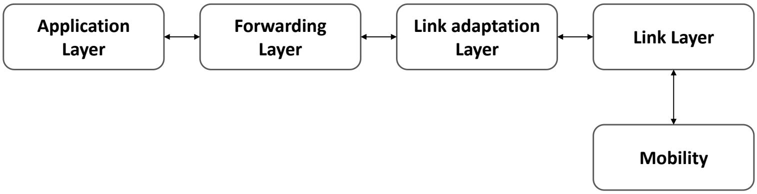


Figure 5: Opportunistic Protocol Simulation (OPS) [adapted from (Udugama, et al., 2019)]

OPS is a set of simulation models having its own grouped forwarding protocols, where the opportunistic network is implemented through the following layers, as explained in Figure 5 (Udugama, et al., 2019):

- Application layer, responsible for generating data, the amount of data to be sent and traffic data in the simulator, to evaluate the network with different traffic generation patterns.
- Forwarding layer, responsible to decide the forwarding routing protocol to disseminate the data in the network.
- Link adaptation layer, responsible to transform messages from one form to another, to be sent to other nodes.
- Link layer, here the characteristics of the connecting medium is defined. Wired or wireless, the range, data rate these parameters are explained here.

- Mobility model, that controls the mobility in the network, based on either real-life traces or already available mobility models from INET. This an input provided to the link layer (INET Framework, 2003).

3 Methodology

To check the merit of an undertaking to be used for real-life applications, and to ensure its feasibility for a specific purpose, an evaluation is needed to be performed. The operations to perform such evaluations are depicted in Figure 6, there are few options available, as Dede, et al., 2018 explained:

- Analytical model: The evaluation process follows mathematical calculation with simpler assumptions for faster evaluation, offering lesser accuracy.
- Simulation: The evaluation process prepares Software models, offering scalability to the network design. Simulators allow to have a pretty accurate result, replicating the real-world scenarios in software.
- Emulation: This process combines both the hardware and software part, so for the evaluation process some parts are implemented in real life, while some are done in the simulators.
- Real-life deployment: The evaluation does experiments done in real life, having maximum accuracy. Large scale experiments are costly and complex but smaller scaled ones offer most precise and dependable results.

In the scope of the paper, analytical and simulation modelling are chosen to be the evaluation processes to obtain the desired results, as described below.

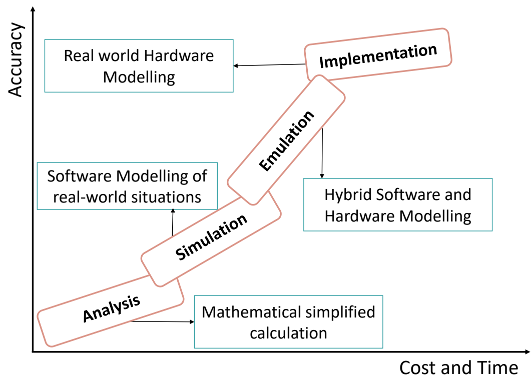


Figure 6: Available processes for evaluation

3.1 Literature study

To understand the SANET communication process, its usability, the correlated routing protocols and other corresponding terms, the first step to begin with the work is the literature review section, which explains the concepts associated with the process. The following evaluation process is then broadly divided into two sections.

1. Analytical calculation, is done to estimate the data efficiency in SANET varying different parameters for a communication situation considering two ships meeting each other.
2. Simulation of a real-life replicated scenario, considering varying network traffic congestion, is done to calculate data efficiency in SANET varying different parameters.

The literature study helps to identify and decide on the connecting technologies and the routing protocols to compare. The reason to opt for ER, RRS and S&W, namely MANET's routing protocols instead of the available SANET's ones is to inspect if the widely used and already available routing protocols are equipped to be used at sea as they are in land, even when the network structure and the communicating partners' nature changes. The three connecting technologies are chosen from the ongoing projects in the field of SANET to have a realistic comparison altogether, between the connecting technologies already being looked into, as listed below:

- WiMax: Project TRITON, which was an approach to develop low cost and high speed connection using WiMax, for ship-to-ship and ship-to-shore mesh network. It was designed to accompany or replace SATCOM in narrow water channels closer to shorelines in Singapore (Shankar, et al., 2008).
- LR WiFi: Project MICRONET, which was an approach to develop an affordable mobile LR WiFi based infrastructure for the fishermen community in India to enable ad-hoc communication (Reddy, et al., 2017).
- VHF: Project NORCOM, which was an approach to develop a single hop ad-hoc network to communicate deep in the sea using VHF, almost hundred kilometers away from the shores of Norway (Yau, et al., 2019).

