Project factsheet information

Project title	**Efficient and Reliable GPS Wireless Ad-hoc Sensor Networks for Marine Monitoring, Searching and Rescuing (MSnR)**
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Partner organizations	• Institute of Marine Environment and Resources (IMER), Hai Phong city, Vietnam • University of Engineering and Technology, Ha Noi, Vietnam • Hanoi University of Technology, Hanoi, Vietnam
Total budget approved	AUD 34,819.00
Project summary	The proposed project combines the Global Positioning System (GPS) with a wireless ad-hoc sensor network to provide an efficient positioning service for all small fishing boats and to reliably restore the weak sea-to-land communication link from small fishing boats to the central in-land stations. The boats' location is available from GPS while the weak sea-to-land link is enhanced by a short-range communication within ad-hoc network comprised of small fishing boats. For the land-to-sea communication link, this solution 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 searching and rescuing process during emergency situations.

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Project Summary

This project propose a wireless ad-hoc network that restores the sea-to-land link from small fishing boats to the central base-stations located near the shoreline and provides an efficient monitoring and positioning service for fishing boats. The wireless ad-hoc network is built upon an existing high frequency (HF) coastal radio system and integrated with a Global Positioning System (GPS) receiver for a real-time location monitoring. The proposed network is therefore cost-effective, efficient and reliable than other commercially available satellite-based systems.

The main problem that is being addressed in this project is the unreliable sea-to-land wireless link from fishing boats to central base-stations. This link is limited by a maximum transmit power of radio equipment on board and the Line-of-Sight (LOS) condition. This problem is more profound for small boats, which are not equipped with radio communication equipment and LOS condition is not usually satisfied due to blockage by islands or large ships or the earth's curvature. During storms, the link condition gets worse because of a higher loss due to rain attenuation. As the result, monitoring and communication with small fishing boats operating far from the coastal line is a challenge task. In addition, searching and rescuing these small boats during or after storms are much more difficult since its current or last-known position is not available.

The proposed wireless ad-hoc network solves this problem for small fishing boats by replacing a long range and unreliable link to base-stations with multiple short range and reliable links between boats, which are in proximity to each other, and boats that are closer to base-stations. The signal takes a longer path and incurs a larger delay but has a higher probability of reaching the base-stations. The additional GPS receiver and Digital Signal Processing (DSP) control board integrated into the existing radio equipment provide the location and monitoring service by periodically updating the central base-stations with ships' current location and condition by sending data packets through the established multiple links of the ad-hoc network.

The proposed solution utilizes an integrated GPS wireless ad-hoc network. A wireless ad-hoc network is a multiple hosts (nodes) that can communicate with each other via wireless links. While the advantages of ad-hoc network are dynamic and mobile, self-configurable and ability to extend wireless coverage range, the GPS receiver provides a free location-based service and has a small size and low cost. The combined GPS wireless ad-hoc network therefore is a hybrid approach, which provides a cost-effective, efficient and reliable solution for sea-to-land communication and monitoring service compared to other satellite-based systems.

The main activities in this project will consist of 1) modeling of a wireless ad-hoc network composed of small fishing boats, 2) construction and evaluation of the network routing protocol and algorithm, 3) network medium access control and 4) evaluation of a small, laboratory-scaled ad-hoc network of 10 nodes. The planned timeline for these tasks is 12 months with approximately equal time distribution for each task. By providing an efficient positioning/monitoring service and a reliable communication link, the project's ultimate goal is to have a low-cost and effective marine monitoring, searching and rescuing system that further strengthen the fishery industry and reduce both financial and human losses to the industry during tropical storms and other natural disasters.

Justification

Current Problems

While large ships or vessels with a more powerful engine are often well-equipped with advanced communication devices such as satellite communications link or high power two-way link with central control stations located along the coastal line, small fishing boats are very ill-equipped. The existing radio system is only adequate for the forward link (land-to-sea) communications, which provides weather and traffic information to small fishing boats at sea from central control stations. The return link (sea-to-land) greatly

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depends on the distance between these small boats to the central stations, the weather condition, the size of radio transmitter and antenna mounted on these boats. It is very common that small boats (less than 50HP) are often equipped with a low power transmitter and a monopole antenna operating at the low 8MHz frequency range. In the extreme weather condition or when the distance exceeds its maximum theoretical threshold, the return link breaks down which in turn ceases all communications from small fishing boats at sea to the central stations. This results in the following two problems:

1. No monitoring possible making it harder to search and rescue during or after natural disasters,
2. In the case of lost or gone missing, no chance to declare a state of emergency and to request an immediate assistance.

Project Solution

This project precisely deals with the above two problems facing by small fishing boats by providing an efficient and reliable Monitoring, Searching and Rescuing (MSnR) system based on the Global Positioning System (GPS) combining with advanced wireless ad-hoc network. In this solution, an integrated GPS receiver and a programmable Digital Signal Processing (DSP) board will be added into the radio transmitter of each boat to re-connect the broken return link. Instead of simply installing a high-cost, high-power radio transmitter in each boat, this solution ingeniously combines the location service offered freely by the GPS and the low power, wireless ad-hoc network that allows smart routing of short messages between boats and central stations. As the result, voice/data messages only need to propagate a shorter distance; hereby increasing its probability of reception.

Operating Principle

Figure 3 illustrates the proposed concept of GPS wireless Ad-hoc sensor network for marine Monitoring, Searching and Rescuing (MSnR) applications. It operates as follows. The forward link from land to sea (red arrows in Fig. 3) 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). In this project, the Tx/Rx frequency of **8.294** MHz will be selected.

Because the transmitting antenna are mounted on base-stations at a typical height of 75m – 100m and a high power is available, this forward link can propagate and 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. 3) 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 then finally connected from the closest boats to the central base-stations.

The routing protocol of the proposed system will be location-based routing. A data packet being routed in these links will contain a ship's identification number (ship ID), its current GPS location, and a short message. In order to establish a wireless Ad-hoc network and to identify its self-position, a small and commercially off-the-shelf integrated GPS receiver with a programmable DSP board will be added to the existing radio transmitter on all of the fishing boats.

The GPS receiver determines the position of each boat while the DSP is responsible for the Ad-hoc network communication and routing protocol. Finally, packets are transmitted over existing radio system on-board. Base-stations in land are connected via a high-speed backbone link (solid green line in Fig. 1).

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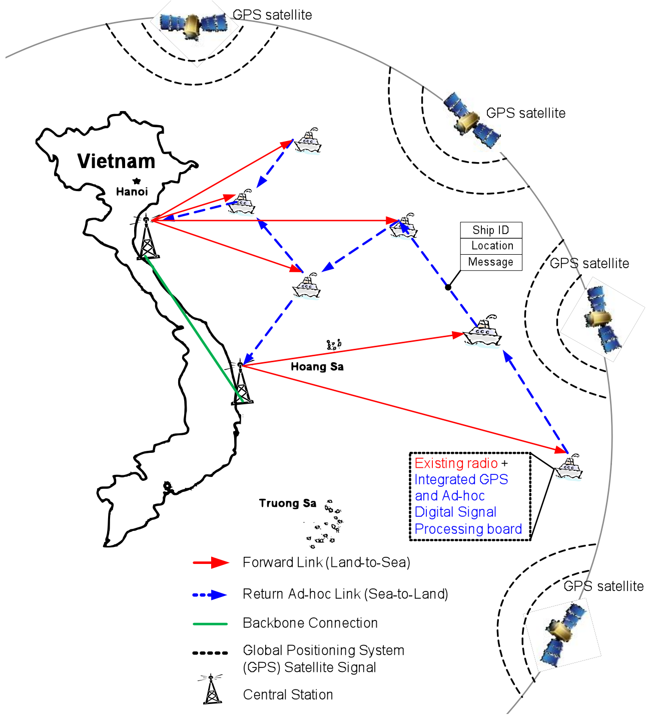

Figure 1: Illustration of the proposed 'GPS Wireless Ad-hoc Sensor Network for Maritime Monitoring, Searching and Rescuing (MSnR) Applications'.

