# Marine Self-organizing VHF Data Link: Operational Principle

*Wen-Li Sun* · Fu-Wen Pang* · Tchang-Hee Hong***

Contents



## Abstract

The marine self-organizing VHF data link is a digital radio link with self-organizing ability, which exploits the STDMA algorithm and operates in marine VHF channels. It can support the applications of surveillance, situation awareness and communication. It is the core technology of the Universal AIS which is considered as a future surveillance system at sea by the IMO. In this paper, the operational principle of the marine self-organizing VHF data link is introduced. Simultaneously, a new access protocol is proposed to enhance the marine self-organizing VHF data link so as to support point-to-point communication. The point-to-point communication is one of the most important bases to establish dynamic internetworks among computers on the bridges in the future.

* 正会员，韩国海洋大学校 大学院

** 韩国海洋大学校 教授

1998 年 12 月发表于《韩国航海学会志》Vol.22, No.4

## 1．Background

The radar is a current cornerstone in surveillance systems at sea. However, it gives little and sometimes inaccurate information. The update rate is generally slow, because it is dependent on the rotation rate of the radar antenna. Due to the shortcomings of radar, the IMO is looking for other ways to replace or complement radar systems in order to meet the future needs. In 1994, the use of GNSS (Global Navigation Satellite System) together with a VHF data link was demonstrated a feasible method.[1] This data link exploits a self-organizing transmission algorithm, called as Self-organizing Time Division Multiple Access (STDMA)[2]. The purpose of the algorithm is to allow short transmissions, from several stations, to be organized in time, so that transmission conflicts are minimized. The algorithm is self-organizing, which means that there are no master stations and slave stations. Hence, it is suitable for operation at high sea.

At the IMO NAV-43 Conference in 1997, an application of STDMA was determined as a future surveillance system at sea, named Universal Automatic Identification System (AIS)[3]. The AIS consists of a GNSS receiver, a communication controller and VHF stations. It can broadcast position and identity through VHF data link in marine frequencies. The AIS was originally proposed on the basis of the requirement of VTS (Vessel Traffic Service) in 1995. To 1997, the function of collision avoidance was included into the Universal AIS. However, the detailed method of implementation has not yet been specified in its draft standards. The Universal AIS will be implemented on a long-term basis. If it could not meet all the required functions, it could become obsolete in the near future. Hence, the establishment of marine self-organizing VHF data link should be considered completely. This link should support both VTS and collision avoidance at sea.

## 2．Basic concept

The marine self-organizing VHF data link (MSVDL), described in this paper, is defined as the digital radio link with self-organizing ability, which exploits the STDMA algorithm and operates in marine VHF channels. The “self-organizing” means the process in which each station can autonomously select their transmission schedule without the management of base station, while avoiding and resolving transmission conflicts automatically. The MSVDL can support surveillance, situation awareness and communication in order to meet the requirements of both VTS and collision avoidance at sea. It is a new application of digital radio communication. Its operation needs the station's position and UTC time. This information is usually derived from the GNSS receiver.

**2.1 Physical section**

The marine self-organizing VHF data link transmits digital data in marine VHF Channel 87 (161.975MHz) and Channel 88 (162.025MHz)[4]. The channel bandwidth is 25kHz. The modulation scheme is Bandwidth Adapted Frequency Modulated Gaussian Minimum Shift Keying (FM/GMSK), which has better discrimination capability than D8PSK.[5] The bit rate is 9600bps. Transmitter output power is generally 2 watts at the low level or 12.5 watts at the high level. The operational range, named "cell" , is about 34 n miles in the case of ship-to-shore, and about 21 n miles in the case of ship-to-ship*.

**2.2 TDMA frame structure [6]**

In the marine self-organizing VHF data link, channel time is divided into fixed length time slots. A frame consists of 2250 slots, which is equal to one minute. It is an important term, since the broadcast period of the marine self-organizing VHF data link is based on one frame. Figure 1 illustrates the frame structure.

