A Study on a Shipborne Automatic Identification System

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요 약

船載用 自動識別시스템(AIS)은 21世紀에 船舶識別, 監視, 通信에 使用하기 위한 重要한 海上裝備가 될 것이며, 現在 여러 先進國에서 開發中에 있다. 本 論文에서는 AIS의 技術的인 方法을 提案하고자 한다. AIS의 主要 部分은 放送트랜스폰더(broadcast transponder)이고 核心技術은 STDMA(self-organized Time Division Multiple Access)라 불리는 高容量의 VHF 라디오 데이터 링크(radio data link)이다. 海上 VHF 채널로 自身의 位置와 身分(identities)을 自動的이고 週期的으로 放送하게 될 AIS가 設置된 船舶들은 船上이나 VTS 센터에 있는 ECDIC의 畵面에 表示가 될 것이다. AIS는 방송서비스 뿐만 아니라 일대일(point to point) 통신 서비스를 支援하게 될 것이다. 본 논문에서는 STDMA의 방안 뿐만아니라 AIS의 構成과 動作原理 그리고 機能을 說明하고자 한다. 이외에 IMO에서의 AIS에 관한 標準化 作業을 본 논문에 紹介하고자 한다.

Abstract

Shipborne Automatic Identification System (AIS) will be an important marine equipment used for identification, surveillance and communication in the 21st century, which is currently being researched in

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developed countries. A technical scheme of AIS is proposed in this paper. The main component of the AIS is a broadcast transponder, and the core technology is a VHF radio data link with high capacity, named STDMA (Self-organized Time Division Multiple Access). The ships installed the AIS, which will automatically and periodically broadcast their positions and identities in the marine VHF channels, can be displayed on a screen of an ECDIS on board or in VTS centers. The AIS is able to support not only broadcast service but also point-to-point communication service.

This paper presents the configuration, operation principle and functionality of the AIS as well as the scenario of STDMA. In addition, the standardization work of AIS in IMO is introduced in this paper, too.

1. Background and introduction

1.1 Background

In order to improve the safety of navigation, efficiency of operation and protection of the environment, the amount of information exchanged between ship and ship and between ship and shore grows rapidly. That problem is concerned all over the world. It is further recognized that future information requirements could be a step increase from those previously considered necessary in both capacity and capability needs. Hence, the international standards of future ship Automatic Identification System (AIS) is currently discussed in International Maritime Organization (IMO), International Telecommunication Union (ITU) and International Association of Lighthouse Authorities (IALA)[1]. The AIS will greatly enhance the capability of information transfer at sea. The IMO Sub-Committee on Safety of Navigation (IMO NAV) has now taken the lead role in establishing the international standards of AIS, since such a system would necessitate a vessel carriage requirement which would be the responsibility of IMO.

As early as 1995 Finland and Sweden cooperated to submit a draft Automatic Identification System performance standard based on the concept of the broadcast transponder in the 41st Session of Sub-committee on Safety of Navigation of IMO (NAV 41). It was named as "Draft Recommendations on Performance Standards for an Automatic Maritime Transponder System for Ship-to-Shore and Ship-to-Ship (4S) Using Self-organized Time Division Multiple Access (STDMA)"[2]. That draft standard was based on the requirement of Vessel Traffic Service (VTS). And then in NAV 42 in July 1996, defining the AIS caused a wide contention among the member states of IMO. There were two main opinions:[3)4)5)]

1. Shipborne Automatic Identification System using broadcast techniques, and
2. Automatic Ship Identification System using DSC techniques.

However, three conclusions have been made.

1. Only one kind of AIS would be selected as the future system on the world basis;
2. The AIS would be used for not only the operation of Vessel Traffic Service (VTS) but also the collision avoidance of ships.
3. The standardization work of the AIS would finish as fast as possible in order to implement this system in the world earlier.

