GPS-Based Wireless Ad Hoc Network for Marine Monitoring, Search and Rescue (MSnR)

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***Abstract*—A GPS-based wireless ad hoc network is proposed for marine monitoring, search, and rescue applications in Vietnam. The network routing protocol and algorithm are evaluated using Network Simulator 2 software. The results indicate a success rate of packages transmission higher than 85% and show the great potential of the proposed concept.**

***Keywords*-Ad hoc network, marine monitoring and searching, Global Positioning System (GPS),**

I. Introduction

Situated in the South China Sea region, Vietnam has more than 3,200 km of coastal line and its fishery industry contributes more than US 1 billion dollars annually to the country gross domestic product. According to the recent survey performed by Vietnam Ministry of Agriculture and Rural Development in June 2006, the Vietnamese fishery industry had a total of 85,785 fishing boats [1]. The majority (62,358 boats or 72.69%) is small ships having its engine size less than 50HP (horse power) but often operates at an average distance of 50 km from the costal line.

While large ships or vessels with a more powerful engine are often well-equipped with advanced communication devices such as satellite communications or high power two-way radio with central base stations located along the coastal line, small fishing boats are either ill-equipped or not equipped at all of any type of radio communication equipment. For boats that are equipped with a two-way radio, it is often adequate for the forward link (land-to-sea) communications. This link provides weather and traffic information to small fishing boats operating at sea from central base stations, which often have a high transmit power. On the other hand, the return link (sea-to-land) greatly depends on a distance between boats to the base stations, the weather condition, the geographical location and maximum power of radio equipment on board. It is not uncommon to find a radio system with a low power and a non-directive antenna on a typical small boat. When such a boats operates at a distance from the coastal line, the link to central base-stations might be broken due signal loss and signal blockage by islands or larger ships. This link loss results in the following two problems:

- No monitoring possible making it harder to search and rescue during or after storms,
- In the case of lost, no chance to declare a state of emergency and to request an immediate assistance.

In this work, we propose a wireless network, which provides an efficient positioning service and restores the lost sea-to-land link from small fishing boats to central base-stations. The proposed network combines the Global Positioning System (GPS) service (positioning) with a wireless ad hoc sensor network (communication). The positioning service is currently available (free of charge) from the US-based GPS while the dropped sea-to-land link is restored by short-range communication links within a ad hoc network comprised of small fishing boats. For the land-to-sea link, the proposed network simply utilizes the existing coastal radio network; hereby greatly reduces the cost. The proposed approach provides continuous reporting and monitoring of all boats and its exact locations for search and rescue process during emergency situations.

II. Literature Survey and Limitations of Current Systems

In Vietnam, there are two systems that are suitable for marine monitoring, search and rescue services. The operation as well as advantages and disadvantages of each system are summarized below.

COSPAS-SARSAT system is jointly sponsored by Canada, the Unites States, the Soviet Union and France. This project requires special purpose radio frequency transmitters, i.e. Emergency Locator Transmitters (ELTs) and marine equivalent Emergency Position Indicating Radio Beacons (EPIRBs), which are automatically activated by aircraft or vessels during emergency and transmit distress signals to multiple low, near-polar orbits satellites. The signals received by the satellites are relayed to a network of dedicated ground stations where the location of the emergency is determined by measuring the Doppler shift between the satellite, with a precisely known orbit, and the distress signal. This is undoubtedly one of the best search and

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rescue systems but also one of the most expensive systems (requiring multiple satellites and special transmitters), which is clearly not suitable for developing nations like Vietnam [2].

MOVIMAR system is a joint project between Vietnam and Collecte Localisation Satellites (CLS), a worldwide leader of satellite-based environmental data collection, location and ocean observations by satellite of the French Space Agency [3]. With satellite images collected from Envisat, Radasat-1, and Radasat-2 (starting from July 2007), this project is going to provide continuous updated activities in the South China Sea to the Vietnamese government and its corresponding agencies and to help in the search and rescue process of missing boats and fishermen in case of natural disasters. This is again a satellite-based project, which provides the broadest and best coverage. While satellite access is provided by the French Space Agency via CLS, this solution requires a GPS receiver and a satellite transceiver with a large parabolic disk-antenna to establish a communication link. A full-satellite equipment is currently not affordable by most fishermen and its considerable size is not appropriate for small fishing boats.