Project objectives

- Objective #1: Performing survey on the distribution of small fishing boats, the behavior of fishermen, the current radio system to evaluate and to construct a model of the Ad-hoc sensor network (coverage size and number of fishing boats in a coverage area)

- Objective #2: Evaluation (using computer simulation) of routing and transport protocols of the Ad-hoc sensor network model

- Objective #3: Developing more detail communication model based on ad-hoc sensor network to improve return communication link (sea-to-land) to be applied to small fishing boats

- Objective #4: Evaluation and testing of the proposed network model and protocol in a laboratory environment using ten (10) hardware boards controlled by computers. Feasibility study of hardware development for a complete, real system to be considered in future projects.

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Project implementation

Objective 1: Field Survey and Ad hoc Network Modeling

Project objective No. 1	Activities	Time required for activities implementation	Overall assessment
Performing survey on the distribution of small fishing boats, the behavior of fishermen, the current radio system to evaluate and to construct a model of the Ad-hoc sensor network (coverage size and number of fishing boats in a coverage area)	Data collection and field survey	6 weeks (March 29th, 2010 – May 10th, 2010)	• Status: completed • Partnership with Institute of Marine Environment and Resources (IMER), Hai Phong city for data collection and the Ministry of Agriculture and Rural Development, Cat Ba, Hai Phong city for field survey. • Result 1: Three types of fishing boats, categorized by its engine size: type 1: less than 20 HP engine, type 2: 20 HP -90 HP engine and type 3: more than 90 HP engine and well-equipped with radio communication devices. • Result 2: Boat registration is effective but boat monitoring is very inefficient and boat-to-basestation communication is poor which makes rescuing a very challenge task. • Result 3: Operators of type 1 and type 2 boats have a very low monthly income of 1.2 millions VND ($65 USD) and often cannot afford to buy radio equipment. • Result 4: Maximum affordable price for the combined GPS + radio system must be less than 3 millions VND or $162 USD.
	Network modeling of fishing boats	4 weeks (April 26th – May 24th, 2010)	• Status: Complete • Result 1: All type 1 boats sail less than 1 day and within 3 Nautical miles (Nm) from shore. • Result 2: Majority of type 2 boats operate within 3 – 10 Nm from shore and sail between 1 – 4days • Result 3: Boats often sail in a group and its fishing locations are arbitrary and unknown.

The field survey was performed at Cat Ba fishing field and with the help of students from Bac Ha International University and assistance from local officials. Important finding results are listed above which help to model the ad-hoc network size, mobility and complexity. Figure 2 shows some photos taken during the field trip and the 28th CAFEO conference and Table 1 shows the survey form that was used during the field trip.

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(a)

(b)

(c)

Figure 2: Photos taken during the field trip survey at Cat Ba fishing field:

a) Small and medium size fishing boats.

b) Radio equipment on a surveyed boat [From top: a 2-way walkie-talkie, a transceiver (ICOM IC-718), and a GPS receiver (Furuno GPS/WASS Navigator].

c) Dr. Do Duc Dung (far left) presented survey result and research proposal during a focused session "Engineering and Technology to Prevent Natural Disaster, Climate Change and Global Warming" at the 28th CONFERENCE OF ASEAN FEDERATION OF ENGINEERING ORGANIZATIONS (CAFEO) held in Hanoi, Vietnam from Nov. 30th to Dec. 3rd, 2010. CAFEO has 10 member countries of ASEAN, including Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.

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Table 1: Field survey form

1 Người được khảo sát tham gia đánh bắt hải sản dưới hình thức:
(Survey individual belongs to the following group)
a) Cá thể (Individual) b) Hợp tác xã (co-operative)

c) Công ty, xí nghiệp khai thác hải sản (Sea product exploiting/processing corporation)

2 Công suất tàu thuyền hiện đang sở hữu (Engine's power of the fishing boat)

a) Dưới 20CV (less than 20HP) a) Từ 20CV đến 45CV (20HP - 45HP)
a) Từ 46CV đến 90CV (46HP - 90HP) i) Trên 90CV (more than 90HP)

3 Thời gian đi biển trung bình (Average time per sail)

a) Dưới 2 ngày (less than 2 days) b) Từ 2 - 4 ngày (2 - 4 days)
c) Từ 5 - 6 ngày (5 - 6 days) d) 1 tuần trở lên (1 week)

4 Phạm vi đánh bắt (Fishing perimeter from shoreline)

a) Dưới 3 hải lý (less than 3 Nm) a) Từ 3 đến 10 hải lý (3 - 10 Nm)
c) Trên 10 hải lý (more than 10 Nm)

5 Cách thức nhận thông tin từ đất liền (Method of receiving information from base-stations)
a) Không có (Not avaialble) b) Bộ đàm (Walkie-talkie) c) Radio (Radio receiver)
d) Bằng thiết bị thu phát chuyên dụng (Specialized 2-way radio transmitter/receiver)

6 Cách thức liên lạc giữa các tầu cùng đi (Method of communication with other boats)
a) Không có (Not avaialble) b) Bộ đàm (Walkie-talkie) c) Radio (Radio receiver)
d) Bằng thiết bị thu phát chuyên dụng (Specialized 2-way radio transmitter/receiver)

7 Cách thức gửi thông tin từ tầu thuyền về đất liền (Method of transmitting information to central base-stations)
a) Không có (Not available) b) Bằng bộ đàm (Walkie-talkie)
c) Bằng thiết bị thu phát chuyên dụng (Specialized 2-way radio transmitter/receiver)

8 Nhu cầu sử dụng phương tiện liên lạc (Main purpose(s) of radio equipment)
a) Gọi điện liên lạc với đất liền (Communication with central base-stations)
b) Gọi điện liên lạc với nhóm tầu thuyền khác (Communication with other boats)
c) Báo cấp cứu, cứu hộ (Emergency declaration)

9 Mức giá chấp nhận được khi trang bị phương tiện liên lạc

(Affordable price for radio equipment)
b) Dưới 3 triệu đồng (less than $162 US) b) Từ 3 triệu đến 10 triệu đồng ($162 - $540 US)

b) Từ 10 triệu đến 25 triệu đồng ($540 - $1,351 US) b) Trên 25 triệu đồng (above $1,351 US)

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Objective 2: Routing Protocol and Evaluation

Project objective No. 2	Activities	Time required for activities implementation	Overall assessment
Evaluation (using computer simulation) of routing and transport protocols of the Ad-hoc sensor network model	Routing protocol and routing data packet	5 weeks (May 24th – June 28th, 2010)	• Status: Complete • Research literature and industrial standards for an existing routing protocol that meets the 4 requirements of fishing boats' wireless ad-hoc network: mobility, geo-location availability, fixed central node, and broadcast. • Result 1: Adopting hybrid proactive-active, location-based routing protocol proposed in [3], namely, Distance Routing Effect Algorithm for Mobility (DREAM). • Result 2: Developing transmit and receive procedures and format of data packet circulated within the network.
	Evaluation of routing protocol using in computer using Network Simulator 2	10 weeks (June 28th 2010 – September 6th, 2010)	• Status: Complete • Result 1: Data packet delivery ratio is greater than 80% with a low latency.

Routing Protocol

Routing protocol in wireless ad hoc network has been a focus of numerous researches in the past decades. These extensive studies have produced at least a dozen protocols within each there are more than a handful number of algorithms to implement a single protocol [**1, 2**]. In this project, we do not attempt to derive a new protocol but rather select an existing and most suitable protocol that meet the following characteristics of our wireless ad hoc network.

- **Mobility:** the wireless ad hoc network comprised of fishing boats is a dynamic mobile network in which each node has a random speed and arbitrary direction.
- **Geo-location availability:** Exact location of each node is available at all time as it is very unlikely that signal from GPS satellites is blocked in an open sea environment.
- **Fixed final destination nodes:** Final destination nodes are central base stations and their location is fixed. For monitoring purposes, all packets are routed to the nearest final destination nodes.
- **Broadcast:** Each node broadcasts its message to all neighboring nodes within its range.

In addition, the main use of our ad hoc network is for monitoring ships' location, hence it does not require continuous data and can support a large network delay tolerance. Based on these characteristics and requirements, we adopted a modified hybrid proactive-active, location-based routing protocol similar to the one first proposed by Basagni in [**3**]. Basagni employed new routing information in his approach, namely a Distance Routing Effect Algorithm for Mobility (DREAM). In DREAM, each node has a routing table that stores

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location of all other nodes in the network. The routing table is updated at the instance when a node receives a message from another node. The geo-location embedded in the message is readily available from the use of GPS. As a result, DREAM can be considered proactive in the way it updates the location information. In DREAM, "when node A wants to send a message *m* to node B, it uses location information for B to obtain B's direction, and transmits *m* **to all its one hoop neighbors in the direction of B**. Each neighbor repeats the same procedure, until B, if possible, is eventually reached" [**3**]. Because a routing path is sought in an on-demand fashion, DREAM can be seen as a reactive approach.

