

Communication

# A Novel Random Access Algorithm for Very High Frequency Data Exchange (VDE)

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**Abstract:** VHF Data Exchange System (VDES) is considered as an important component of the future maritime communication system by the International Maritime Organization (IMO). On the basis of existing Automatic Identification System (AIS), VDES adds the other two higher capacity subsystems: Application Specific Message (ASM) and VHF Data Exchange (VDE). The Random Access Channel (RACH) of VDE was first introduced in the International Telecommunication Union (ITU) Recommendation M.2092-0. As the slot planning of RACH in VDE is interval, which is significantly different from the continuous slot map for access algorithms in AIS, the existing slot access algorithms cannot meet the requirements of VDE. The simulation results show that the VDE slot map can reduce the normalized throughput of the existing algorithm by 39%. A novel random access algorithm called Adaptive Traffic Load Contention Resolution Diversity Slotted ALOHA (ATL-CRDSA) is proposed in this paper. The algorithm combines the load control strategy and contention resolution scheme to overcome the challenges of the new RACH of VDE. Simulation results show that ATL-CRDSA has remarkable improvement on RACH, and makes RACH very efficient and provides low latency of the packets. The insights gained from this study may be of assistance to the Media Access Control (MAC) layer design for upcoming versions of VDES standard.

**Keywords:** random access channel; load control; ATL-CRDSA; VDE; VDES

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## 1. Introduction

Nowadays AIS as a maritime communication system plays a significant role to avoid ship collisions. However, AIS channel overload has become an urgent problem to be solved with the increasing traffic. In 2012, the International Telecommunication Union (ITU) first proposed the concept of VHF Data Exchange System (VDES) 1. On the basis of existing AIS, VDES adds the other two higher capacity subsystems, which are Application Specific Message (ASM) and VHF Data Exchange (VDE). VDES has an ability to support novel maritime services in e-Navigation. More importantly, it relieves the safety-critical channel from an excessive burden by dedicating a specific spectrum to new services. Therefore, VDES can effectively alleviate the pressure of AIS data communication and provide higher and stronger data exchange capability in the global maritime VHF mobile band. VDES as an advanced version of AIS has been established as an important component of future maritime communication systems in e-Navigation by International Maritime Organization (IMO) 2.

According to ITU Recommendation M.2092-0, which provides the technical characteristics of VDE, ASM and AIS in the VHF maritime mobile band (156.025-162.025 MHz), VDE includes VDE-Terrestrial (VDE-TER) and VDE-Satellite (VDE-SAT) 3. VDE-TER is used to support high-density traffic in near-shore, e.g., ports and waterways, via shore stations. VDE-SAT provides access to the maritime services beyond line of sight at shore, e.g., on the high seas or in the arctic region, via low-earth orbiting (LEO) satellites. To provide messaging service to vessels on such newly available yet limited VHF resources, VDE is allocated to deal with the information beyond

safety and navigation directly. This paper mainly focuses on the random access channel access algorithm of VDE-TER. In VDE, data transmission bandwidth may be 25 kHz, 50 kHz or 100 kHz according to the channel environment 4.

From 2013, ITU and International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) have been investigating technical standards required in the development of VDES, including technical characteristics, performance requirements, and system tests. It is expected to adopt VDES resolution in 2021 or 2022. Therefore, it will lay the policy and technical foundation for the VDES application 5. So the technical specifications will be continuously amended and additional details will be supplemented according to experience requirement in implementing the technical solutions for VDES.

With the equation of VDE technical specifications, VDE functions are becoming more concrete. As stations could send data at any time in the VDE application, packet collision is a big challenge. This characteristic is similar to the conditions of S-ALOHA (Slotted-ALOHA) random access to some extent 6. Although S-ALOHA 788 has been proposed for 40 years, and its slightly improved versions are today widely used for terminal access or short packet transmissions in a shared medium, such as underwater acoustic sensor network 10, LoRaWAN networks 11, Machine-Type Communication (MTC) 11. The slot map in VDE function is interval, which is much different from the traditional S-ALOHA's continuous slot map. For the VDE RACH, we need to solve the following problems: (1) In ITU Recommendation M.2092-0, the slot map does not match the specific Logical Channel (LC). An efficient slot map based on VDES protocol is necessary. (2) The non-consecutive slot map will greatly reduce the normalized throughput of the traditional access algorithm. Therefore a new random access algorithm needs to be introduced. (3) In the VDE application, the number of mobile stations nearby the shore station is very large. Great load will increase the packet collision ratio and loss ratio, making the normalized throughput of VDE approach to 0. According to the above challenges, the existing S-ALOHA and its various improved slot access algorithms 1314 cannot meet the function and performance requirements.