To NAV 43 in February 1997, the member states reached identity of views. The AIS using STDMA broadcast technique was selected as a future system on the world basis, named as "Universal Shipborne Automatic Identification System". The time scale to achieve this standard is considered to be between 2001 and 2004.[1)]

1.2 Introduction

The purpose of the AIS is improving the safety of navigation, protection of the environment, and the management of waterways on a worldwide basis.[6] The ships installed the AIS will automatically and periodically broadcast their positions and identities in the marine VHF frequency channels without involvement of ship's personnel. All of ships participated in the AIS can be displayed on the screen of an ECDIS on board or in VTS centers. The display information includes position, identity, movement and status, as shown in Fig. 1.[7] The STDMA technology is used as the radio data link technology of the AIS. It is a self-organized TDMA scenario. There are no master or slave stations. The STDMA uses the concept of a frame. A frame equals one minute and is divided into 2250 slots. The frame start

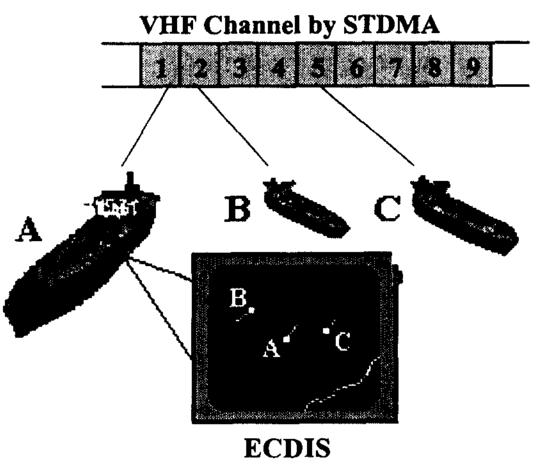

Fig. 1 General concept of the AIS

coincides with the UTC minute. Each AIS equipment establishes and stores through monitoring the TDMA channel a frame map which reflects TDMA channel activity. And then it chooses slots for its use according to the self-organized rule. The capacity of the data link is very high. More than 2000 position reports per minute can be transmitted on the AIS radio channels. The STDMA data link supports not only the broadcast service but also the point-to-point communication service.[8]

The STDMA first was developed by the Swedish Civil Aviation Administration (SCAA), which is a new radio digital communication scenario used for aviation traffic management in the future. It is the core of GP&C (Global Positioning & Communication) which is a name for a data link technology. The GP&C can be used for navigation, identification, surveillance, situation awareness and communication. Today the draft international standard of STDMA has been developed in the International Civil Aviation Organization (ICAO), which has been named VDL Mode 4. Several European funded projects included the CARD project of the SCAA are developing and demonstrating new future systems based on the STDMA technology.

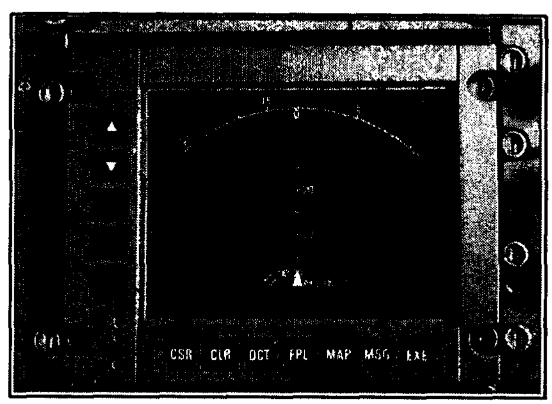

Fig. 2 MMI5000 in the F28.[9]

Fig. 2 illustrates a new system, MMI 5000, based on the GP&C technology, which is installed in a SAS Fokker F28.[9] This means that the current navigation aids and means of surveillance will be gradually phased out, and that new air traffic management systems with emphasis on satellite navigation and data links will be used for communication, navigation and surveillance in the near future.[10]

2. The performance of the AIS[6][8]

2.1 The configuration and functions of the AIS

The main component in the AIS is 4S transponder which is also referred as GNSS transponder. It consists of three parts.

- A GPS receiver
- A communication processor
- Two multiple channel data VHF transceivers

The GPS (DGPS) receiver provides ship's position with the resolution of one ten thousandth of a minute, speed over ground, course over ground and UTC time used as the timing signal by STDMA data link. The communication processor is a computer which controls the data VHF transceivers operating in two frequency channels of the marine mobile VHF band respectively. The two channels, which have been designated by the WRC-97 for AIS use worldwide, are Channel 87B (161.975 MHz) and Channel 88B (162.025MHz). On the high seas and in all other areas, the normal default mode of operation is a two-channel operating mode, where the AIS simultaneously receives on both channels in parallel. Regular scheduled transmissions alternate between the two channels, too. Additionally, the AIS can operate in regional channels which are designated in marine mobile VHF band by a local administration.