In our routing protocol, the routing table at each node is updated in a similar fashion since GPS receiver is available however; it only contains **locations of one-hoop neighboring nodes.** As a result, the routing table is significantly smaller and hence less time is taken for record updates. Secondly, our routing protocol is different to DREAM in the way each node broadcasts a message *m*. Due to the nature of available radio equipment, it is cheaper to send messages omni-directionally instead of directionally as the latter requires an antenna array. Consequently, each node in our network **broadcasts** its message *m* to **all its one-hoop neighbors regardless of their directions.** Based on the relative positions, each neighbor decides to drop or relay the message *m*. If the neighbors decide to relay the message, they repeat the same procedure, until the final destination is eventually reached. The exact routing algorithm is explained in the next section.

Format of Routing Data Packet

Figure 3(a) and 3(b) show the data packet used in the ad-hoc network and the corresponding location of each data field within the open system interconnection (OSI) layers.

Moving from top to bottom of the OSI model, the source latitude (SLA) and longitude (SLO), initial time (IT) and status (STA) are affixed at the application layer. The first three data fields (SLA, SLO and IT) are ported directly from an integrated, on-board GPS receiver. Source Latitude is the source node GPS's latitude position at the time the packet is being sent. Source Longitude is the source node GPS's longitude position at the time the packet is being sent. Initial Time (IT) is the time at which a packet is transmitted. 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 the base-station.

In the network layer, hoop count (HC) and reserved (R) fields are added to the data field passed from the Application layer. As presented in the first technical report, the Network layer employs location-based routing and operates in receive (Rx) when accepting data from the lower Data link layer or transmit (Tx) mode when passing data to the Data link layer. Hop Count (HC) indicates the number of nodes that a data packet has been traversed. It is set to 0 at the source node and increased by one at each subsequent forwarding node. Reserved field is reserved for other purposes if any.

The Data link layer attaches the source ID (SNI) and destination (DNI) before sending the complete packet to the next physical layer (PHY) for transmission. In this project, the PHY layer uses 802.11 standard for simplicity but without loss of generality. Sourse_ID is the ID (identification) of a boat (source node) which transmits the data packet. This field acts as the Source Node Identifier (SNI). Destination_ID is the ID of a boat or the base-station (destination node) which is an intended receiver of the data packet. This field is the Destination Node Identifier (DNI). When DNI is set to all 0s, the data packet is sent to all other nodes.

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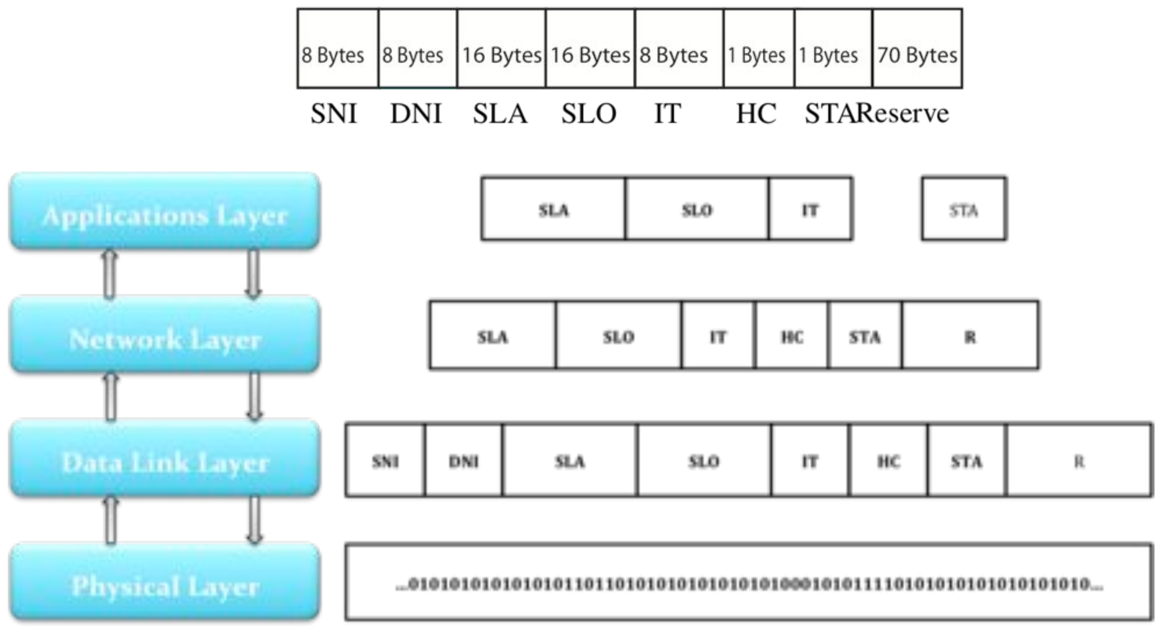

Figure 3: (a) Proposed data packet used in the ad-hoc network. (b) Corresponding location of data packet within open systems interconnection (OSI) model.

Routing Algorithm

The ad hoc network provides real-time monitoring of all boats, hence each node (boat) in the network regularly sends a message (*m*) to the nearest base-station. Since a direct path between a source node to the base station might not be available, the message *m* will have to go thru multiple nodes before reaching the destination node. 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 message *m*. Furthermore, a relay mode must also process the message and decide whether to forward or drop the message depending on its location relative to the source and destination nodes. Receive and transmit procedures of the routing protocol are described in the following section.

Figure 4 shows the flow chart of a node operating in its receiving mode. Under this mode, the node detects if a message is received. In the case where no message is received after 10 consecutive time intervals, the boat can be considered isolated or out of range. The system will alert the operator to take proper actions. On the other hand, when a node receives a message, it first checks the HC value. If HC = 0, the message was sent from one of its one-hoop neighbors and the node will update its look-up table (LUT).

The LUT at every node contains the sending node (source) IDs, the initial time of the packets most recently sent by neighboring nodes, and their locations as shown in Fig. 5a. After updating its LUT, the receiving node will compare its relative location to the destination node with that of the source node. If this distance is larger, indicating that the receiving node is not closer to the base-station than the source node, the receiving node will drop the packet and return to its receive mode of operation to accept other incoming message.

In contrast, if the distance is shorter, the receiving mode will check whether message *m* is already sent before by comparing the source ID and the initial time of the message *m* with those recorded in its forward table (FT). If there is no matching one, the receiving mode will relaying the message *m* after update the HC as well as its FT. Otherwise, it will drop the message to reduce the redundancy of the transmitted messages. The

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format of FT is shown in Fig. 5b. To prevent the FT's size from getting too large, the records older than a preset time interval will be deleted.

Figure 6 shows two different transmitting scenarios of a given node. When it is relaying a message coming from other nodes, it re-transmits the message after adding 1 to the HC. On the other hand, if it is a source node transmitting the message to the base station, HC is equal to 0 and the remaining data fields (SNI, location, status and IT) are set to the values of the current node.