Meanwhile, how to improve the utilization of slots while realizing the VDE function is also investigated in this paper. Contention Resolution Diversity Slotted ALOHA (CRDSA) is proposed in 15, which uses a replica to eliminate interference. However, in the VDE application, the normalized throughput of the CRDSA decreases rapidly when a large number of mobile stations access RACH at the same time, it cannot meet the functional requirements of VDE. Considering the VDE network with massive number of stations and the idea of load control in 1617, a novel hybrid algorithm with high normalized throughput and load control strategy is proposed in this paper, which is called Adaptive Traffic Load Contention Resolution Diversity Slotted ALOHA (ATL-CRDSA).

The main contributions of this paper include: (1) There is no specific slot map in ITU Recommendation M.2092-0 4. Through analyzing VDE functional requirements, we allocate each slot in the VDE frame and construct a new slot map. It can provide reference for future research. (2) We propose a new slot access algorithm ATL-CRDSA for VDE, which can meet the system requirements in terms of normalized throughput, packet collision ratio, packet loss ratio and system stability.

The rest of this paper is organized as follows. We discuss the related work in the second section. The frame structure, slot map and ATL-CRDSA algorithm are given in the third section. The performance bounds of ATL-CRDSA are derived and simulation results are given in the fourth section. Finally, the main conclusions are summarized, and further research is put forward.

## 2. Related Work

In the early 1970s, the first RACH media access control (MAC) protocol was proposed, which is ALOHA. It enables geographically dispersed users to share the channel to transmit data packets at random time. The vulnerable period is the slot length of a packet that is prone to collision with other packets when it is sent. The vulnerable period of ALOHA is two packet-length. Data packets will be retransmitted when they collide in accessing the RACH. ALOHA's retransmit strategy is that each transmitter waits for a random period of time and then retransmits. If a collision occurs again, the

above-mentioned retransmit strategy repeats until the data packet is successfully transmitted. When the channel load is heavy, the probability of data packet collision is very high, so the channel utilization of ALOHA protocol is only 18%. With the continuous increase of communication capacity, how to avoid or solve collisions in access algorithms has become a crucial issue. In S-ALOHA, when the data packet arrives, it will wait for a while in the cache and send it at the beginning of the next slot. If only one packet arrives during this slot, the packet will be sent successfully in the next slot. Each packet must be transmitted within one slot. It halves the collision probability in ALOHA by dividing time into synchronized slots. However, when two or more data packets arrive in this slot, collision will occur. The random retransmit mechanism after S-ALOHA collision is the same as ALOHA. As a result, S-ALOHA shortens the vulnerable period to one packet-length, reduces the collision probability, optimizes the normalized throughput performance, and increases the maximum normalized throughput of the channel to 36.8%.

To improve the normalized throughput of RACH, transmitting multiple copies of the same packet is used to reduce the packet loss rate in Diversity Slotted ALOHA (DSA). Copies of data packets can be either transmitted synchronously on different frequencies or in different slots at the same frequency. It is proved that the transmission delay of multi-copy transmission is smaller and the normalized throughput of the channel is larger than that of S-ALOHA at low load conditions. However, the mechanism of DSA will greatly increase the channel load, which in VDE is very limited, so this algorithm cannot be applied in VDE directly. Duplicate data will be generated in successfully demodulated data packets, which are also a waste of channel resources. In order to assist the collision resolution, by introducing iterative interference cancellation (IIC) and frame-structure, Contention Resolution Diversity Slotted ALOHA (CRDSA) is proposed. In fact, the terminal will always send two copies in two randomly selected slots within the same frame. This is similar to setting the retransmission limit as 2. As the two copies have the same preamble and payload information bits, so when one copy is demodulated successfully, the recovered information will be used to cancel the interference that the other copy may generate on the other slot. Thus CRDSA greatly optimizes the performance of the system. Furthermore, Irregular Random Slotted ALOHA (IRSA) is proposed by considering the coding among the multiple replicas of a packet. The number of copies in IRSA does not exceed the random value of the declared number. Because of its large random value, the maximum normalized throughput can be up to 0.97 (packet/slot). All the same, similar to the disadvantages of DSA, too many replicas will seriously increase the load of the VDE channel and reduce the utilization of channel, which is not suitable for the VDE application.