III. Proposed System

A. Operating Principle

Figure 1 illustrates the proposed concept of GPS wireless ad hoc sensor network for marine Monitoring, Search and Rescue (MSnR) applications. It operates as follows. The forward link from land to sea (solid, red arrows in Fig. 1) uses the current radio system with high-power base-stations along the coastal line to transmit weather and relevant information to all fishing boats (licensed operating frequencies of 8.294 MHz, 12.356 MHz and 18.843 MHz and transmitting power of 1000W [4]). In this project, the Tx/Rx frequency of 8.294 MHz is selected. Because the transmitting antenna are mounted on base-stations at a typical height of 100m and a high power is available, this forward link can reach all of fishing boats in the horizon. In contrast to the forward link, the return link from sea to land (dash, blue arrows in Fig. 1) is limited by the low power and antenna height installed in all small fishing boats. This problem is remedied by the wireless ad hoc sensor network, which allows the return link to be first established between all fishing boats and connected from the closest boats to the central base-stations. The routing protocol of the proposed system is a location-based routing. A data packet being routed in the return links contains a ships identification number (ship ID), ship's GPS location, and a short message. In order to establish a wireless ad hoc network and to identify its position, a small and commercially off-the-shelf integrated GPS receiver with a programmable DSP board are added to the existing radio transmitter on all of the fishing boats. The GPS receiver determines the position of each boat while the DSP controls for the ad hoc network communication and routing protocols. Finally, packets are transmitted over existing radio system on-board.

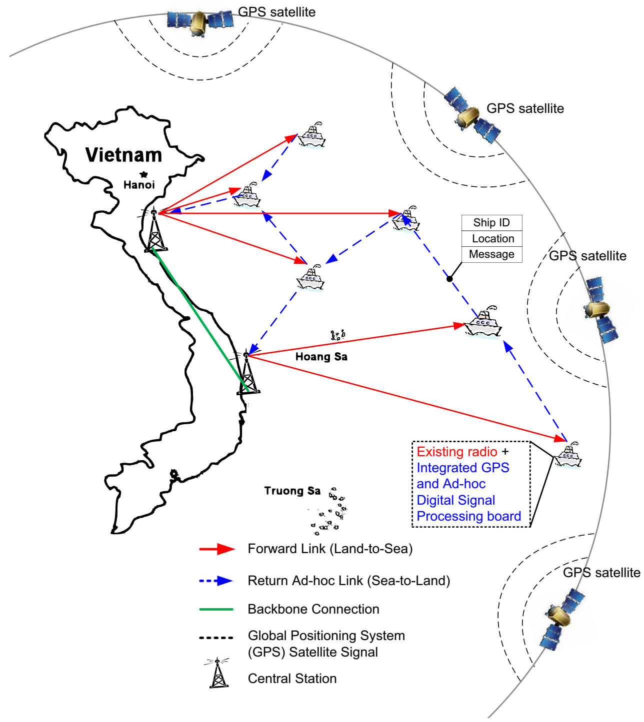

Figure 1. Illustration of the proposed GPS-based wireless ad hoc network composed of small fishing boats operating as transmit/relay nodes.

B. Advantages

The proposed system have the following four advantages:

1) This system is cost effective because a) it utilizes the currently existing and functioning radio system in the mainland and radio transmitter installed in all fishing boats and b) it harnesses the freely available GPS for location monitoring.
2) The efficient combination of GPS and wireless ad hoc network remedies the fundamental limitation of sea-to-land communications and the bottleneck of monitoring, search and rescue process. By periodically (every 5 minutes for instance) reporting its location and status, positions and conditions of all fishing boats can be monitored at the central station in land. The exact position and condition (type of boat and size of the crew) will ensure all emergency services to be dispatched in a timely manner during natural disasters where a faster response equals to a greater chance of survival.
3) The short range ad hoc connection between neighboring fishing boats is inherently more reliable and less susceptible to weather condition during disasters. As the result, this system increases the probability

Table I
FORMAT OF LOOKUP TABLE (LUT).

Record	Source ID	IT	Location
1			
2			
...			
N			

Table II
FORMAT OF FORWARD TABLE (FT).