To check the suitability of SANET under different surroundings, three use cases are chosen, reproducing events that happen in real life.

- Search and Rescue: The use case takes into account a SAR situation where the ships need to communicate and inform the whole network as soon as possible, the data amount is very low to be sent as it is just a notification, stating the emergency, but the main deciding factor here is the time to inform, as people's lives are at stake.
- Route information: This use case considers sharing nautical charts to the ships from the central provider, which happens at regular intervals. This is a time relaxed information to share, but the file size is high.
- Insurance video: This use case considers the data transmission for insurance obligation. As there is a requirement of providing proof to demand the insurance amount, the use case considers that proof to be a high quality video message, which can be transmitted in a time-relaxed manner.

A variety of scenarios can be simulated via the analytical and simulation models, by setting different parameters, such as:

- The number of ships (number of nodes) that creates the traffic for the simulation,
- Speed of the ships, used to create the mobility model, defining how the ships move, along with their direction of movement,
- Data amount, decides the size of message to be sent, which is chosen based on the use cases considered,

- Connecting technology, acts as the medium of communication between the ships offering various data rates and covering ranges,
- Routing protocols, which are the deciding factor of how the ships will communicate in a multi-hop network, under different circumstances.

Additionally, for the simulation model, the area and time of simulations are also added as the input parameters, as the boundary conditions.

3.2 Analytical Modelling

To look over the credibility of SANET theoretically, based on the above explained use cases, some real-life meeting situations are considered where two ships move towards each other, cross and move away from each other in either parallel or angular paths. The speed of the ships along with their directions are taken as the parameters to compare the concerned connecting technologies and the routing protocols. By changing the parameters, different scenarios are created for the two ships to meet each other. The first step in this section is to calculate the Time of Contact (TOC). TOC is the time until when the ships stay inside each other's communication range to convey information. When the TOCs are known, the next step is to calculate the data amount and the overhead amount for all the occurrences, varying the connecting technologies as well as the routing protocols. From the maximum transmittable amount and the total transmitted data amount and duplicate or summary vector amount, the percentages are calculated respectively for both data amount and overhead and they are compared. As the result, the values are plotted in graphs to show the comparison and based on them the conclusions are obtained and analyzed. To dig deeper, the influence of the direction of movement and the separation distance between the ships along with the message's nature is explained in the results section of the paper (4.1 Analytical Modelling). As for unicast communication, S&W performs similar to ER, thus the analytical section considers only RRS and ER.

3.3 Simulation Modelling

This segment focuses on replicating a real-life marine outline in OMNET++ and OPS (Udugama, et al., 2019; Kuppusamy, et al., 2019). To serve this purpose, the simulation models are made following two principles, as:

- Model 1: Synthetic data model, where the data associated to create the model is based on different considerations, assumptions and practical data sources, which allows the model to be scalable and flexible to create various conditions for the analysis of the communication process under different amount of ship traffic on the sea.
- Model 2: Real-life trace analysis, where the model is created based on real-life traffic details, recorded AIS data, accessible and available online publicly. This model provides an opportunity to analyze the effectiveness of the communication technique, on the foundation of a real-life marine traffic.

3.3.1 Synthetic Model

The synthetic model is a mobility model that is produced by recreating a real-life open sea situation, where the number of ships is gradually increased, to enable communication between them.

To create the mobility of the ships to be used for simulation, a python script is written, which takes the following inputs:

- Number of ships: 10, 50 and 100
- Speed of ships: randomly chosen between 13.5 knots to 21.5 knots
- Simulated area and simulation time
- Ships moving from east to west or vice versa in parallel way
- Ships moving from east to west or vice versa with an angle
- Minimum separation distance between the ships: 2.7 knots

Accumulating all this information the collision-free mobility model is prepared for the ship network.