In the application for long-distance transmissions, such as satellite communication, the system is asynchronous and the frame synchronization between stations will increase the burden. Therefore, some enhanced algorithms with the asynchronous frame are proposed. As no slots are present in the frame in Contention Resolution ALOHA (CRA), the replicas of the terminals can be placed within the frame without limits, expect that replicas of a user may not completely interfere with each other. Moreover, partial interference is more probable to be decoded than complete interference. Based on CRA, Enhanced Contention Resolution ALOHA (ECRA) sends two copies of each packet. ECRA combines the advantages of CRDSA and CRA. If the interference generated by a replica is sufficiently small and the error correction code is strong enough, the packet can still be decoded correctly. The mechanism of IIC can remarkably improve the performance of ERCA. In the long transmission delay, heterogeneous transmission delay or time-varying network, an asynchronous Flipped Diversity ALOHA (AFDA) using diversity transmission and interference cancellation for MAC protocol is proposed, which uses Zigzag decoding to solve packet loss problem. Because of the time slots between all stations in VDE are synchronous. These asynchronous algorithms are not suitable for the RACH of VDE.

Based on the analysis of the slot map of the frame structure and performance requirements, the CRDSA is found to be most suitable for VDE. Copy packets will not increase the channel load significantly and maximize the normalized throughput. Meanwhile, we add load control based on the CRDSA to enhance the robustness of VDE and apply it in the application.

### 3. Frame Structure, Slot Map and ATL-CRDSA

### 3.1. Frame Structure and Slot Map

In VDE, signals and interference are changing with time and location, so shore stations measure channel quality according to received mobile station signals and request the corresponding mobile station to use adaptive modulation and coding to maximize spectral sufficiency and normalized throughput [26]. In VDE, the physical channel is divided into the upper leg and the lower leg. The upper leg is used for data transmission between shore-to-ship and ship-to-ship, and the lower leg is used for ship-to-shore data transmission. The physical channel configuration of VDE is shown in Fig. 1.

Rec. ITU-R M.2092					Rec. ITU-R M.2092			
1024	1084	1025	1085	157.275	2024	2084	2025	2085
157.200	157.225	157.250	157.275	-	161.800	161.825	161.850	161.875
				161.800 kHz				
VDE-TER Ship-to-shore					VDE-TER Shore-to-ship and ship-to-ship			

Figure 1. VDE Physical Channel configuration

VDE introduces the concept of LCs in the frame, which defines functions for a set of continuous slots [4]. Each slot is allocated with one LC in one frame. The LCs are classified into data channels for data transmission and signalling channels for signalling transmission and synchronization. The connection between mobile and shore stations is session-oriented with a LC being reserved for a particular mobile station for a given time. The division of LCs is based on fixed time slots, and each channel uses a configurable number of slots at a predetermined frequency. In VDE, signalling channels are divided into Terrestrial Bulletin Board (TBB) Signalling Channels, Announcement Signalling Channel (ASC) and RACH. There are 12 LCs in VDE-TER, five of which are data channels and seven are signalling channels [26].

In order to illustrate the application scenario of VDE, we present the slot map of VDE, show the available slots for RACH.

#### 3.1.1. Frame Structure

According to ITU Recommendation M.2092-0, VDE frame structure is shown in Fig. 2. The length of a frame is 60 seconds, each frame is divided into 2250 slots, and each slot occupies about 26.67 milliseconds. VDE packet transmissions shall always fit into one slot. The number of bits transmitted per VDE packet shall be fixed, depending on the modulation and coding scheme used. A packet shall consist of one or multiple VDE messages, zero padding and a 4-byte Cyclic Redundancy Check (CRC). The time slots in VDES are synchronized by the Coordinated Universal Time (UTC). Six slots are combined into one Hex Slot (HS), and the cycle period of the LC is six HS [28].

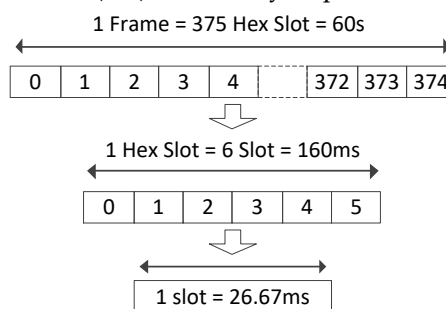


Figure 2. VDE Frame structure

#### 3.1.2. Slot Map

In VDE, 2250 slots correspond to the specific LC shown in Fig. 3. Each column represents a HS. Note that the number inside each block indicates the slot number. The yellow block in Fig. 3 is the TBB signalling channel, which occupies 18 slots 428 in a frame. The blue blocks correspond to ASC1-ASC5, which can control five parallel data transmission tasks. The red block indicates RACH, which realizes the channel access of VDE. The green block corresponds to the data channel for sending and receiving data.