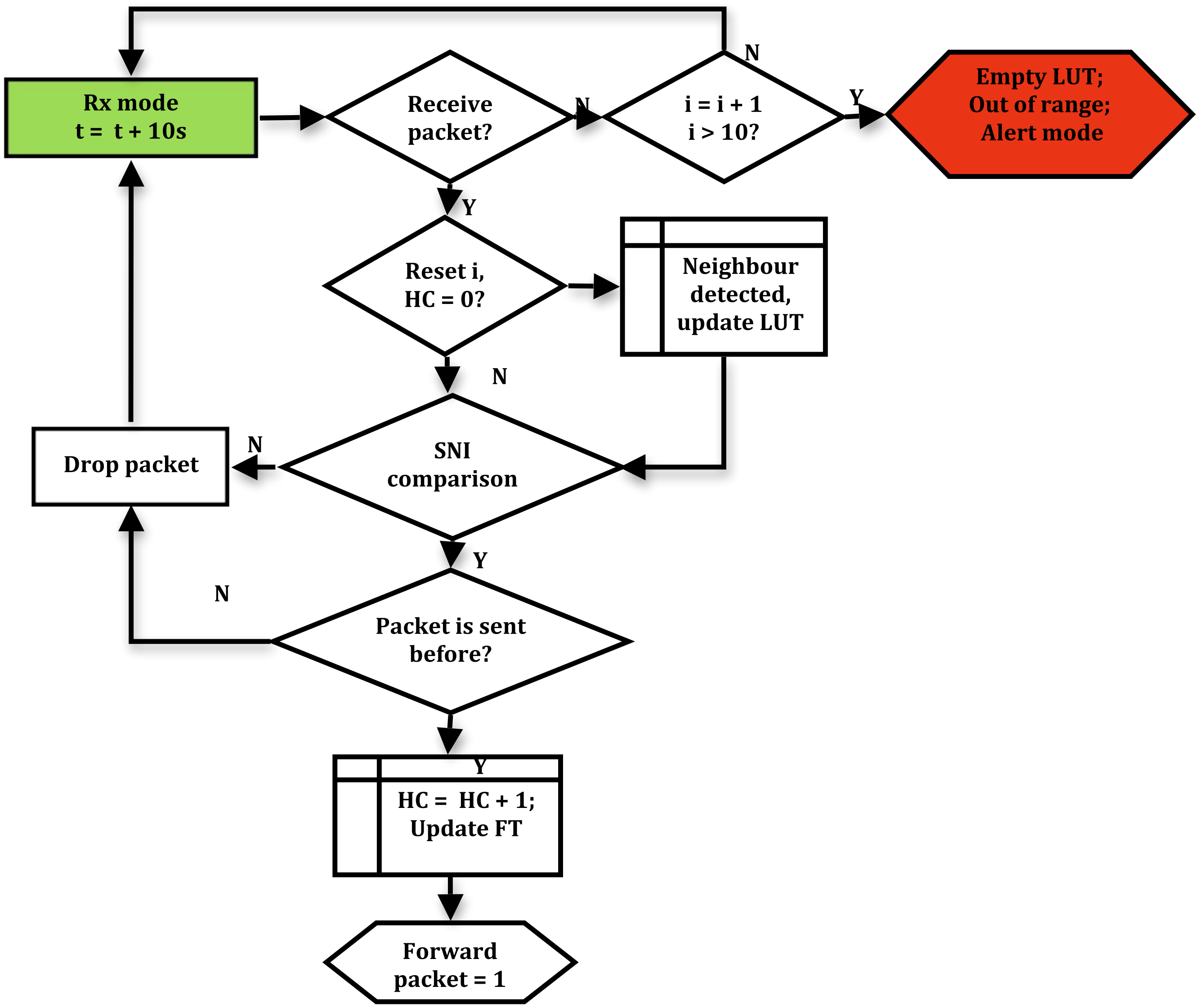

Figure 4: Receive mode operation of a node in the wireless ad hoc network.

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Record	Source ID	IT	Location
1			
2			
.			
N			

(a)

Record	Source ID	IT
1		
2		
.		
N		

(b)

Figure 5: Format of a) the look-up table (LUT) and b) the forward table (FT).

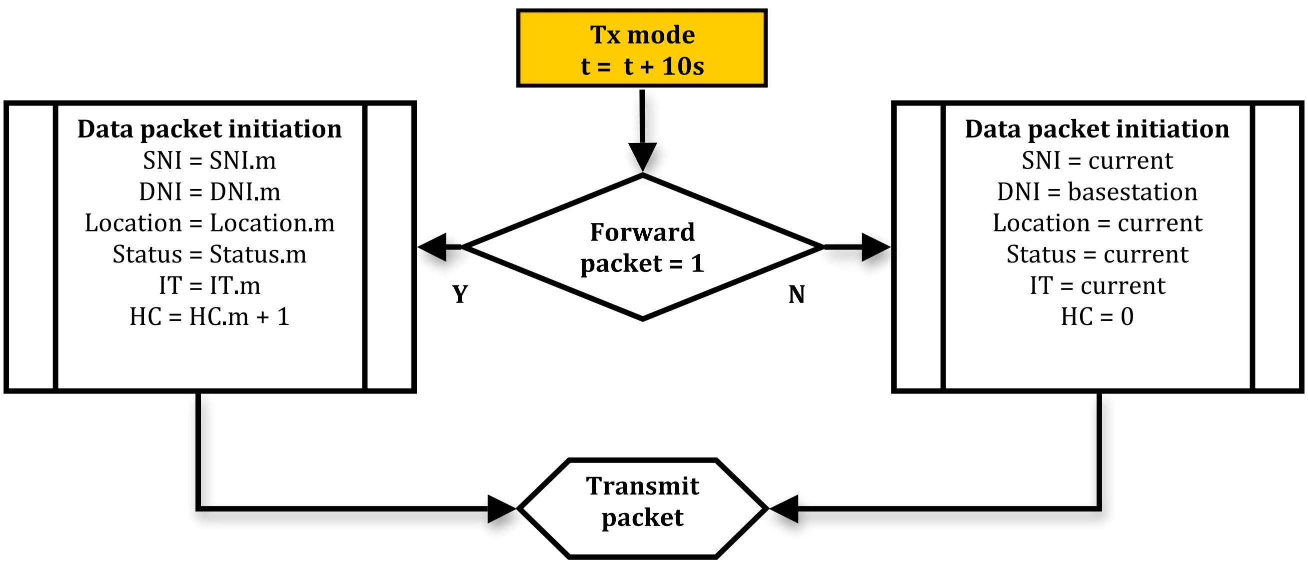

Figure 6: Transmit mode operation of a node in the wireless ad hoc network.

The proposed routing protocol was evaluated using Network Simulator 2 and shown a packet delivery ratio above 80% for various number of nodes and node's speeds. In the next objective, the routing protocol is combined with a medium access control and the proposed wireless ad hoc network is fully evaluated.

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Objective 3: Medium Access Control and System Simulation

Project objective No. 3	Activities	Time required for activities implementation	Overall assessment
Developing more detailed communication model based on ad-hoc sensor network to improve return communication link (sea-to-land) to be applied to small fishing boats	Building Medium Access Control (MAC) suitable for 2-way radio communication in ad-hoc wireless network	6 weeks (September 13^{th}, 2010 – October 25^{th}, 2010)	• Status: Complete • Result 1: Propose a hybrid combination and smart selection of TDMA and CSMA/CD to solve the channel utilization issue in wireless ad-hoc network. The proposed MAC is termed iMAC.
	Evaluate routing algorithm and MAC in Network Simulator 2 (NS2)	12 weeks (October 25^{th}, 2010 – January 17^{th}, 2011)	• Status: Complete • Result 1: Theoretically confirm (using NS 2) the operation of the proposed wireless ad-hoc network employing the proposed routing algorithm (objective 2) and iMAC. • Result 2: Packet delivery ratio reaches up to 90% and network utilization remains above 70% for all simulated network size.

Drawbacks of existing Medium Access management of the Data link layer

As illustrated in Figure 3b, the data link layer affixes the last two data fields (SNI and DNI) and arranges data into a final frame. The MAC of the data link layer manages the access of each wireless ad-hoc node to the shared air medium. The two common approaches for shared medium access are Carrier Sense Multiple Access (CSMA) and Time Division Multiple Access (TDMA) techniques.

In both approaches, at any given time, only a single node can access the air medium and therefore can either transmit or receive data packets. In CSMA, all nodes compete for a time slot while in TDMA; each node is allocated a specific time slot. The contention-based CSMA is simple, requires no time synchronization and is robust to network changes.

However, it has a high control overhead (for two-hop collision avoidance) in addition to high idle listening and overhearing overheads. Moreover, CSMA is prone to low throughput and high latency even during low contention. On the other hand, TDMA is a schedule-based; therefore it is collision free since nodes in proximity transmit during different times.

The drawback of TDMA is that it requires time synchronization and it not very robust to changes in the environment. In contrast to CSMA, TDMA system has low idle listening and overhearing overheads. Figure 7 illustrates the effective channel utilization versus the number of nodes in a given network. As can be seen, CSMA is most effective when there are a low number of nodes. On the other hand, TDMA approaches that of an ideal situation when the number of nodes increases.