3.3.2 AIS Model

For the AIS data model, the first step is to download an AIS data log file that had the information of all the ships travelled in a single day. For the purpose of this paper the AIS data file of the date 31.12.2020, having the details of the ships for that particular day (NOAA Office for Coastal Management, 2021). The area chosen is near Miami Port having the longitude under the boundary of -79° to -82° and the latitude of the focus area was between 25° to 26°. For the chosen time and area, 175 ships are available in the downloaded AIS data set. The obtained data was transformed into a mobility model file using a python script, translating it to a Bonn motion file (OMNET++, 2020), readable by the simulator, which identifies that for every time instance t there is a corresponding value to X and Y. As the AIS data contains the latitude and longitude data for the ships for a given timestamp, the transformation to the Bonn motion file starts with identifying the minimum values for the timestamps, latitude and longitude as the base values, and then calculating other values from their distance to the base values. The ships containing data for only 1 entry are ignored in the beginning as they are to be depicted as stationary ships. The Bonn motion file is prepared having 150 ships' data to be used as for the real-life trace analysis, developing a network using SANET for communication.

The main contrast from the analytical model to the simulated models is the change in the amount of traffic in the network, which allows to evaluate the viability of the process, while reproducing the real-life traffic at sea. The simulation model offers the possibility of modelling, varying congestion that in turn affects the time of contact among ships. These variations cannot be captured effectively in the analytic model. Out of all the inputs considered, the number of ships, speed of each ship, area, and time of simulation are considered to be as fixed inputs to the simulations. Based on all these situations produced by varying the input parameters different real-life scenarios are modelled to inspect the viability of SANET.

Each simulation model provides their own sets of advantages. As the scalability offered by the synthetic model allows to change the network size and number of ships to evaluate its effect on the communication process, while the real-life trace analysis gives the chance to simulate a real-life scenario to examine the process. Both the simulation models provide the opportunity to evaluate the efficiency over a range of situations.

For both the simulation representations, the process of developing the underlying mobility models are different, for the rest of the situation similar circumstances are to be examined for the SANET process, as explained below in Table 2.

Table 2: List of simulations for Synthetic and AIS data model

	Case Study Setup		Routing protocols	Connecting Technology
Situation	Data type	Data size		
SAR	Image	2 MB	ER	WiMax
Route information	Nautical charts	660 MB	RRS	LR WiFi
Insurance proof	Video message	1050 MB	S&W	VHF

To explain the simulation setups in details, three examples are described below:

1. In a network, one of the ships has time-critical information, as an image, to share with other ships and the shore. The situation considers the sending of small data (2 MB) in an emergency, from one to all.
2. The central provider from the shore transmits the nautical chart to the ships, updating them in a timely regular manner. The situation considers a one to all transmission, where the source is stationary, and the destinations are dynamic in nature, for a large file (660 MB) in a time-relaxed manner.
3. In compliance with the insurance policies, a ship has proof of a broken part in the form of a large-sized video. It needs to send the video to another ship, for further transmission. The situation considers unicast communication between two ships sharing a very large file (1050 MB) in a time-relaxed manner.

Each of the simulations for both models is repeated 30 times to account for stochasticity. To make the results more realistic, it is considered that the communication range of the ships follows free space path loss policy (Christian Wolff, 2021), so with the distance the strength of the connection reduces.

The obtained results are evaluated based on the following performance metrics, as:

1. Delivery ratio: Calculated by dividing the total data bytes received (a) by the total data bytes maximum receivable (b), as:

$$Delivery\ ratio = {}^{a}/_{b} \tag{1}$$

2. Overhead amount: Calculated by subtracting the total data bytes received (a) from the total bytes received (c), as:

$$Overhead\ amount = (c - a) \tag{2}$$

3. Average delay: Average time taken to disseminate the data in the whole network or to send to a particular destination

4 Results

The following section is focused on explaining the obtained results from the analytical and simulation modelling sections as explained above.