0BB	6BB	12BB	RA	A1	A2	A3	A4	A5	RA	A1	A2	A3	A4	...
1	7	13	RA	25	31	37	43	49	RA	61	67	73	79	...
2	8	14	RA	26	32	38	44	50	RA	62	68	74	80	...
3	9	15	RA	27	33	39	45	51	RA	63	69	75	81	...
4	10	16	RA	28	34	40	46	52	RA	64	70	76	82	...
5	11	17	RA	29	35	41	47	53	RA	65	71	77	83	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	A4	A5	RA	A1	A2	A3	A4	A5	RA	A1	A2	A3	A4	A5
...	2167	2173	RA	2185	2191	2197	2203	2209	RA	2221	2227	2233	2239	2245
...	2168	2174	RA	2186	2192	2198	2204	2210	RA	2222	2228	2234	2240	2246
...	2169	2175	RA	2187	2193	2199	2205	2211	RA	2223	2229	2235	2241	2247
...	2170	2176	RA	2188	2194	2200	2206	2212	RA	2224	2230	2236	2242	2248
...	2171	2177	RA	2189	2195	2201	2207	2213	RA	2225	2231	2237	2243	2249

Figure 3. VDE-TER ship-to-shore slot to LC mapping

In the VDE application, the first three HS of each frame are allocated to the TBB signalling channel. TBB is sent by the shore station to define each Physical Channel with its VDE slot map for a control station service area. During this period, the mobile station can only receive information from the shore station, and cannot transmit any data. The HS corresponding to the same ASC number in ASC1-ASC5 handles a set of data transmission tasks respectively. The RACH resources of VDE-TER are very limited. This cyclic sorting mode in VDE can optimize the ability of data-parallel processing.

VDE-TER can realize request, resource allocations or short message transmission between shore station and mobile station in RACH, and ship-to-ship communication in the shore station service area. By monitoring the TBB, mobile stations will determine if they are within a control station service area. When a mobile station carries on the burst information transmission, the transfer starts with a Resource Request message to announce the source and destination. The following Resource Allocation message is transmitted to assign a channel to the data session. The LC is kept allocated until all fragments have been received by the mobile station and an ACK has been received or a retry limit has been exceeded. In addition, some smaller packets in communication, such as acknowledgment or paging, can also be transmitted directly on RACH.

### 3.2. ATL-CRDSA Algorithm

In a real environment, the number of mobile stations access to the RACH will increase greatly due to the large density of mobile stations within the range of the shore stations. Previous studies have shown that the normalized throughput of random access algorithms based on competition mechanism increases first and then decreases with the increase of load 29. For the sake of optimizing the system performance, we introduce load control in the CRDSA to keep the system normalized throughput running at a high level steadily.

#### 3.2.1. CRDSA Contention Resolution

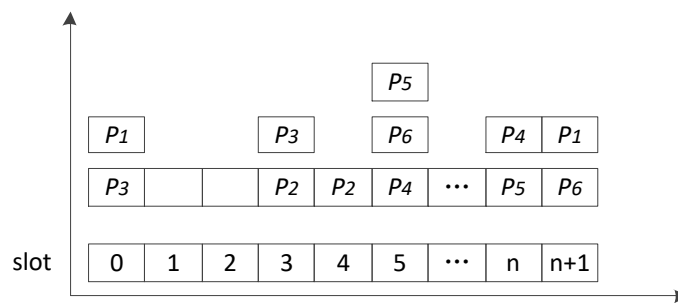
Compared to S-ALOHA and DSA, it is found that one way to improve the normalized system normalized throughput is increasing the replica of data packets. In VDE, RACH is the discontinuous HS, which means channel resources are very limited. The number of replicas will obviously increase



the channel load and a higher load will greatly affect the performance. Therefore, it is not suitable to increase the normalized throughput of VDE by adding replica simply.

In CRDSA, by exploiting interference cancellation techniques, only one replica is added, the effect on the channel load is acceptable. The demodulation process confirms the signalling packet by FEC parameters and completes the decoding of the signalling packet. Valid information of two replicas in the same signalling packet contains the slot location of the corresponding replica. In fact, if one of the replicas is successfully decoded, the information about the other allows resolving the possible generated collisions. Therefore, it can recover most of the signalling packets due to collision.

Fig. 4 shows an example of contention resolution in the CRDSA. In Fig. 4, the signalling packet  $P_2$  on slot 4 can be demodulated successfully, and then  $P_3$  suffered the collision of  $P_2$  on slot 3 can be recovered. Similarly,  $P_1$  and  $P_6$  can also eliminate interference. Meanwhile, we can also see the limitations of the algorithm. When two copies of the signalling packets interfere with each other, they cannot be demodulated effectively. In Fig. 4, the  $P_4$  and  $P_5$  signalling packets are in this situation. Anyway, this dual-packet iterative demodulation scheme can significantly improve normalized throughput.



**Figure 4.** Contention resolution schematic

The performance of CRDSA is evaluated in the continuous slot system using MATLAB in Section 5. Meanwhile, the upper limit is deduced theoretically in 15, and two assumptions are made here: (1) all data packets can be demodulated correctly; (2) the collision probability of the preamble can be ignored.