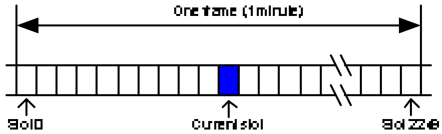

Fig. 1 Frame structure

Each time slot is accessible for receiving or transmitting by any station. One position report occupies one slot. Other transmissions can occupy more slots, up to the maximum of five slots, dependent on the application.

**2.3 Time synchronization**

The marine self-organizing VHF data link requires time synchronization for basic station access. Its would-wide time standard is Universal Coordinated Time (UTC) which is usually derived from GNSS. Each frame synchronizes to a minute of UTC. There are four methods to realize the synchronization. They are represented by four synchronization states which are inserted into the Communication State transmitted with information package. These four synchronization states are:

- UTC direct: a station is direct access to UTC timing with the required accuracy.

* Assuming that the height of the antenna of ship stations is 30 meters above mean sea level and the height of the antenna of base stations is 150 meters.

- UTC indirect: a station, which is unable to get direct access to UTC, but can receive other stations which indicate "UTC direct", synchronizes to those stations.
- Synchronized to base station: ship stations, which are unable to attain direct or indirect UTC, but are able to receive transmissions from a base station, synchronize to that station.
- Number of received stations: stations, which are unable to attain the above synchronization, synchronize to the station receiving the most other stations.

### 2.4 Information packet

In the marine self-organizing VHF data link, data transfer is performed using a bit-oriented protocol Which is based on the High-Level Data Link Control (HDLC) as specified by ISO/IEC 3309, - definition of information packet structure. The packet format is illustrated in Figure 2.

The total length of the default packet is 256 bits. This is equivalent to one slot. Data encoding is NRZI (Non-Return to Zero Inverted). The frame check sequence uses the Cyclic Redundancy Check (CRC) – CCITT 16 bit polynomial to calculate the checksum. The 12 bits in the buffer are used for distance delay, which are equivalent to 202.16 n miles. The user ID (Identity) is MMSI (Mobile Marine Service Identity), which is 30 bits long. The Communication State contains the information used for data link management such as Synchronization State. The message ID is 6 bits long, which indicates the type of message transmitted on the data link. These messages include position report, binary broadcast message, interrogation, etc. They have total about 22 types and support all kinds of applications.

### 2.5 Operation mode

There are three modes of operation in the marine self-organizing VHF data link:

- Autonomous and continuous mode
- Assigned mode

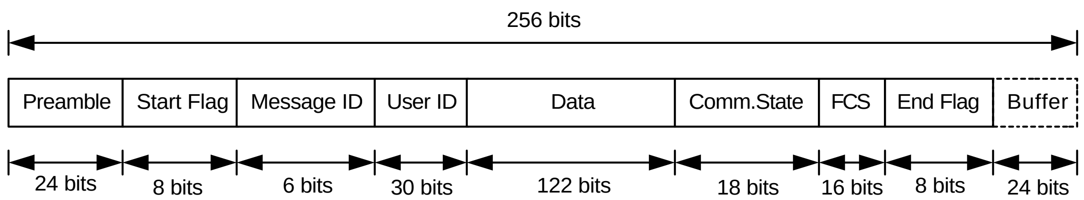


Figure 2 Format of the information packet

- Polling mode

The default mode is the autonomous and continuous mode. Operating in this mode, a station autonomously determines its own schedule for transmission and automatically solves scheduling conflicts without the control of base stations. This mode supports the application of surveillance, since each station periodically broadcasts its position and identity at a report rate. The default report rate is once per 12 seconds, but it often varies according to the ship's speed and the change of the ship's speed and course.

The operation modes can be switched as required by a competent authority such as VTS center. Assigned mode supports base station to manage communication channels and regional traffic. There are two levels of assignments in assigned mode. One is the assignment of report rate. The other is the assignment of transmission slots. Polling mode supports the interrogations from ships or base stations. Operation in this mode does not conflict with that in the other two modes.