The AIS can operate in three modes as following:

1. An autonomous and continuous mode in all areas;
2. An assigned mode in an area where a shore control center is responsible for traffic management. The ship report rate may be set remotely by that center.
3. A polling mode where the data transfer occurs in response to interrogation from a ship or a base station.

The AIS uses the Non-Return to Zero Inverted (NRZI) waveform for data encoding. The modulation scheme is Bandwidth Adapted Frequency Modulated Gaussian Minimum Shift Keying (GMSK/FM). The transmission bit rate is 9600bps. The AIS is able to operate with a channel bandwidth of 25kHz or 12.5 kHz. 25kHz bandwidth is used on the high seas. 25 kHz or 12.5 kHz is used in territorial waters according to the local administration. Transmitter output power of the AIS is not exceed 25 watts. The nominal levels are 2 watts at the low power and 12.5 watts at the high power.

The AIS is able to connect with other sensors and to input data from those sensors automatically. The outside terminal connected with the AIS is Electronic Chart Display and Information System (ECDIS) by which the data can be displayed, inputted and retrieved. Of course, a security mechanism is provided to prevent unauthorized alteration of input or transmitted data. In a word, the AIS is capable of providing information automatically and continuously to VTS centers and other ships without involvement of ship's personnel, receiving and processing information from other stations, responding to interrogation with a minimum of delay, and providing positional and maneuvering information at a data rate adequate to facilitate accurate tracking by VTS centers and other ships.

2.2 The content and update rates of information in the AIS

The most important function of the AIS is the periodic broadcast of position and identity information in order to realize identification and surveillance for ships automatically. Marine Mobile Service Identity (MMSI) is used as ship identity in the AIS. The position report of the AIS is illustrated in Table 1. In addition, the AIS also provides many kinds of messages which are used for functionality and system management.

The information provided by the AIS can be divided into four classes as following.

1. Static information
   - MMSI
   - Call sign and name
   - Length and beam
   - Type of ship
   - Location of GPS on the ship
2. Dynamic information
   - Ship's position
   - Time in UTC
   - Course over ground
   - Speed over ground
   - Heading
   - Navigational status
   - Rate of turn
3. Voyage related information
   - Ship's draught
   - Hazardous cargo
   - Destination and ETA
4. Short safety-related messages

The different information types are broadcast in different periods. Hence, different update rates

Table 1. Position report of the AIS

Parameter	bit(s)	Description
Message ID	6	Identifier for this message
DTE	1	Data terminal ready
Data Indicator	1	Indicates data available to transmit
User ID	30	MMSI number
Navigational Status	2	Under way, at anchor, not under command or restricted maneuverability
Rate of Turn	8	127 degrees/min
SOG	10	Speed over ground
Position Accuracy	1	High(<10m) or low (>10m)
Longitude	29	Longitude in 1/10000 minute
Latitude	28	Latitude in 1/10000 minute
COG	12	Course over ground
Heading	9	Degrees (0-359)
Time Stamp	6	UTC second when the report was generated
Spare	9	Not used
Comm. State	18	Communication status
Total number of bits	168	

Table 2. Information update rates.

Static information	Every 6 minutes and on request
Dynamic information	Dependent on speed and course alteration from 2 sec to 3 min.
Voyage related information	Every 6 min. and on request
Short safety-related messages	as required

are required in Table 2.

3. The technology of STDMA[8)11)]

3.1 TDMA frame structure and Integrated timing concept

In the STDMA technology, channel time is divided into fixed length time slots. A frame consists of a group of slots that span a period of one minute, which is an important term used in the STDMA channel management. In the AIS system, a frame contains 2250 slots, as shown in Fig. 3. Each slot is identified by its index from 0 to 2249. All of slots are accessible for receiving or transmitting by stations communicating on the data link. One position report will occupy one time slot on the data link. Other transmissions can occupy more than one slot dependent on the application.