When the normalized load is  $G$  and the number of iterations is  $N_i$ , normalized throughput  $T$  can be expressed as:

$$T(N_i | G) = G \cdot P_{pd}(N_i | G) \quad (1)$$

$P_{pd}(N_i | G)$  indicates the probability of successful demodulation of signalling packets. The probability  $P_{pd}$  can be derived as:

$$P_{pd}(N_i | G) = 1 - [(1 - P_{pd}^A(N_i | G)) \cdot (1 - P_{pd}^B(N_i | G))] \quad (2)$$

$P_{pd}^A$  and  $P_{pd}^B$  indicates the probability of successful decoding of twin copies of the same signalling packet respectively. For symmetric, Equation (2) can be recursively derived as follows:

$$P_{pd}(N_i | G) = 1 - (1 - P_{pd}^A(N_i | G))^2 \quad (3)$$

As  $P_{pd}^A = P_{pd}^B$ , the upper limit of probability  $P_{pd}^A$  can be deduced as follows:

$$P_{pd}^A(N_i | G) \leq P_{al}^A(G) + \sum_{i=1}^{G \cdot M_{sn}^{RA} - 1} P_{in}(i | G) \cdot [P_{pd}^B(N_i - 1 | G)]^i \quad (4)$$

$P_{al}^A(G)$  represents the probability that there is no collision occurs.  $P_{in}(i | G)$  stands for the probability that the signalling packet to be collided with  $N$  interference signalling packets in the same slot.  $G \cdot M_{sn}^{RA}$  represents the maximum number of packets that can be present over one slot.  $G \cdot M_{sn}^{RA} - 1$  represents the number of interference packets that can be present in one slot. According to  $P_{pd}^A = P_{pd}^B$ , (4) can derive as follow:

$$P_{pd}^A(N_i | G) \leq P_{al}^A(G) + \sum_{i=1}^{G \cdot M_{sn}^{RA} - 1} P_{in}(i | G) \cdot [P_{pd}^A(N_i - 1 | G)]^i \quad (5)$$

where the initial value  $P_{pd}^A(0) = 0$ . For signalling packet  $P_k$ , the probability of twin copies appearing on the corresponding slot  $S_n$  in a frame is as follows:

$$P\{P_k \in S_n\} = P\{P_k^A \in S_n\} + P\{P_k^A \notin S_n\} \cdot P\{P_k^B \in S_n\} = \frac{2}{M_{sn}^{RA}} \quad (6)$$

Assuming that the transmission slot is randomly selected and will not be sent on the same time slot, the probability of the  $i$ th interference signalling packet on a given slot  $S_n$  can be obtained. As the  $i$ th packet are superimposed in slot  $S_n$ , the remaining  $G \cdot M_{sn}^{RA} - 1 - i$  packets will not be present in slot  $S_n$ .

$$P_{in}(i | G) = \binom{G \cdot M_{sn}^{RA} - 1}{i} [P\{P_k \in S_n\}]^i \cdot [1 - P\{P_k \in S_n\}]^{G \cdot M_{sn}^{RA} - 1 - i} \quad (7)$$

When the replica of the signalling packet is with no interference, we can obtain

$$P_{al}^A(G) = P_{in}(0 | G) = [1 - P\{P_k \in S_n\}]^{G \cdot M_{sn}^{RA} - 1} \quad (8)$$

According to Equation (5), the first iteration can demodulate the signalling packet without interference, and the second iteration can eliminate the case of only one interference packet, and so on. It will end until the time slot with the most interference is demodulated successfully. But one case which is presented as the  $P_4$  and  $P_5$  in Fig. 4 will form deadlock. So the demodulation probability of equation (5) represents the upper limit of CRDSA.

### 3.2.2. Traffic Load Control

Load control strategy was first used in cellular networks [29], and later applied to machine to machine (M2M) communication systems. Load control can enhance robustness which is an important part of system security. In the VDE application, the number of mobile stations nearby the shore station usually is very large, and the channel load increases dramatically.

We define the maximum normalized throughput of the system  $T_{max}$ . When  $T(N_i | G) < T_{max}$ ,  $T(N_i | G)$  will increase as the  $G$  goes up. To the contrary, when  $T(N_i | G) \geq T_{max}$ , the increase of  $G$  will greatly add the probability of signalling packet collision, resulting in the decrease of  $T(N_i | G)$  from the maximum value.

In VDE, the shore station can monitor the channel to obtain the statistical information of RACH, estimate the  $T(N_i | G)$ , and determine the normalized load  $G$ .