## 3. Slot selection and reuse

An important feature of the marine self-organizing VHF data link is its slot selection and reuse. If channels are not busy, slot selection is straightforward since a slot that has not been previously reserved by another station can be easily found. Otherwise, slot selection is difficult, and the marine self-organizing VHF data link allows a station to use a slot previously reserved by another distant station. The result is that the coverage area of a station reduces in range gracefully but there is no sudden reduction in the ability to communication.

### 3.1 Slot state and access

Each slot can be in one of the following states:

(1) FREE: meaning that the slot is not reserved and is available for use by anyone;
(2) INTERNAL ALLOCATION: meaning that the slot is reserved by the own station and can be used for transmission;
(3) EXTERNAL ALLOCATION: meaning that the slot is reserved by another station and can not be used by the own station;
(4) AVAILABLE: meaning that the slot is used by the most distant station and can be used by the own station when channels are busy.

The process of slot selection has the following stages:

(1) An application wanting to use a slot in the future first specifies a range around that slot.
(2) The station derives a list of candidate

slots. The candidate slots are a part of the slots in the range and consist of slots that are always FREE slots and AVAILABLE slots when channels become busy. It is important to derive a number of candidate slots, at least 4, in order to reduce the possibility of more than one station selecting the same slot.

(3) When selecting candidate slots in one channel, both channels should be considered. If a candidate slot which in either channel is occupied by a close station, should be omitted from the list of candidate slots.

(4) Finally, a probability persistent algorithm is used to select a transmission slot from the candidate slots, which is described as following. The station sets up Start Probability (10 to 20) and Probability Increment (1 to 50) in advance. Then lets Current Probability equal Start Probability. When the first candidate slot is detected, the station randomly selects a value between 0 and 100 for the slot. If this value is equal to, or less than Current Probability, transmission will occur in this candidate slot. Otherwise, the station lets Current Probability equal it plus Probability Increment and detects the next candidate slot.

### 3.2 Slot reuse

There are two rules for the reuse of previously reserved slot, which are Robin Hood and Co-channel interference (CCI) protection .

The Robin Hood algorithm[2] allows a station to use slots previously reserved for broadcast transmission by another station as long as the following conditions are met, when the link load exceeds 90% of the theoretical maximum.

(1) the slot reserved by the most distant and over 12 n miles station; and

(2) not selecting the same station more than once per frame.

This results in a graceful reduction in the broadcast range of a station on busy channels as shown in Figure 3.

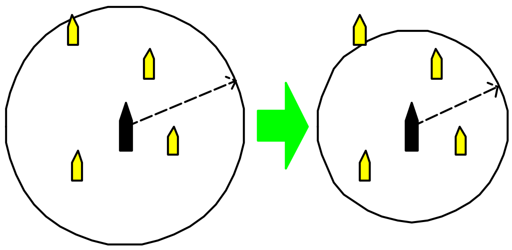

Figure 3 Effect of the Robin Hood rule

CCI protection allows slots previously reserved for point-to-point communication between two stations to be used by another station. CCI protection is based on the

---

The Universal AIS does not contain this content.

successful discrimination between a strong signal and a weak signal. For FM/GMSK modulation, discrimination can occur as long as interfering signals are different at a power radio of 5 dB[5], equivalent to a distance ratio of 1.8 on the basis of free space attenuation of signals with distance. Figure 4 illustrates the CCI protection.