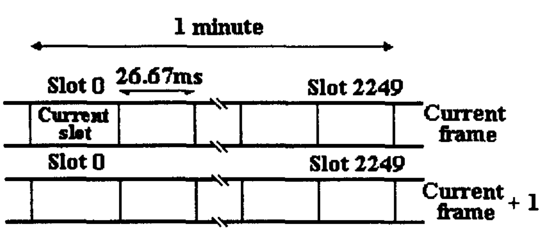

Fig. 3 Frame structure

The technology of STDMA requires time synchronization for basic station access without mutual interference. The common time reference for the AIS is Universal Coordinated Time (UTC). The primary time source is GPS time but other sources may be used as long as they can be related to UTC. The timing concept for STDMA is called the Integrated Timing Concept (ITC). The ITC adopts UTC as the single world-wide time base. Four techniques are used to yield the estimate of UTC. The order of methods indicates the most preferred technique from 1 to 4.

1. GPS receiver: A user equipped with a GPS receiver can determine the UTC time. This is the primary time reference for the AIS making it independent from base stations.
2. Synchronization with other user which has GPS time: When a station is unable to get UTC from GPS receiver but can receive signals from other stations which indicate synchronization with UTC, it will synchronize to one of those.
3. Synchronization with a base station: Mobile stations, which are unable to attain synchronization by above methods but can receive transmissions from base stations, will synchronize to the base station which indicates the highest number of received stations.
4. Synchronization with a mobile station: When all mobile stations in a certain area lost UTC standard and can not receive transmissions from any base station, they will synchronize

to a mobile station which indicates the highest number of other stations.

3.2 Message structure

In the AIS system the technology of STDMA provides twenty two message types that can be used to support a wide variety of data transfers and broadcasts. An message is transmitted inside the data portion of a data packet. The structure and transmission timing of the message, data packet and slot are illustrated in Fig. 4. The meanings of the items in Fig. 4 are explained in Table 3, and the time parameters are showed in Table 4.

Table 4. Transmission timing

T(n)	Time (ms)	Description
T0	0.000	Slot start
Tx	0.832	Beginning of training sequence
T1	1.000	RF power and frequency stabilization time
T2	3.328	Start of transmission packet
Ts	4.160	Slot phase synchronize marker
T3	24.128	End of transmission
T4	T4T3+1.000	RF power reaches zero
T5	26.670	End of slot. Beginning of next slot

For transmission a station can use a long data packet which occupies maximum five consecutive slots. Transmission using a long data packet can omit the overhead part such as ramp up, training sequence, flags, and so on. The flexible message structure of STDMA allows a station to transmit messages whilst simultaneously placing reservations for future slot usage.

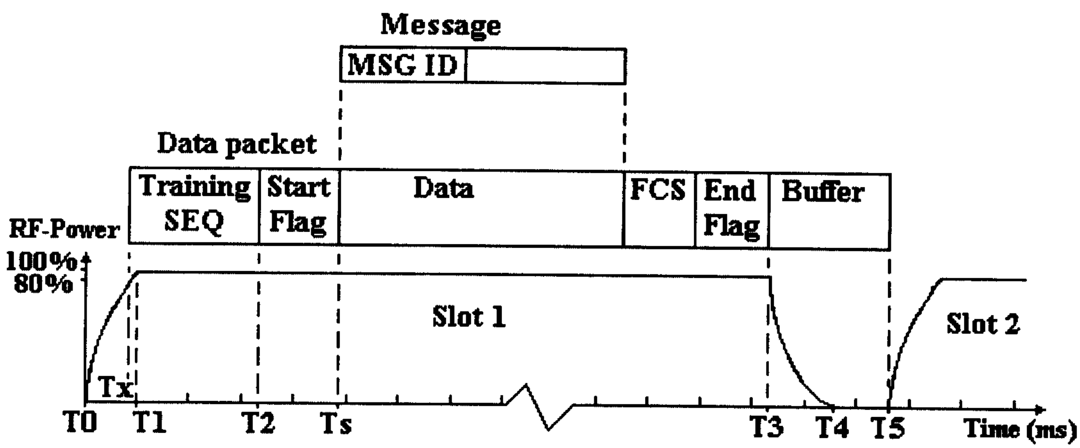

Fig. 4 The transmission timing of message, data packet and slot

Table 3. The meanings of symbol in Fig.