According to Equation (1), we can get:

$$G = T(N_i | G) / P_{pd}(N_i | G) \quad (9)$$

And then

$$G_m = T_{max} / (1 - (1 - P_{pd}^A(N_i | G))^2) \quad (10)$$

In the CRDSA, the collision ratio of the signalling packet will increase and normalized throughput will decrease rapidly if the actual load is higher than  $G_m$ . In the ATL-CRDSA, we introduce an additional probability  $p_{ATL}$ , which is broadcasted by the shore station. The current signalling packet of the mobile station will be sent by probability  $p_{ATL}$ .

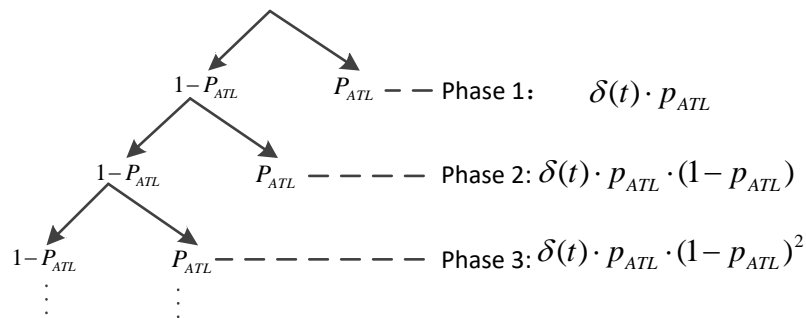
The probability of load control strategy is defined as:

$$p_{ATL} = \begin{cases} 1 & G < G_m \\ G_m / G & G \geq G_m \end{cases} \quad (11)$$

According to the ATL-CRDSA, when the load is less than  $G_m$ , the transmission probability of a mobile station does not change. Contrary, when the load exceeds  $G_m$ , the shore station broadcasts  $p_{ATL}$ , and the signalling packet will be sent by  $p_{ATL}$ , will be abandoned by  $(1 - p_{ATL})$ , thus the load of the system is always near  $G_m$ .

If the probability density function is set to  $\delta(t)$ , it can be found that the probability density function is  $\delta(t) \cdot p_{ATL}$  when signalling packet transmission is successful in Phase 1. Meanwhile, the

probability density of successful transmission in Phase 2 is  $\delta(t) \cdot p_{ATL} \cdot (1 - p_{ATL})$ . Similarly, the probability density of successful transmission in Phase 3 is  $\delta(t) \cdot p_{ATL} \cdot (1 - p_{ATL})^2$ , as shown in Fig. 5.



**Figure 5.** Probabilistic distribution density tree of ATL-CRDSA

Applying the CRDSA to VDE can increase the normalized throughput of the RACH. Besides that, the load control strategy is introduced to ensure that the channel can maintain excellent performance in the heavy load condition, such as around the shore station.