4.1 Analytical Modelling

Due to the change in direction, the delivery ratio changes. For two ships moving in the same direction, the TOC stays higher, allowing the ships to communicate longer, while the opposite direction movement restricts the TOC and the data transmission (Figure 8.b). Similar to the effect of the free space path loss policy, when the separation distance between the ships is increased, the delivery ratio decreases (Figure 8.a). Based on the connecting technology, WiMax sends most amount of data in comparison to the other alternatives. VHF has the highest range thus it is able to communicate even when WiMax and LR WiFi fail to establish a contact, but having the lowest data rate VHF shows decreased delivery ratio in comparison. ER and RRS achieve comparable delivery ratio when the message is unique in the network, but as the messages become seen in the network, RRS performs poorly as the whole amount is transmitted as duplicate, while ER stops the transmission after exchanging the summary vectors, having a comparably negligible amount of overhead, thus showing better performance (Figure 7).

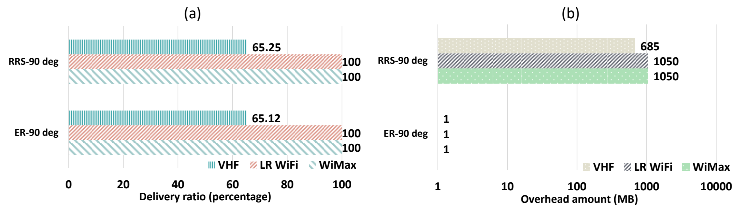


Figure 7: Delivery ratio (a) and Overhead (b) comparison between ER & RRS, effect of Seen and Unique video message in the network; meeting situation between Bulk carrier and RORO carrier

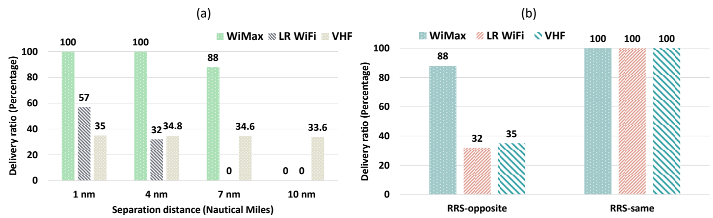


Figure 8: Delivery ratio comparison for effect of Separation Distance (a) and Direction of Movement (b) between two Cargo ships sharing 660 MB sized large file through RRS

4.2 Simulation Modelling

4.2.1 Image

For the synthetic simulation, as the traffic is varied from 10 ships to 50 ships to 100 ships, the effect of it on the delivery ratio becomes evident. The results are explained for VHF only for the following situations, as it showcases superior performance covering the largest area of communication. The delivery ratio of the data decreases with the increase of traffic in the network for ER and S&W, but for RRS, it is able to broadcast the whole data for any number of ships being present in the network (Figure 9).

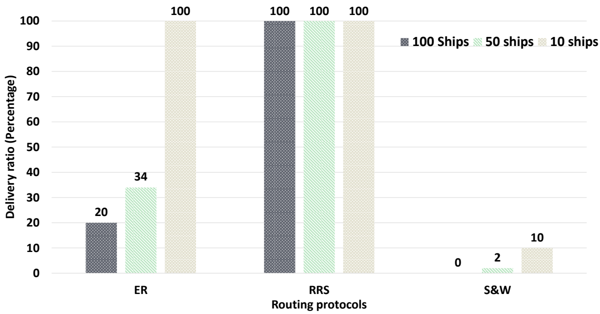


Figure 9: Delivery Ratio comparison for Synthetic model simulation

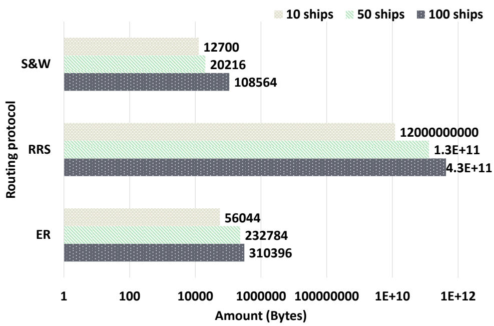


Figure 10: Overhead amount comparison for Synthetic model simulation

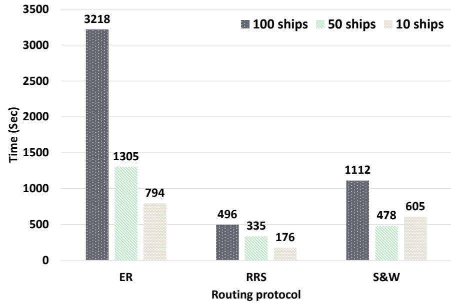


Figure 11: Average Delay comparison for Synthetic model simulation

Even though the problem of having the huge amount of overhead (Figure 10) is associated, along with the time advantage, RRS comes ahead as a better alternative for the considered situation of transmitting time critical information (Figure 11).