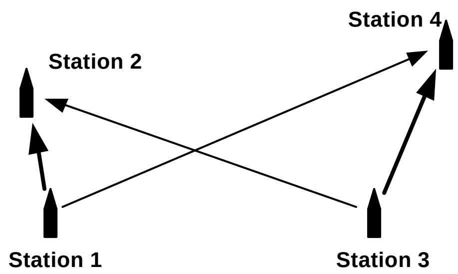


Figure 4 CCI protection

Station 1 can use the slot preserved by Station 3 to communicate with Station 4 to communicate with Station 2 as long as the following conditions are met:

(1) the distance between Station 2 and Station 3 is equal to, or more than two times the range from Station 2 to Station 1; and

(2) the distance between Station 4 and Station 1 is equal to, or more than two times the range from Station 4 to Station 3.

## 4. Channel access protocols

Channel access protocols are used for controlling access to the data transfer medium. The application and operational mode determine which protocol to be used. These following access protocols co-exist and operate simultaneously on the TDMA channel.

### 4.1 Self-Organizing TDMA (SOTDMA)

The SOTDMA is the most important access scheme in the overall operation of marine self-organizing VHF data link. It supports the broadcast of position and identity information by a station to all other stations in the vicinity. Messages, which use the SOTDMA access protocol, are of a repeatable character. Each station transmits a periodic broadcast reservation message which contains:

(1) The station ID;

(2) Position information;

(3) Communication state:

- Time Out (value 8 to 0): it indicates that how many frames the reservation will be held. If it is zero, it means that this is the last transmission in this slot.
- Synchronization State: it indicates the time source which is used for synchronization.
- Slot Offset (value -2048 to 2047): if Time Out is zero, then the Slot Offset

will indicate the relative jump to the slot in which transmission will occur during next frame.

### 4.2 Incremental TDMA (ITDMA)

The ITDMA is used by an application which wants to reserve a new slot by means of the current transmission slot. Prior to transmitting in the ITDMA slot, the station must specify the following parameters:

- Slot Increment (value 0 to 8191): it is a relative offset from the current transmission slot to the reserved slot. If it is zero, no more ITDMA allocations are done.
- Slot Number (value 1 to 5): it indicates the number of consecutive slots which are preserved.
- Keep Flag: it indicates that the preserved slot (or slots) will be kept in the next frame.

These parameters are inserted into the ITDMA Communication State transmitted with the information package.

### 4.3 Random Access TDMA (RATDMA)

The RATDMA is used by applications when there is no prior reservation. It uses a probability persistent algorithm, as described in Section 3.1, to allocate a slot for the own transmission.

### 4.4 Fixed Access TDMA (FATDMA)

The FATDMA allows base station to transmit at pre-defined update rate regardless of reservations on the channel. When transmitting a package containing a FATDMA reservation, the station specifies the following parameters:

- Start Slot (value 0 to 2249): it is the first slot to be used by the station.
- Increment (value 0 to 1125): it is the offset between transmissions. If it is zero, it means that the station transmits one time per frame.
- Block Size (value 1 to 5): it indicates the number of consecutive slots reserved.

The FATDMA transmission is not changed for the duration of the operation of the station, or until resetting the update rate.

### 4.5 Information transfer request

This protocol supports point-to-point communication. Station 1 transmits information to Station 2, simultaneously issuing a reservation for Station 2 to response. When using this protocol, the station specifies the following parameters:

- Destination Address (MMSI): it identifies the target station
- Frequency: it determines the channel on which a response is required.

- Increment (value 0 to 2249): it is the offset from the current slot to the reservation slot. If it is zero, it means that the response from destination is not required
- Block Size (value 1 to 5): it indicates the number of consecutive slots reserved.

## 5. Autonomous and continuous operation

### 5.1 Initialization phase

At power on, a station enters this phase which lasts one minute. During this time, the station monitors the TDMA channel to determine channel activity, participating member IDs, current slot assignments, positions of other stations and possible existence of base station. At the end of this phase, a dynamic directory of all members operating in VDL is established. And a frame map is constructed, which reflects TDMA channel activity. After one minute, the station will enter the data link as described below.

### 5.2 Network entry phase

During this phase, the station selects its first slot for transmission in order to make itself visible to other participating stations. The first transmission is always the default position report. The station first determines the Nominal Increment (NI) based on Report Rate (RR).