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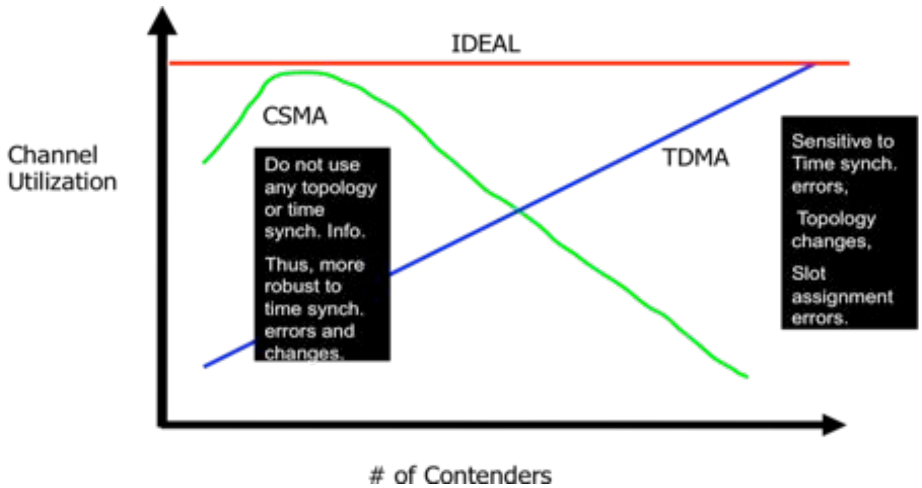

Figure 7: Effective throughput of CSMA and TDMA

In addition, nodes in a wireless ad-hoc network are often deployed in remote area and operated on battery power. Battery or portable electrical power is a scare resource, which might not be conveniently or sometime impossible to be recharged. Wireless ad-hoc network employing CSMA or TDMA as its medium access control wastes its energy because of the following four important sources:

1. Idle listening (required for all CSMA protocols)
2. Overhearing (because RF is a broadcast medium)
3. Collisions (Hidden terminal problem)
4. Control overhead (e.g. data used for Request to send (RTS), Clear to send (CTS), and acknowledgement (ACK))

Proposed MAC solution for small fishing boats wireless ad-hoc network

In this work, we propose a hybrid MAC solution. The core idea of the hybrid MAC protocol is a combination and smart selection of TDMA and CSMA. With reference to Figure 8, the operating principle is as follows.

A coverage area is divided into an equal number of concentric circles (red, blue, green, black in Figure 8), which share the same central point at the local base station (red star). These circles have a radius equal to a multiple of 2.5 km (r = n*2.5) where n is an integer number (n = 1, 2, 3, 4…).

Nodes residing on different concentric circles [i.e. circles with n = 2 (blue) and n = 4 (black)] are given two different time slots to transmit/receive. This is similar to TDMA. When there are two or more nodes within the same concentric circle [i.e. circle with n = 3 (green)], these nodes employ CSMA protocol with a carrier detection capability to avoid transmit collision. In addition, to save energy, these nodes will be turned ON in a short time and turned OFF in the remaining period when they do not transmit nor receive.

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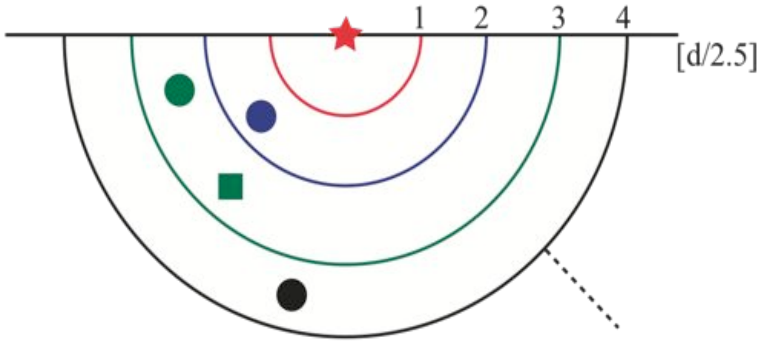
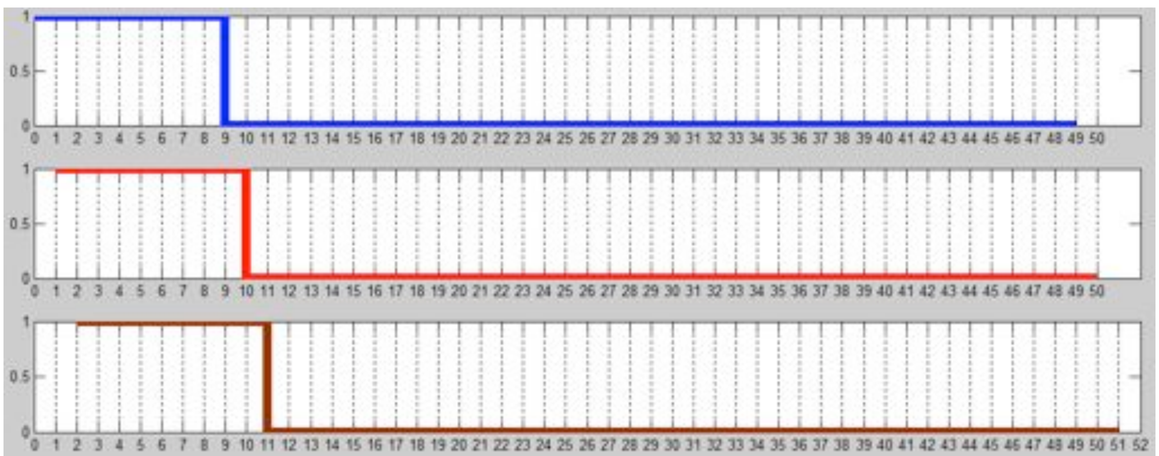


(a)



(b)

Figure 8: a) An illustrative representation of the coverage area and b) Timing diagram for each cluster in the coverage area.

The iMAC's control architecture includes the following three operating modes:

Mode 1: ON/OFF Mode

In this work, each node is assumed to transmit periodically its data packet in every T = 10 seconds. As shown in Figure 2, data packet has 135bytes and hence the total time required to transmit or receive each packet is much smaller than the period T. In order to save its energy, each node is set to operate in an active (ON or listen) mode and an inactive (OFF or sleep) mode during the period T. The active mode duration is 1 second while the inactive mode duration is 9 seconds. During the listen mode of operation, we further subdivide the period (1 second) into 10 sub-time slots, each of 0.1 second. One time slot is given for transmit operation and the other nine time slots is reserved for receive operation. Figure 9 shows the conceptual timing diagram of the listen/sleep modes and the 10 sub-time slots of listen mode.

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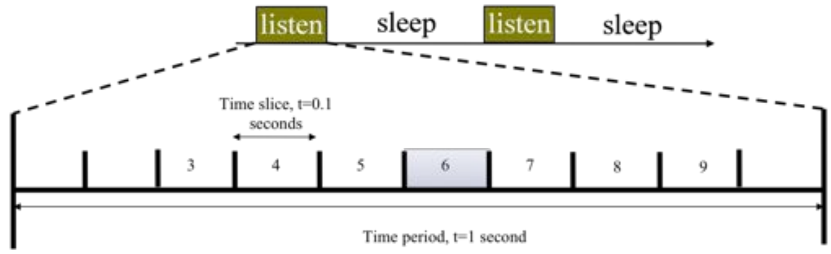

Figure 9: Timing diagram for each mode during its active mode of operation.

Mode 2: TDMA Transmit/Receive (Tx/Rx) for nodes in different clusters

In this mode, we further assume that the coverage area has a radius d = 25km. According to Figure 8a, we have 10 non-overlap clusters (n = 1, 2, … 10). The transmit/receive operation of nodes in different clusters is set as follows. In the first cluster (n =1), nodes transmit in the 6th sub-time slot (shaded slot shown in Figure 9) while receive during sub-time slots 1st to 5th and 7th to 10th. For nodes in the second cluster (n = 2), transmit and receive time slots offset those of the first cluster by one sub-time slot of 0.1 ms (i.e. transmit during the 7th sub-time slot and receive during 1st to 6th and 8th to 10th sub-time slot). Similarly, the nodes in clusters 3 to 10 transmit and receive in sub-time slots that are offset by one sub-time slot (0.1ms) to nodes in the adjacent clusters. Using this time scheduling, nodes that reside in different clusters can only transmit in the same time slot after 100 sub-time slots. This is equivalent to 100 x 2.5km = 250 km, which is much greater than the coverage area of radius of 25km. As the result, interference caused by nodes from different clusters transmitting at the same time is minimum and can be neglected. After completing their transmit and receive operations, nodes enter sleep mode and a timer is set to reactivate nodes after an appropriate time. The operation of this mode can be represented mathematically in the following steps.