Parameter	bit(s)	Description	
Ramp up	8		
Training SEQ	24	Training sequence	
Start Flag	8		
Data (message)	168	MSG ID	Message ID
			Message
FCS	16	Frame check sequence	
End Flag	8		
Buffer	24	Bit stuffing and distance delays	
Total	256		

3.3 Slot selection

An important feature of STDMA is the method used to select slots for a new transmission or for placing reservations for future transmissions. When a channel is not busy, slot selection is straightforward since a slot that has not been previously reserved by a another station can be easily found. When a channel becomes busier such that unreserved slots are harder to find, STDMA allows a station to use a slot previously reserved by another distant station on the basis of Robin Hood rule. The advantage of the method of slot selection is that slot selection is carried out by all stations and there is no reliance on a base station to carry out channel resource management. The slot selection process is illustrated by Fig. 5.

The process of slot selection has the following steps:

1. An application wanting to send data or to place a reservation to send data in the future first specifies a range in which a slot will be chosen.
2. The station then derives a list of candidate slots. The candidate slots are a part of the slots in the range and consist of slots that are either "FREE" (unreserved) or "AVAILABLE" slots which, although previously reserved by another station, can be made available for use because of Robin Hood rule. Before finally selecting a slot, it is important to derive four candidate slots in order to reduce the possibility of more than one station selecting the same slot.
3. When selecting among candidate slots for transmission in one channel, the candidates in both channels shall be considered. If a slot in either channel is occupied by a station which is at close distance, the slot will be omitted from the candidate slots.
4. A slot is selected randomly from the candidate slots which have the same probability of being chosen.

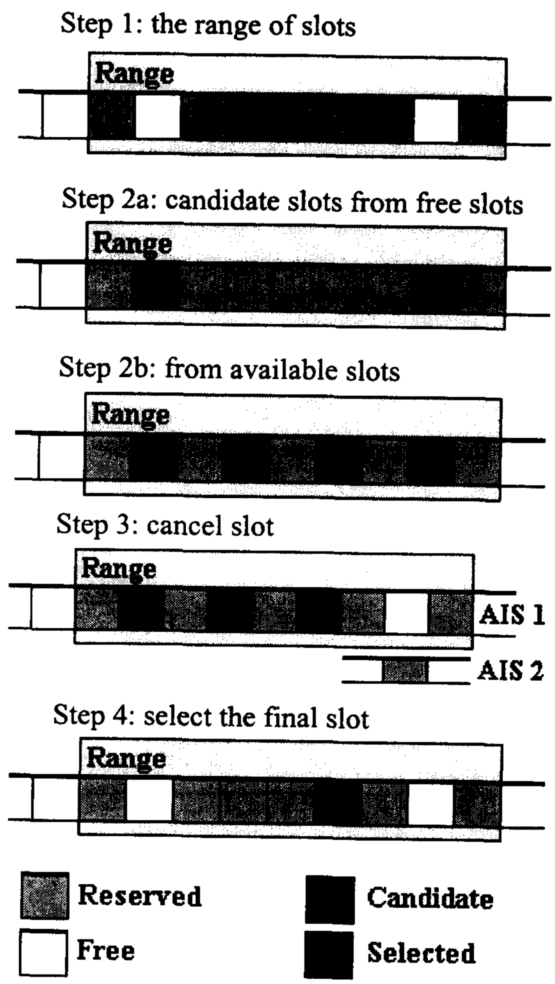

Fig. 5 The process of slot selection

When the link load exceed 90% of the theoretical maximum, the Robin Hood principle allows a station to use slots previously reserved for broadcast transmission by another station as long as slots reserved by the most distant stations are chosen in preference to those of nearer stations which are all on the distance exceeding 12 nautical miles. This results in a graceful reduction in the broadcast range of a station as the channel becomes busy and there is no sudden reduction in the ability to communicate.

3.4 Slot access protocols

In the AIS system there are four kinds of slot access protocols. These protocols will co-exist and operate simultaneously on the TDMA channel.