The AIS simulation with 150 ships too shows that to send a small sized data VHF works better. It is able to communicate with the ships far away due to its wide range and send the complete data within the stipulated time. Comparing the routing protocols, RRS is able to broadcast more data in every situation (Figure 12), but with the presence of a humungous amount of overhead, as it keeps on sending the data over and over again (Figure 13).

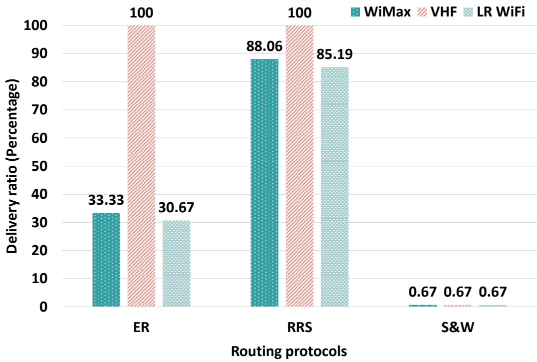


Figure 12: Delivery ratio comparison for AIS model simulation

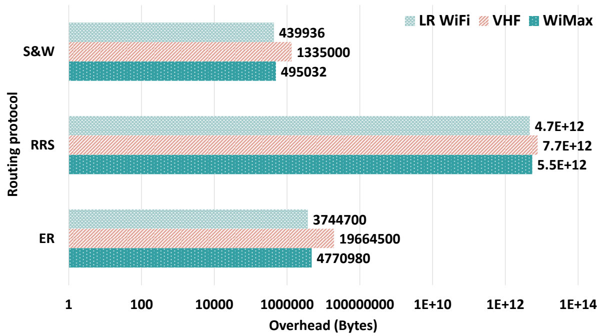


Figure 13: Overhead amount comparison for AIS model simulation

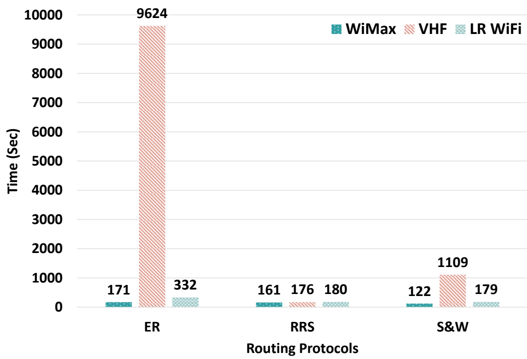


Figure 14: Average Delay comparison for AIS model simulation

ER works in a standard way, with VHF it is also able to send the whole amount of data, while producing considerably less amount of overhead compared to RRS. The S&W routing protocol performs poorly, being limited by the amount of copies of the data available to it. RRS also shows a better timely delivery of the image, when compared to the other two alternatives (Figure 14). As the situation considered, is a time-critical emergency scenario, RRS proves to be a better option, checking off all the requirements. If the situation is considered to be a time-relaxed scenario, ER having better overhead management, demonstrates its efficiency.

4.2.2 Nautical Charts

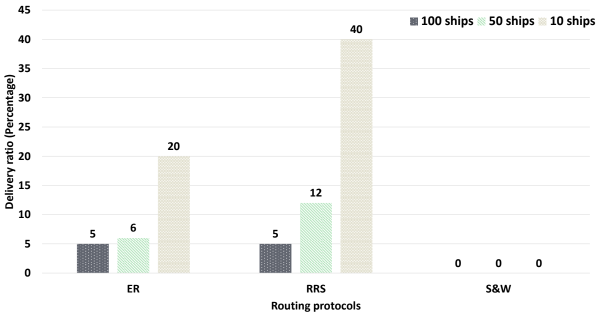


Figure 15: Delivery Ratio comparison for Synthetic model simulation

With the increase in data size, VHF becomes unable to send the data and WiMax becomes a better alternative. For the synthetic model simulation, due to the increased traffic the delivery ratio of the nautical chart decreases from a 10 ship network towards the 100 ship network. RRS offers better delivery ratio than the other two alternatives in all the situations (Figure 15), but still struggles with the enormous amount of overhead (Figure 16). The limitation on the copies of messages and the hop count deteriorates the performance of the S&W routing protocol and it remains unable to send the data under any circumstances.