Step 1: Calculate r and t_0 from current GPS location
Step 2: Compute n=[r/2.5] and $t=t_0+n*0.1$:
  Go to Listen state
Step 3: Transmission Control
  For i=t to t+0.5: Receive
  For i=t+0.5 to t=t+0.6: Transmit
    Call CSMA/CD Tx/Rx mode
  For i=t+0.6 to t=t+1.0: Receive
Step 4: Go to Sleep state & set timer

Mode 3: CSMA/CD Transmit/Receive (Tx/Rx) for nodes in the same cluster

For nodes that reside in the same cluster, TDMA Tx/Rx schedule does not operate well due to 1) packet collision from two nodes transmit simultaneously, and 2) hidden node receiving packet from two separated nodes. In order to eliminate these drawbacks, nodes that reside in the same cluster operate using CSMA with carrier detection (CSMA/CD). The operation consists of the following steps.

Step 1: A node that needs to transmit a data packet repeatedly senses and detects transmission in the air medium. Figure 10 shows the signal detection of a busy channel between 20ms and 55ms.
Step 2: When the medium is free of transmission, the node transmits immediately.
Step 3: The same node continues to sense the air medium to ensure no collision has occurred during its packet transmission.

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Step 4: In case collision occurs, nodes that have just transmitted a data packet will transmit an alert packet to declare collision to other nodes. Other nodes stop transmitting.

Step 5: After sending a collision notification, nodes that experience data collision shall wait and re-transmit.

Step 6: When nodes in Step 5 complete re-transmitting, all nodes return to normal operation (Step 1).

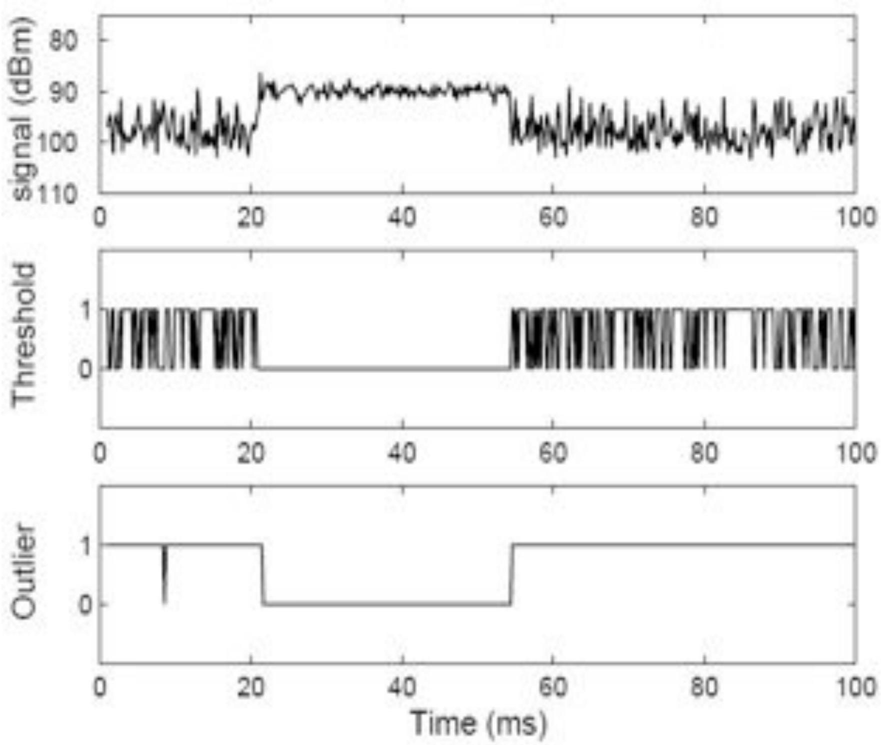

Figure 10: Signal detection at an ad-hoc node showing a busy channel between 20ms and 55ms.

Simulation results of a wireless ad-hoc network employing proposed routing protocol/algorithm and iMAC

The proposed routing protocol/algorithm and iMAC are implemented and tested in Network Simulator 2 (NS2), a discrete event simulation tool providing routing, transfer control protocol, and multicast protocols over both wired and wireless networks. The simulation environment has the following setup summary:

1. Simulator: NS 2, version 2.34
2. Physical layer
    a. Center frequency and bandwidth: 8.1MHz and 200kHz
    b. Modulation type: Quadrature Phase Shift Keying (QPSK)
    c. Max support data rate: 300kbps
    d. Antenna: Omnidirectional with gain of 0 dBi at 10 m
    e. CPTThresh = 10dB, CSThresh = 1.559e-11 W, RXThresh = 3.652e-10 W
    f. Free space propagation model
3. MAC layer: proposed iMAC (implemented in C++), currently without CD

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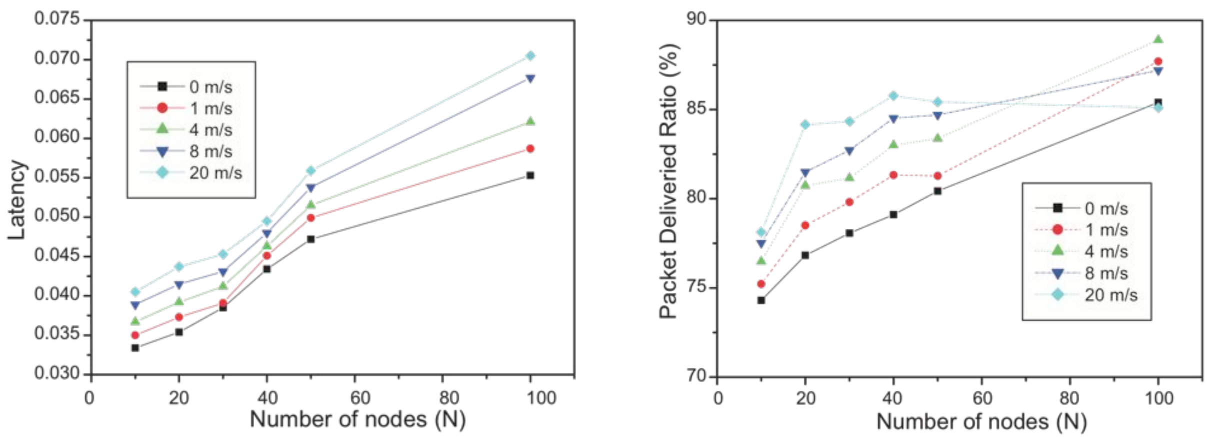
4. Link layer:
    a. Min delay: 50 micro seconds
    b. Average delay: 25 micro seconds
5. Routing protocol/algorithm: proposed DREAM protocol (implemented in C++)
6. Node movement model: Random waypoint with various speeds of 0m/s, 1m/s, 4m/s, 8m/s, and 20m/s.
7. Simulation Duration: 10 seconds
8. Packet queue limit: 20 packets
9. Coverage area dimension: 1500 x 1500 (flat grid)
10. Transmission range: 250

Figure 11 shows the NS2 simulation results. As can be seen in Fig. 7a, the packet latency increases proportionally with the number of network nodes. This is expected since a large network necessarily causes a long delay due to the fact that packets must be relayed through a larger number of nodes. Usually, high packet latency is not desirable in application requiring high throughput and low latency such as video streaming or on-line game. For the proposed ad-hoc network, such low latency is acceptable since monitoring application does not require high data rate. While a large network results in a longer delay, it brings about an important and desirable by-product, that is, a high packet delivery ratio (PDR). As shown in Fig. 7b, the PDR increases with the number of nodes in the network as each packet has a better chance to reach the central station in a dense and populated network than a sparse network. The average achieved packet throughput is 210 kbps for various network sizes.