Record	Source ID	IT
1		
2		
...		
N		

of successful reception of urgent messages sent from fishing boats to central stations. Therefore, emergency-rescuing teams can be properly dispatched.

4) The proposed solution is a value-added system to the current marine radio network and provides a triple-play service to the return link: 1) Location tracking and monitoring, 2) Search and rescue, and 3) Voice and data messaging.

In direct comparison with other full satellite-based systems, this proposed system is a hybrid approach which exploits the best advantages of both satellite (global coverage and accurate position) and radio communication based on wireless ad hoc (low-power and local short-range communications). In addition, the proposed solution provides a smaller form-factor and a cheaper hardware since GPS receiver has become a commodity due to the economy of scale and price of DSP board has significantly dropped.

IV. METHODOLOGY

A. Routing Protocol

The main use of our proposed ad hoc network is for monitoring ships location, therefore it does not require continuous data and can support a large network delay tolerance. Based on these requirements, we adopted a modified hybrid proactive-passive, location-based routing protocol similar to the DREAM protocol first proposed by Basagni in [3]. In our routing protocol, the lookup table (LUT) at each node is updated when the node receives a packet. Unlike DREAM or other passive protocol, the LUT only contains locations of one-hoop neighbouring nodes. As a result, the LUT is significantly smaller and hence less time is required to record a update.

Due to the nature of available marine radio equipment, it is cheaper to send data packets omni-directionally instead of directionally as the latter requires an antenna array. Consequently, each node in our ad hoc network broadcasts its packet *m* to all its one-hoop neighbours. Based on relative positions, each neighbour decides to drop or relay the packet *m*. In case the neighbour node decides to relay the packet, it first switches from receive to transmit mode, then re-transmits the packet *m* and updates its forward table (FT). Other node repeats the same procedure, until the final destination (basestations) is eventually reached. The exact routing algorithm is explained in the following section.

B. Routing Data Packet Format

The description of each field in the data packet is as follows. Source-ID is the ID (identification) of the ship (source node) which transmits data packets. This field is the Source Node Identifier (SNI). Destination-ID is the ID of the ship or base-station (destination node) which is an intended receiver of transmitted data packets. This field is the Destination Node Identifier (DNI). When DNI is set to all 0s, the data packets are sent to all other nodes. Source Latitude is the source node GPSs latitude position at the time the packet is being sent. Source Longitude is the source node GPSs longitude position at the time the packet is being sent. Initial Time (IT) is the time when the packet is transmitted. Hop Count (HC) indicates the number of nodes that a data packet has been traversed in the network. It is set to 0 at the source node and incremented by 1 at each subsequent forwarding node. Status indicates the current status of the source node. It is set to all 0s when the source node is in its normal mode of operation, and set to all 1s if it is in an alert mode, i.e. when the source node seeks help from other ships or base-stations. Reserved field a reserved area for other purposes.

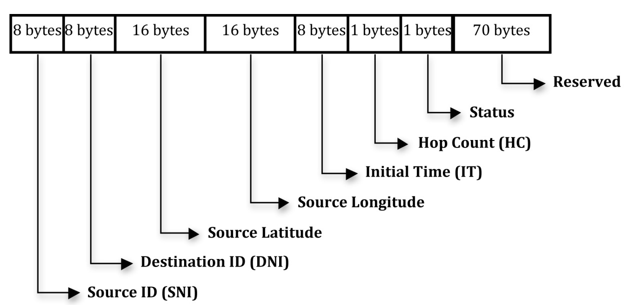

Figure 2. Format of the data packet used in the proposed GPS-based wireless ad hoc network.

C. Routing Algorithm

As mentioned earlier, the routing protocol used in the proposed wireless ad hoc network is a location-based routing, where the location of all nodes (except base-stations) is available from the GPS receiver integrated in the DSP control board. Base-stations are destination nodes and have a fixed location (latitude and longitude) at all time. Because the main purpose of the proposed network is to provide real-time monitoring of all ships, each node (ship) in the network regularly sends a packet *m* to the nearest base-station. Since a direct path between a source node to the base-station might not be available, the packet *m* has to go thru multiple nodes before reaching the base-station. Therefore, each node in the network must both receive and transmit (when it acts as a source node) or relay (when it acts as a relay node) the packet *m*. Furthermore, a relay mode must also process the packet and decide whether to forward or drop the packet depending on its location relative to the source and destination nodes.