NI = 2250 / RR

The Nominal Start Slot (NSS) is randomly selected between current slot and NI slots forward. It is the reference to select the Nominal Slot (NS). The NS is used as a center around which slots are selected for transmission. The first NS is always equal to NSS.

Then, the station determines the Selection Interval (SI) with the following equation.

SI = 0.2 x NI

The Nominal Transmission Slot (NTS) is randomly selected among candidate slots within the SI, which is then marked as INTERNAL ALLOCATION and assigned a random Time-out between 3 and 8. Now the station waits the NTS approach. When the NTS is coming up the station enters the first transmission frame phase.

### 5.3 First transmission frame phase

During this phase, the station continuously allocates its transmission slots and transmits default position reports using ITDMA access.

Prior to transmitting, the next NS is calculated using the equation below.

NS = NSS + n x NI ; ( n = 0, 1, 2 … RR-1 )

The next NTS is then selected using the same method described above. The offset from current NTS to next NTS is calculated and saved in the Communication State of the current ITDMA transmission. When the NTS comes up, the first transmission occurs.

The above process will be repeated until the end of the fist transmission frame of the station. After this frame, the station enters the continuous operation phase.

### 5.4 Continuous operation phase

The station remains in the continuous operation phase until shut down, entering assigned mode or changing report rate.

The NTS was selected ahead in the frame. The station now waits until it is approached. Upon reaching the NTS, the Time-out counter, for that slot, is examined. If it is zero, a new NTS shall be selected with the same NS and SI based on above process. At the NTS, the transmission happens. The Time-out associated with the slot is decreased by one. The station then proceeds by waiting for the next NTS.

### 5.5 Changing report rate

When the report rate changes, the station enters Changing report rate phase. During this phase, the station reschedules its periodical transmission to fit for the new report rate. This procedure persists for at least two frames, in which ITDMA transmissions are inserted between SOTDMA transmission for the duration of the change.

## 6. Services

The marine self-organizing VHF data link provides two communication services:

- Broadcast communication service;
- Point-to-point communication service .

Broadcast communication service supports surveillance, situation awareness, releasing short safety related message and differential GPS correction. An application of it is the AIS which is being standardized in IMO. The AIS is going to be a primary surveillance system at sea in the near future. It will be an alternative or complementary system of Radar.

Point-to-point communication service supports individual digital communications between ships. These communications include consultation for collision avoidance, SAR (Search And Rescue), etc. This service is the basis on which an internetwork at sea can be established.

## 7. Conclusion

In this paper, the marine self-organizing VHF data link has been defined and the operational principle of this link has been presented based on the authors' research work. This data link includes not only the broadcast protocols that support the Universal AIS but also the point-to-point communication protocols. The marine self-organizing VHF data link can better support VTS operation and collision avoidance at sea.

## References


[1] Gunnar Frisk, Fredrik Claesson, Nick McFarlane, "Simulation of ADS-B using VDL Mode 4 in the LA Basin Scenario and a European Scenario", Swedish CAA, 1998.

[2] International Civil Aviation Organization, " VDL Mode 4 SARPs, Version 5.4", March 1997.

[3] International Maritime Organization, "Draft Recommendation on Performance Standards for a Universal Shipborne Automatic Identification System", IMO, Feb. 1997.

[4] ITU-R M. [8C/XA], "Technical Characteristics for a Universal Shipborne Automatic Identification System", March 1998.

[5] Robert E, Boisvert, "Issues Regarding the Use of STDMA for ADS-B" , Massachusetts Institute of Technology, Lincoln Laboratory, 42PM-Squitter-0009, 1996.

[6] Wen-Li Sun, Fu-Wen Pang, Sang-Ku Hwang, Tchang-Hee Hong, " A Study on a Shipborne Automatic Identification System", Journal of the Korean Institute of Navigation, Vol. 22, No.2, June 1998.