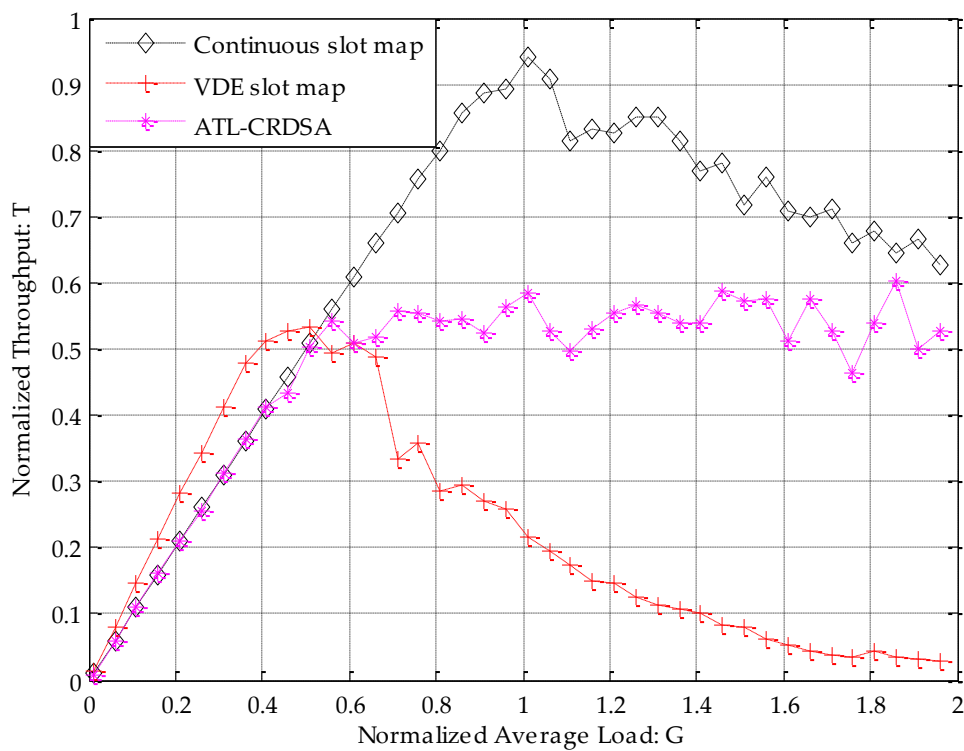
#### 4. Performance Evaluation

To illustrate the performance of ATL-CRDSA, we simulated the random access of 200 mobile stations around the shore station to the RACH, respectively obtained the performance of CRDSA in the continuous slot map environment and the VDE slot map environment, and finally simulated the performance of ATL-CRDSA in the VDE slot map environment. In order to study the performance of the algorithm, we made a detailed comparison of normalized throughput, packet collision ratio and packet loss ratio.

##### 4.1. Normalized Throughput: $T$

In Fig. 6, we compare the normalized throughput of ATL-CRDSA in VDE slot map with CRDSA in continuous and VDE slot map. In the continuous slot map environment, when the optimal normalized average load of CRDSA is 1, the normalized throughput  $T$  can reach 0.93 (packet/slot). However, due to the particularity slot map of VDE, the normalized average load of the system is reduced to about 0.5, and the normalized throughput is reduced to 0.53 (packet/slot). Moreover, when the system achieves optimum performance, the increase of load will quickly destroy the behavior of the system, and the normalized throughput will decrease rapidly. The rate of decline will reach 0.67, which is much larger than that of 0.3 in the continuous slot scene. It can be observed that when the normalized average load increases to 2, the normalized throughput of CRDSA in the VDE slot map is close to 0, which completely fails to meet the requirements of the VDE application. It can be found that the normalized throughput of ATL-CRDSA can be maintained about 0.52 (packet/slot) even if the load continues to increase. From simulation results that when the load of the system reaches its optimum level, a continuous load increase will seriously damage the system performance. ATL-CRDSA is an effective solution to solve this problem.