Figure 3 shows the flow chart of a node operating in its receive mode. Under this mode, the node detects if a packet is received. In case when no packet is received after 10 consecutive time intervals, the ship can be considered isolated or out of range. The system will alert the operator to take a proper action. On the other hand, when the node receives a packet, it verifies the packet's HC value. If HC = 0, the packet has been sent from one of its one-hoop neighbours and the node updates its LUT. The LUT at every node contains the source node's IDs, the initial time of the packets most recently sent by neighbouring nodes, and their locations as shown in Table I. After updating its LUT, the receiving node compares its relative position to the destination node with that of the source node. If the distance is larger, indicating that the receiving node is not closer to the base-station than the source node, the receiving node decides to drop the packet and return to its receive mode of operation to accept incoming packets. In contrast, if the distance is shorter, the receiving mode verifies if the packet *m* is already received by comparing the source ID and the initial time of the packet *m* with record values in its FT. If a match does not exist, the receiving mode relays the packet *m* after updating its FT. Otherwise, it drops the packet to reduce the redundancy of transmitted packets in the network. The format of a FT is shown in Table II. In order to prevent the FTs size from getting too big, any record older than a preset time interval will be deleted.

Figure 4 illustrates two different transmitting scenarios of a given node. In the relay mode, it re-transmits the received packet after adding 1 to the HC. On the other hand, when it is a source node transmitting a packet to the base-station, HC = 0 and the remaining data fields (SNI, location, status and IT) are set to the values of the current node.

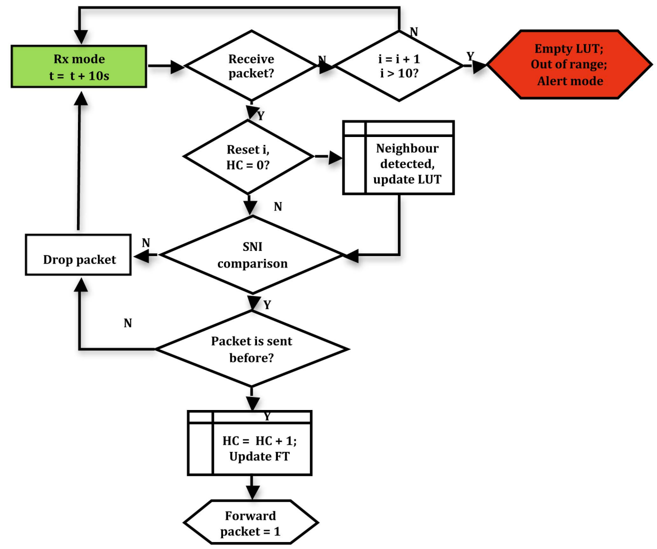

Figure 3. Receive mode operation of a node in the proposed GPS-based wireless ad hoc network.

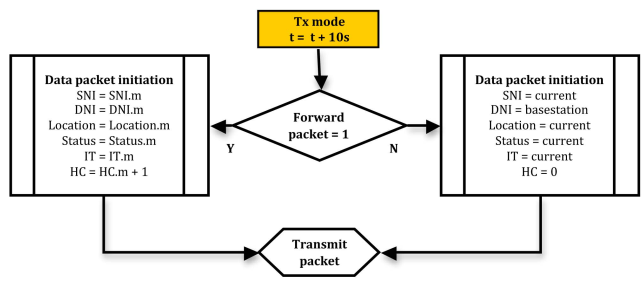

Figure 4. Transmit mode operation of a node in the proposed GPS-based wireless ad hoc network.

V. Network Simulation Results

The simulation is performed using NS2 and has the following environment set up

- Area: flat grid 1500x1500
- Number of nodes (N): 10, 20, 30, 40, and 50
- Simulation duration: 2000 seconds
- Physical/Mac layer: IEEE 802.11 at 1Mbps, 240 m (in grid) transmission range;
- Mobility model: random waypoint model with no pause time, and node movement speed (S) 0m/s, 1m/s, 4m/s, 8m/s or 20m/s
- Each sender sends 1 packet/10 second with each packet is 128 bytes long;
- The senders start sending data 30 seconds later. After 1900 seconds, all senders stop transmitting data;

Figures 5 and 6 summarize the simulated results of the proposed wireless ad hoc network consisting of N = 10, 20, 30, 40 and 50 nodes where each node is allowed to move in any direction with a speed of S = 0m/s (stationary), 1m/s, 4m/s, 8m/s and 20m/s. For each network configuration (N nodes and S velocity), the simulation is performed for 100 times before an average value is reported. Following conclusions can be drawn from these results.