(a) (b)

Figure 11: NS 2 simulation results of a wireless ad-hoc network. a) Packet latency, and b) Packet delivery ratio

Table 2 summarizes the average packet throughput and effective channel utilization. What is interesting to note here is that channel utilization remains almost constant with increasing network size. Compared to Fig. 7, the constant network utilization has approached the ideal situation (horizontal red line shown in Fig. 7). It demonstrates that the hybrid approach of TDMA and CSMA proposed in this project has theoretically remedied the bottleneck of TDMA and CSMA in wireless ad-hoc network as discussed in the previous section.

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Table 2: Average packet throughput and channel utilization

Number of Nodes (N)	Average throughput (bps)	Channel utilization (%)
10	230	76.67
20	226	75.33
30	223	74.33
40	221	73.67
50	219	73.00
100	208	69.33

Objective 4: Hardware Implementation and Field Measurement

Project objective No. 4	**Activities**	**Time required for activities implementation**	**Overall assessment**
Evaluation and testing of the proposed network model and protocol in a laboratory environment using ten (10) hardware boards controlled by computers. Feasibility study of hardware development for a complete, real system to be considered in future projects.	Building 10 prototypes and evaluation in a laboratory environment	15 weeks (January 17th, 2011 – May 2nd, 2011)	• Status: 3 prototypes are completed. Work in progress for a remaining 7 prototypes. • The original plan as outlined in the Grant proposal is to build 10 prototypes. Due to some difficulty and delay in obtaining hardware parts, debugging software implementation (most challenging part), the research team does not meet the target of 10 prototypes by the end of the project. However, additional 7 prototypes are currently being implemented. • Result 1: All three tested prototypes operate as expected.
	Test the ad-hoc wireless system in a real outdoor environment.	8 weeks (May 2nd, 2011 – June 27th, 2011)	• Status: Test of 3-node ad-hoc network is completed. Future test of 10-node will be carried out once 7 prototypes become available. • Result 1: Successfully retrieve packet and node locations in real-time at the central base station. A proof-of-concept of the wireless ad-hoc network is experimentally confirmed. A video recorded the testing is available at: http://www.youtube.com/watch?v=5TvekIcILIE

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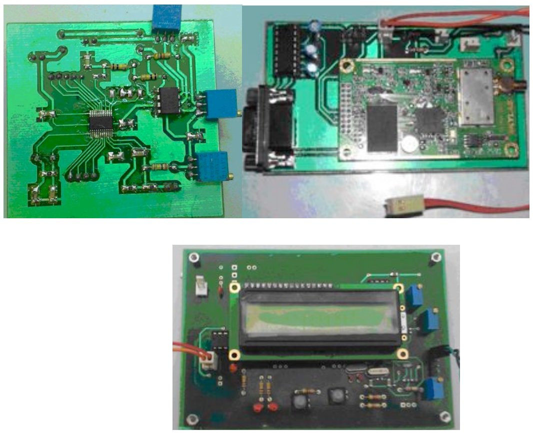
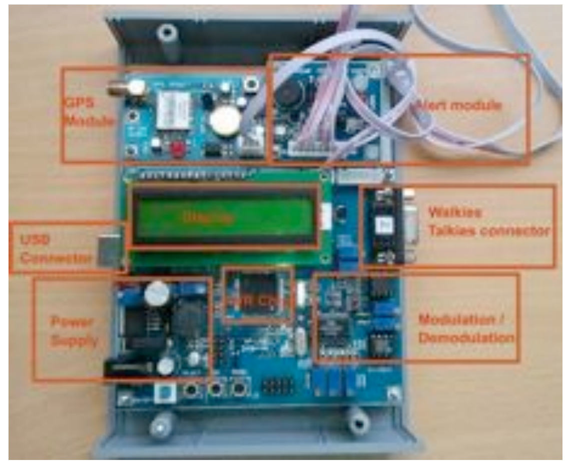
Hardware implementation

Prior to this ISIF project, hardware prototypes for individual components (GPS + display, micro-controller) were built and tested, shown in Fig. 12a. Using ISIF 2010 fund, the research team has built a complete and integrated prototype including GPS receiver module, alert module, AVR microcontroller; modulator and demodulator for transmit and receive operation. Figure 12b shows a hardware prototype with a short description for each block. Three prototypes have been assembled in this project thus far and seven more prototypes are currently being built.



(a)



(b)

(c)

(d)

Figure 12: Hardware prototypes a) Photos of initial, proof-of-concept separated hardware built prior to the start of ISIF project (as shown in the ISIF grant application) b) A complete and fully integrated hardware prototype built in this project. Main components are: GPS module and alert module (top), USB connector, display and walkie/talkie connector (middle) and regulated DC power supply, AVR micro-controller, and modem (bottom), c) Three duplicate prototypes built and tested so far using ISIF 2010 research fund, and d) Assembly and testing a prototype in the laboratory.

Field measurement of a 3-node wireless ad-hoc network

Figure 13a shows an ad-hoc node of the proposed wireless ad-hoc network. It is comprised of a hardware prototype shown in the previous section, a radio and a portable battery. The network of 3 nodes was first

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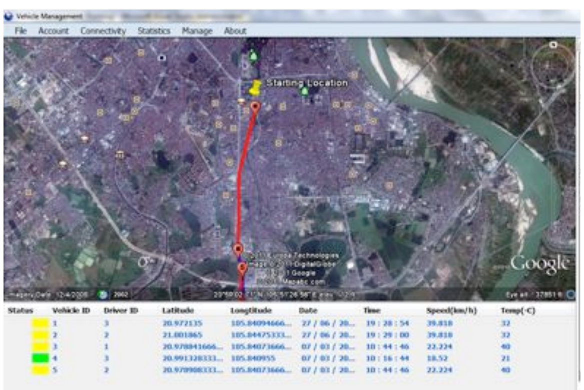
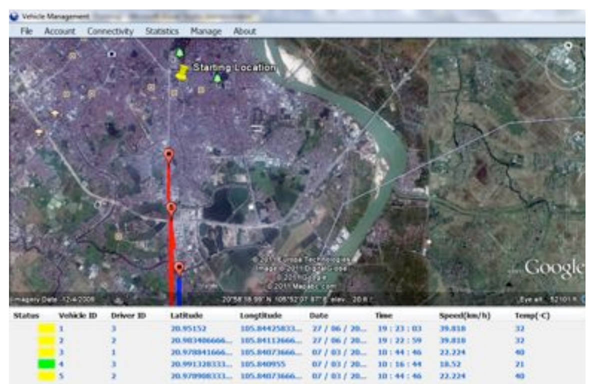
verified in the laboratory environment before it was measured outdoor. The field measurement was carried around Hanoi University of Technology with a central base station situated in the university laboratory and each ad-hoc node being setup in a car and driven around and outside the campus. Figure 13b shows an ad-hoc node in the back seat of a vehicle used in the field measurement.

(a)

(b)



(c)



(d)

Figure 13: Field measurement of a 3-node wireless ad-hoc network. a) An ad-hoc node consisting of a walkie/talkie radio, a hardware prototype and a portable battery. b) A setup of the ad-hoc node in the back of a car in an outdoor field measurement around university campus. A screen capture of our vehicle management tool used in conjunction with Google Earth for monitoring nodes' location. c) Two nodes in the same cluster. d) Two nodes in different clusters far from the central location. Monitoring information includes node status, node ID, longitudinal and latitudinal locations, and time.

The team experienced some difficulties during the field measurement. Most of the difficulties were from the radio front-end due to weak received signals and high noise interference. Different radio channel and power were randomly tested until the received signal reaches above its threshold for packet detections. Various scenarios were carried out during the test. Figure 13c and d illustrates two representative situations. In the first case of Fig. 13c, two nodes are within proximity (in the same cluster). Packet are periodically sent from these nodes and successfully received at the central station. Locations of these nodes are displayed at the central station using our network management tool. In the second case of Fig. 13d, two nodes are now in different clusters where one node is in range of the central station and forward the message of the other far

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from the central station. Their locations are successfully displayed and monitored in real-time at the central station.