1. Self Organized TDMA (SOTDMA)
   The SOTDMA access protocol is used by mobile stations to support the broadcast of position and identity information by a station to all other stations in the vicinity. The purpose of the protocol is to offer an access algorithm which quickly resolves conflicts without intervention from controlling stations. Messages transmitted by SOTDMA are of a repeatable character and are used in order to supply a continuously updated surveillance to other users of the data link.
2. Incremental Access TDMA (ITDMA)
   The ITDMA supports a station to preserve transmission slots in the occasion of data link network entry, temporary changes and transitions in periodical report rates and reservation of safety related messages. The first ITDMA slot is always allocated by SOTDMA or RATDMA. Prior to transmitting in the first ITDMA slot, the station randomly selects the next following ITDMA slot and calculates the relative offset to that location. This offset is transmitted within the message to indicate that slot reserved by the station.
3. Random Access TDMA (RATDMA)
   RATDMA is used by applications when there is no prior reservation. This is generally done for the first transmission slot during data link network entry, or for messages of a non-repeatable character. RATDMA uses a probability persistent algorithm to determine the transmission slot in the candidate slot.
4. Fixed Access TDMA (FATDMA)
   FATDMA is used by base stations and controlling stations only. By FATDMA, base stations can be programmed to transmit at pre-defined times regardless of reservations on the channel in order to prevent mobile users reserving slots adjacent to base station reservations under certain circumstances. FATDMA allocated slots are used for repetitive messages.

4. Conclusion

The AIS system provides a platform on which to develop new applications. Based on the AIS system, a number of new systems can be developed, which will offer a lot of functions such as:

1. All positions are shown on an electronic navigation chart in VTS center, SAR center and on the bridge, which are from own ship, other adjacent ships installed AIS and those transmitted by base station and discovered by the radar on shore. And those position reports include a wide variety of navigation information such as identity, course, heading, speed etc.
2. Some special alarm functions can be realized to alert the officers on the bridge when ships in the vicinity enter into certain area or distances from own vessel and the water depth around own vessel is not sufficient.
3. Area control centers can monitor signals from ships' AIS for the purpose of supervision and control of traffic at sea in congested areas. Predetermined routes can be designed and put into the system on board or from the shore control center.

4. Messages of navigation warnings, tidal information, weather information, DGPS corrections etc. can be transmitted and displayed by using the AIS radio data link.
5. Tracks and messages can be stored in the on board computer and at the shore based information center. This creates a "Black Box" which has the same function to one in an airplane. Additionally pollution control can be improved because the identity and track of all vessels can easily be recorded to make evaluation and investigation possible after a pollution emission has occurred.

The establishment of the international standard of the AIS is now in process in IMO, ITU and IALA. The draft standard established is not perfect in system capability and the definition of applications as compared with the standard of the GNSS transponder for aviation. In addition, the implementation of the AIS will bring a lot of new problems. For example, which position information has higher priority between the AIS and radar. The implementation of the AIS will also induce the change of some conventional methods of operating vessel. Those require IMO to make new rules or to amend relational provisions further. However, the AIS could be a new generation system after GMDSS. It will bring the revolutionary progress in the field of globe navigation and communication at sea.

Reference

[1] ROSS Engineering, "SHIPBORNE TRANSPONDERS", March 13, 1997.

[2] Finnish delegation and Swedish delegation, "Automatic ship identification transponder systems performance standards for navigational equipment systems and equipment", NAV 42/7/31, May 1996.

[3] Swedish delegation, "Outstanding matters related to the introduction of the 4S VHF transponder on a large scale", NAV 42/7/32, May 1996.

[4] IALA, "AUTOMATIC SHIP IDENTIFICATION TRANSPONDER SYSTEMS", NAV 42/inf.5, May 1996.

[5] Friends of the Earth International, "Automatic ship identification transponder systems", NAV 43/7/10, April 1997.

[6] The Technical Working Group, "Report of the Technical Working Group", NAV 43/7, Feb. 1997.

[7] Gill-Yong Han, etc. "Mandatory Carriage Requirements of New Navigational Instruments (Revision of SOLAS Chapter V)", Journal of the Korean Institute of Navigation, Vol. 22, No.1, March 1998.

[8] ITU-R M. [8C/XA], "TECHNICAL CHARACTERISTICS FOR A UNIVERSAL SHIPBORNE AUTOMATIC IDENTIFICATION SYSTEM", March 1998.

[9] Kieran Daly, "Reaching for free flight", Flight International, 22-28 January 1997.

[10] Kieran Daly, "Talk this way", Flight International, February 1996.

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