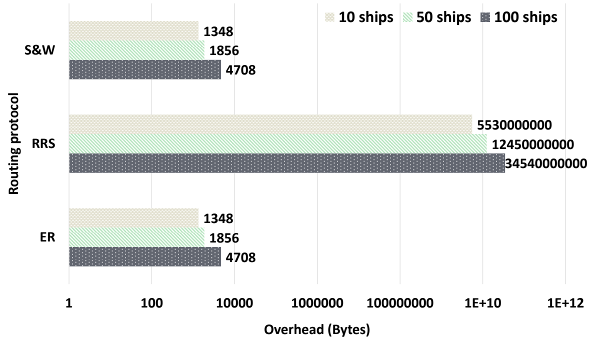


Figure 16: Overhead amount comparison for Synthetic model simulation

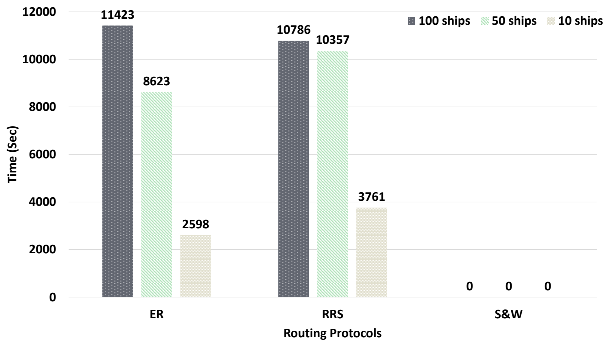


Figure 17: Average Delay comparison for Synthetic model simulation

The AIS-based model simulation also shows similar results, even though the ER protocol transmits data in a standard way, RRS broadcasts with more delivery ratio in every case (Figure 18), except transmission of data with VHF. RRS delivers data with time advantage but in the presence of huge duplicate transmission. But even though ER and S&W too are unable to send any data while using VHF, they still produce a certain amount of overhead due to the exchange of summary vectors, in case of RRS the overhead amount in the VHF situation remains zero (Figure 19).