For a given node's speed, both packet delivery ratio (PDR) and latency increase with an increasing number of nodes. This is due to the fact that there are more available links between source nodes and the destination node in a dense network. As the network getting denser, however, the latency increases, as a packet *m* needs to transverse multiple hoops before reaching the final node.

On the other hand, for a fixed number of nodes and an increasing node's velocity, the PDR drops while latency increases. When each node increases its speed, the state of the ad hoc network changes rapidly. Consequently, the rate of packets being dropped increases and it, in turn, results in a lower PDR. However, the latency does not increase as fast in a dense network (large N) compared to a spare network (small N). This is because an optimum link is available when there are approximately $N = 40$ nodes in the network. When more than 40 nodes are available in the network, both PDR and latency does not increase significantly. This can be seen as the network has reached its saturating state and any additional node does not improve the quality of the transmit/receive packet.

It is worth to mention here that in the routing algorithm simulation, each node transmits a packet after 30 seconds with a PDR of approximately 90%, therefore it is guaranteed that within a 5-minute timeframe a nodes location will be updated at the central base-station (30seconds/packet * 10packets = 300 seconds = 5minutes). At this time, the MAC layer uses 802.11 with 1Mbps data rate. This condition might not be realistic for radio transceiver operating at a low HF frequency of 8MHz and is currently being modified to reflect a more practical situation.

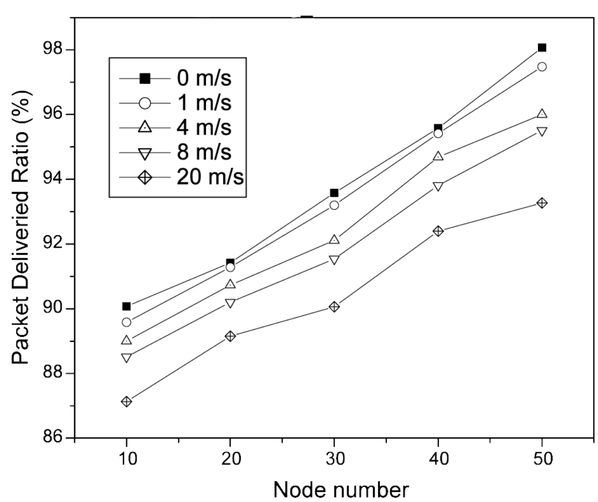

Figure 5. Packet Delivery Ratio (PDR) results using Network Simulator II software.

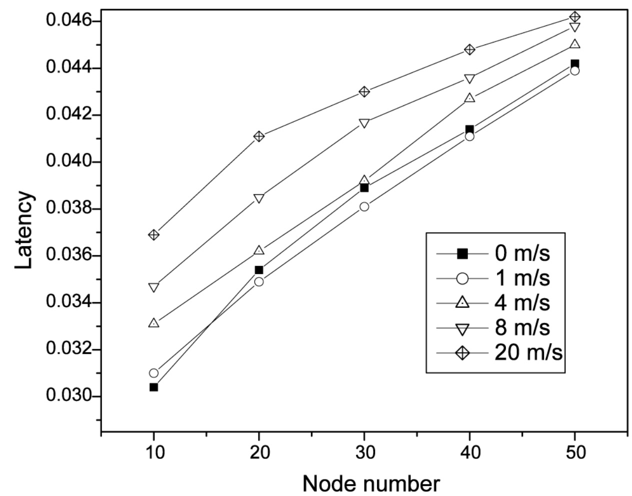

Figure 6. Latency results using Network Simulator II software.

VI. Conclusion

A GPS-based wireless ad hoc network has been proposed and its routing protocol and algorithm have been evaluated using Network Simulator 2 software. The results indicate a success rate of packages transmission higher than 85% and show the great potential of the proposed concept for marine monitoring, searching, and rescuing applications.

Acknowledgment

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