Project outputs and dissemination

Information sharing and dissemination outputs

Output 1	**CAFEO 28 Conference oral presentation (Hanoi, Vietnam)**
Status	Completed
Assessment	The proposal was presented in "Engineering and Technology to Prevent Natural Disaster, Climate Change and Global Warming" section of the CAFEO 28 conference and was provided with lot of positive feedbacks from local and regional engineers attended the section. Good experience to improve both research and communication skills of the research group
Dissemination efforts	The proposal, initial survey and network model results were presented by Dr. Do Duc Dung at the 28th CONFERENCE OF ASEAN FEDERATION OF ENGINEERING ORGANIZATIONS (CAFEO) held in Hanoi, Vietnam from Nov. 30th to Dec. 3rd, 2010. CAFEO has 10 member countries of ASEAN, including Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. Information available at: http://afeo.org/pdf/28CafeoInformation.pdf
Output 2	**ISMS 2011 Conference research paper (Kuala Lumpur, Malaysia)**
Status	Completed
Assessment	Research material was presented in a focused section "Mobile/Ad-hoc wireless networks, mobicast, sensor placement, target tracking" of the conference. The experience, as planned, was a good exposure of the project to receive feedbacks from the international research community in this field.
Dissemination efforts	Ad-hoc network model and simulation results were published at the 2nd International Conference on Intelligent Systems, Modelling and Simulation (ISMS) 2011 in Kuala Lumpur, Malaysia and Phnom Penh, Cambodia from Jan. 24th to 28th, 2011. Conference information and title of the submitted paper is available at: http://www.isms2011.info/

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Output 3	ATC 2011/ComNaVi workshop presentation (Da Nang, Vietnam)
Status	Completed (writing the 4-page scientific paper) Work-in-progress (preparing the presentation)
Assessment	The submitted paper (in Vietnamese) has been accepted for an oral presentation in a focused Workshop on Communications and Navigations for the Development of Vietnam's Marine Economy (REV/ComNaVi 2011) This workshop has a larger number of audiences and greater impact (both nationally and internationally) and therefore it will be a replacement of the ISIF end-of-project workshop (as planned in the ISIF proposal). Workshop link: http://www.rev-conf.org/tutorial-workshop/workshop.html
Dissemination efforts	Dr. Do Duc Dung and Mr. Ta Duc Tuyen will be presenting the project, research results and measured data at the 2011 International Conference on Advanced Technologies for Communications (ATC 2011) in Da Nang City, Vietnam from Aug. 2nd – 4th, 2011. Conference information available at: http://www.rev-conf.org/ The annual ATC conference is one of the largest conferences on wireless communication technology held Vietnam with attendants from all over the world. An opportunity to present our ISIF project has a very big impact.
Output 4	**APMC 2011 conference (Melbourne, Australia)**
Status	Completed (writing the 4-page scientific paper) Work-in-progress (preparing presentation and attending conference if abstract got accepted)
Assessment	A 4-page paper has been submitted. A notification of acceptance will be available by Aug. 31st 2011. Submission number: 1693 Submitted to session SC10: Sensing, systems and applications
Dissemination efforts	The 2011 Asia-Pacific Microwave Conference (APMC) will be held in Melbourne, Australia from Dec. 5th to 8th 2011. This year, APMC will celebrate it's 25th anniversary and expect to draw the largest number of attendants. Conference information available at: www.apmc2011.com If the submitted abstract is accepted, Dr. Do Duc Dung will attend and present the ISIF project and research results.

New product outputs

Output 5	Hybrid DREAM routing and protocol
Status	Completed
Assessment	A new hybrid routing protocol and algorithm have been developed, implemented in C++, numerically verified with Network Simulator 2, and experimentally tested with a wireless ad-hoc network consisting of 3 nodes in an outdoor environment.
Dissemination efforts	The high level architectures of the protocol and algorithm have been disseminated in the above output 1 to output 4. However, the actual C++ implementation is considered proprietary and therefore has not been disclosed.

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Output 6	**iMAC**
Status	Completed
Assessment	A new combination of medium access control (termed iMAC) suitable specifically for the proposed wireless ad-hoc network for fishing boats have been developed, implemented in C++, numerically verified with Network Simulator 2, and experimentally tested with a wireless ad-hoc network consisting of 3 nodes in an outdoor environment.
Dissemination efforts	The operation principle of the iMAC has been proposed in the submitted paper of the output 3. However, the actual C++ implementation is considered proprietary and therefore has not been disclosed.
Output 7	**Three hardware prototypes**
Status	Completed (3 prototypes) Work-in-progress (additional 7 prototypes)
Assessment	3 hardware prototypes have been built, test and proven functionality.
Dissemination efforts	No dissemination effort of any kind has been made on this output.

Lessons learned from project implementation

An important lesson learned from project implementation is the task management and budget time for each task. Activity #2 of objective 3 (iMAC evaluation) and activity #1 of objective 4 (implementing prototype) have taken a significant longer time than original planned. The technical difficulties encountered in error debugging and hardware implementing has been greatly underestimated and that results in a delay in meeting project's deadline.

Project management and sustainability

Administrative staff at Bac Ha International University (BHIU) has been very familiar with all the aspect in this second ISIF project that we have obtained the past 2 years. It certainly helps in having this project meeting all of its objectives. The team will continue implementing the remaining 7 prototypes and test the 10-node wireless ad-hoc network as proposed. This last activity is financially covered by the remaining ISIF 2010 fund and therefore will not be a burden to BHIU. The team will continue to hold regular meetings at the Research Center on Electronics, Communications and Information Technology (ECIT) at BHIU.

Impact

First, the project's result is expected to have a high impact to the fishing industry. The solution provides a simple tool to monitor fishing boats and helps the industry reducing its the annual loss from natural disasters. The second group who will be most benefit from this solution is low-income fishermen. The simple and low-cost solution provides them a mean to communicate effectively with central base stations. In addition, their real-time location is always tracked and their boat's condition is constantly monitored.

The success in field measurement of a 3-node wireless ad-hoc network is very crucial because it confirms experimentally the proposed solution and its readiness for a widely commercial deployment.

The overall impact to the hosting institution is invaluable as the project not only sharpens it's faculty members' research and development skills, it also provides a good practice to administrative staffs and strengthens the university's position within the local research community.

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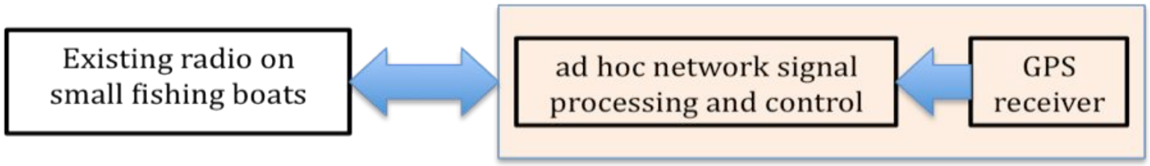
Overall Assessment



The proposed solution, illustrated in the block diagram above, is practically innovative and extremely cost effective. It has been designed to address the existing sea-to-land communication link issue and to provide a real-time and reliable monitoring service, which facilitates search and rescuing procedure during and after marine natural disasters. The smart algorithm developed in this work can be modified and applied to other systems required real-time monitoring service such as vehicle management for taxi or transport vehicles.

A significant amount of time and countless effort have been invested in developing the ad-hoc signal processing, routing and medium access control. The team's effort has generated a functioning and proof-of-concept wireless ad-hoc system. Some effort has also been made during the course of the project to disseminate the research idea and results in conferences and workshops. In addition to improving research skill, each individual of the research team has made significant effort in mastering technical communication skill. Some possible weaknesses that can be further improved include task assessment and time management.

The project fund has been properly disbursed to compensate participated researchers, to enhance the research facility at the hosting university (purchasing computers, digital signal processing boards) and to acquire all the hardware required to implement the prototypes. Overall, the research team formed by a group of elite researchers and experienced engineers from Bac Ha International University, University of Engineering and Technology, and Hanoi University of Technology has successfully executed all the project's objectives.

Recommendations

As a grant recipient of ISIF funding for two consecutive rounds of funding, Bac Ha International University in Vietnam deeply appreciates the opportunities and possibilities that ISIF fund has provided. The research team does not have any recommendation to ISIF as everything has been working out very well. To ISIF's funding partners, we strongly recommend that this funding to be continued. We understand the current economic outlooks might not allow such financial commitment and therefore we would like to recommend funding a smaller number but well-selected projects every year or every two years. When it comes to investment, nothing is more important than regularity. Investing in ICT has one of the highest rates of return and deepest impact, keep it grows.

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