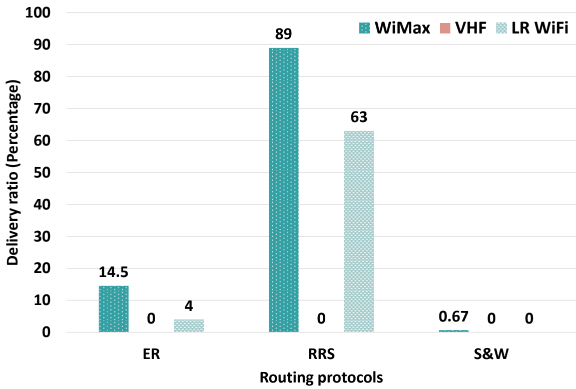


Figure 18: Delivery Ratio comparison for AIS model simulation

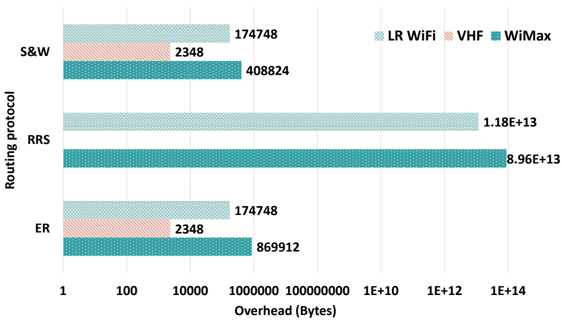


Figure 19: Overhead amount comparison for AIS model simulation

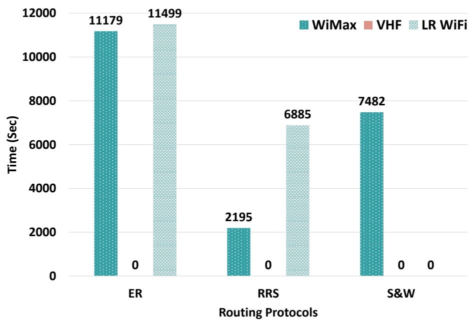


Figure 20: Average Delay comparison for AIS model simulation

Even though the image and nautical chart sending scenarios consider a similar network setup where a single source sends the data, and the rest of the network acts as the destination, the dissimilarities in the delivery ratio is a result of the change in the process parameters and it showcases the effect of them on the communication process following SANET. As the delivery ratio reduces while transmitting nautical charts in the network, it depends on the increase of the data size from image to the charts, along with the effect of the mobility of the source, which is changed from a moving ship to a stationary shore station, which circulates the nautical chart in the network. This provides evident of the dependency of SANET on the mobility of the nodes in the network to have better communication.

4.2.3 Video Message

For the synthetic modelling, all the routing protocols are able to send the data to the destination, even when the network size changes. But in this case, RRS produces no overhead, as while staying connected, the source utilizes all the time to deliver the huge amount of data (Figure 21). For ER and S&W, the overhead is the summary vector, exchanged for the anti-entropy session, which is produced whenever two ships meet. Thus having least overhead and comparable time management (Figure 22), with similar delivery ratio, RRS broadcasting becomes a preferable option in this situation.

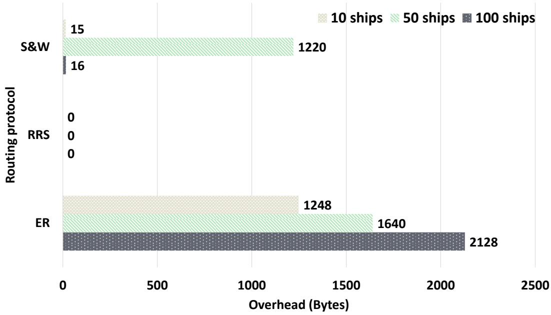


Figure 21: Overhead amount comparison for Synthetic model simulation

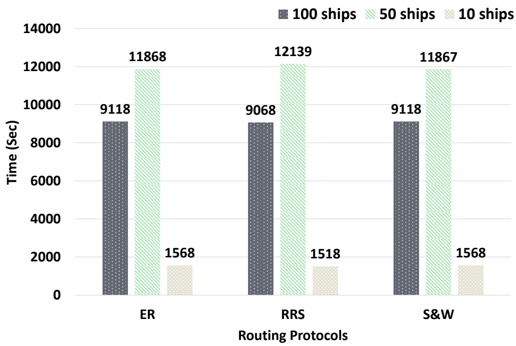


Figure 22: Average Delay comparison for Synthetic model simulation

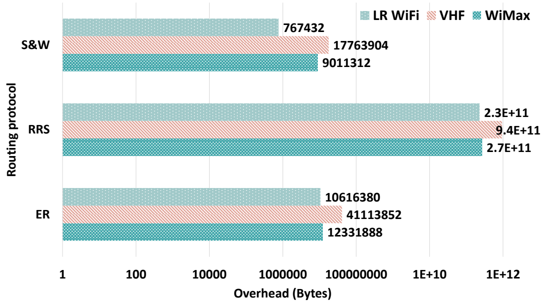


Figure 23: Overhead amount comparison for AIS model simulation

For AIS based model too, similar to the previous scenarios, RRS produces a lot of overhead (Figure 23), but it's the only option where the data reaches its destination. Even though ER and S&W are not able to send the complete data to the destination, as they keep on meeting other ships, they keep on producing summary vectors too, creating overhead in the network for zero delivery ratio.

5 Discussion

The results explained above, obtained through the calculation processes and observed as graphs, show that no routing protocol and connecting technology individually or even as a particular combination can be named as the most preferable option to go for in every situation. It is always dependent on the fixed and variable inputs that decide the characteristics of the situations, as it is seen in the simulation modelling. Because it considers the effect of having increased network traffic, when the number of sources and destinations are varied in the network for sending different amount of data.

The synthetic model network shows the effect of gradually increasing the traffic. So for the network with a small number of ships, it is possible for all the connecting technologies to have higher delivery ratio, but as the number of ships increases, the ratio keeps on decreasing. The same effect is observed for increasing data amount, so even for a large network with 100 ships, the efficiency is 100% mostly, when the data being exchanged are small in size as the image, and it reduces by a large amount when the amount of data to be exchanged is changed to video messages. The AIS-based simulation model validates these results on the basis of real-life trace analysis.

The dissimilarities in the performance of the routing protocols and the connecting technologies when simulated against the AIS data and the synthetic model can be described by the difference in their underlying mobility models, as the difference in the movement of the ships, having different speeds, different directions, holds a very large influence on the process. As from the findings of the analytical estimation section it is seen that the changes in these process parameters actually decides how efficient the communication will be.

Accumulating all the data from the graphs explained above the conclusions can be drawn that:

1. ER offers a standard performance in all scenarios,
2. RRS with broadcasting works better when there is a single source.
3. S&W protocol works better when there is a single destination.

While VHF performs better for transmitting smaller data files for distant communication and WiMax performs better for the transmission scenarios involving faster communication and sharing larger data files.

Also, the disparity between the analytical and simulation's outcome can be explained by the way the message is considered for estimation. The analytical section takes the data by their size, so it even considers the data is being sent when even only 1 MB has reached the destination, thus showing delivery ratio based on that. The simulation section takes the data as a whole packet, so when the complete amount is not received by the destination, it takes no data has been transferred and approximates the efficiency accordingly.

From all these above discussions it could be said that even though using SANET for the marine communication purpose cannot solve the problem of having delays to deliver messages to their destination, for certain protocols under certain situations, as it was visible in SATCOM too, but it is able to provide solution to the following problems, as:

- It is a solution to the problem of having higher cost associated with SATCOM, as SANET utilizes the already available technologies, to share data with each other, avoiding the huge capital and operational cost.
- It provides a solution from having the complex regulations (Ilcev, 2019) associated with SATCOM to be used.
- It also provides a solution to the problem of SATCOM usually offering a low data rate (Yau, et al., 2019), as with WiMax the maximum achievable data rate was 6 Mbps.
- SANET being able to communicate locally, also provides a solution for the blind spot problem in SATCOM. When in certain regions SATCOM is not able to communicate due to the coverage breakage, SANET, with the availability of ships in the proximity, can create contact and share information.

6 Conclusion and Future Scope

The paper considers three routing protocols that showcase different characteristics and three connecting technologies that are already being inspected for ongoing projects based on SANET. All the components are compared under the same umbrella - having the same circumstances around them, facing the same changes in the basis of case study simulation. To the best of our knowledge, this is the first time where all these factors are examined all together.

The flow of the paper also allows to find the solution of SANET being evaluated over a wide range of spectrums, covering multiple possible scenarios. The change in the situations to evaluate SANET’s feasibility also proved that the efficiency is highly dependent on the situation established, along with showing the effect of the mobility pattern that the ships follow. As the route information of the ships is mostly known beforehand, utilizing the information, SANET could be used in real-life scenarios more efficiently.

The paper has its own limitations, as it considers only three available protocols and connecting technologies. There are other options available, out of which some might work in a more efficient way, for the situations taken into account. The paper opens up multiple research opportunities to be explored in the future, as:

- Look-up based optimization: A database prepared and made available to the ships containing a range of varied situations and the solutions, based on the situation which routing protocol to be used. Thus, when the circumstance changes, based on the available list, the routing protocol is chosen automatically.
- Parameter control: An option to prepare a system that allows the ships to choose their destination for a specific data file, based on the requirement, pointed by their GPS location, to avoid unnecessary hopping of the message, or to customize the network based on the time and place of implementation.
- Security aspect: If any ship is eavesdropping or changing the data being sent, or even stopping the dissemination process by not forwarding the data anymore to create problems, future work can focus on solving these problems to make SANET a much more secure network to opt for.

As for the maritime shipping operators, along with the timely delivery of the information, it is also important to have a lower cost of operation, and a simplified communication process equipped with a higher rate for data transferring. It could be said that even though having SANET as the only option for communication might not be the ultimate choice to be used right away, the process holds its merits to be integrated into the ships and used together with SATCOM, complementing each other's deficiencies, to provide an efficient medium to exchange data at the sea in real-life and gradually increase its application area in the shipping process.

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