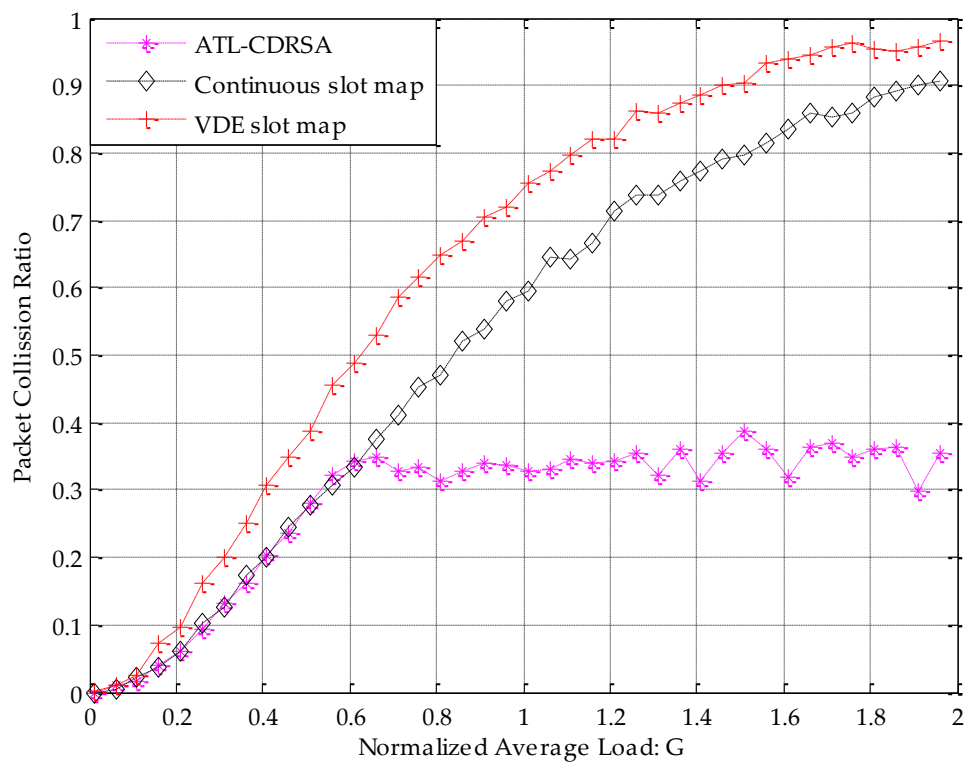




**Figure 6.** Normalized throughput of ATL-CRDSA in VDE slot map, CRDSA in continuous and VDE slot map.

#### 4.2. Packet Collision Ratio

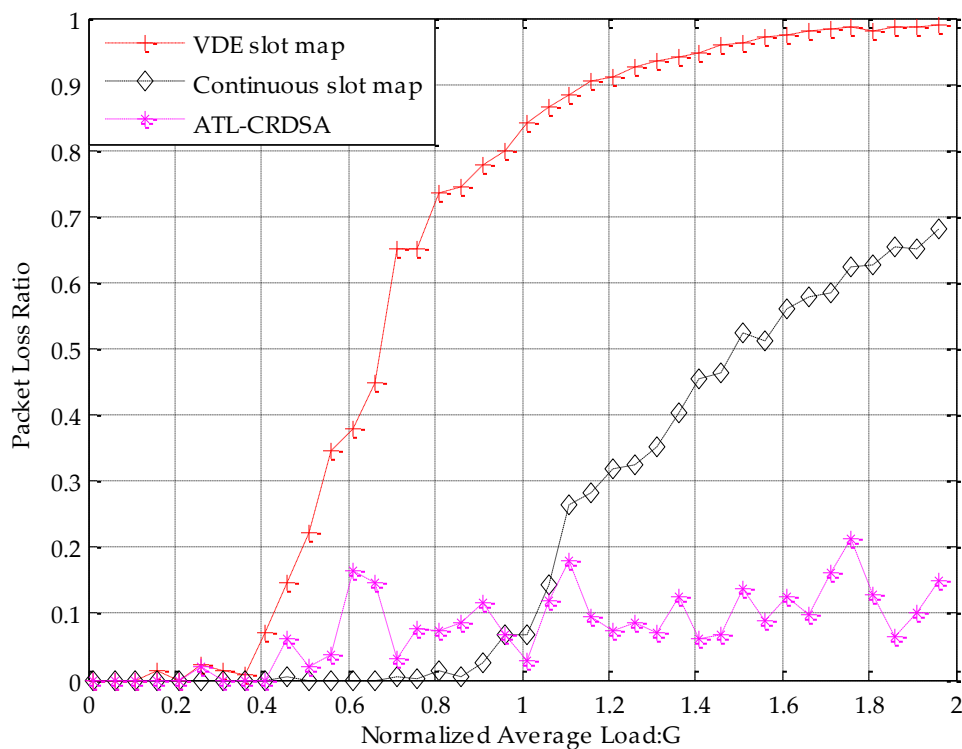
In Fig. 7, the packet collision ratio of the three circumstances over  $G$  is presented. Compared to the VDE slot map, the packet collision ratio of CRDSA in continuous slot map is significantly better but it is still worse than the ATL-CRDSA. Above the value of  $G = 0.6$ , CRDSA in continuous slot map keeps increasing and reaches about 0.9 when the  $G$  comes to 2. It is three times as much as ATL-CRDSA.



**Figure 7.** Packet collision ratio of ATL-CRDSA in VDE slot map, CRDSA in continuous and VDE slot map.

#### 4.3. Packet Loss Ratio

In Fig. 8, for the CRDSA, in a continuous slot map system, when  $G = 0.8$ , there will be more apparent packet loss. When  $G = 2$ , the packet loss ratio will reach 0.7. In comparison for VDE slot map, when the normalized load  $G = 0.4$ , it will start to lose packets. When  $G = 2$ , the packet loss ratio will reach 1. The performance of packet loss ratio of CRDSA will be degraded due to the reduction of available slots and the interval of available slots. But the packet loss ratio will always keep at a low level for ATL-CRDSA. It can satisfy the needs of the system very well.



**Figure 8.** Packet loss ratio of ATL-CRDSA in VDE slot map, CRDSA in continuous and VDE slot map.

## 5. Conclusions

The ITU is seeking a new scheme towards digital communication applied in the maritime community. In the final version, VDE is a crucial component of VDES which can handle all the digital communication. Exploit a new algorithm for RACH in VDE can enhance system performance. In this paper, taking into consideration of the RACH's interval slot map and huge number of mobile stations, the ATL-CRDSA algorithm is proposed and in-depth analyzed for the special RACH model of VDE. It is shown that ATL-CRDSA provides reliable performance by introducing iterative interference cancellation (IIC). In practice, to overcome the impact of channel load on the system performance, the load control strategy is introduced. The simulation results show that the VDE slot map can reduce the normalized throughput of the existing algorithm by 39%. When the normalized throughput exceeds the optimal point, the normalized throughput decline rate of the VDE slot map is 2.2 times higher than that of the continuous slot map system. To fully optimize the application of ATL-CRDSA in the VDE application, the allocation of the RACH slot map for VDE needs further improvement. In this paper, we consider that data transmission in the channel will not lose byte files and there is no noise interference in the transmission environment. In practical applications, the communication environment will be more complex. For further study, we should find out the effect when introducing the channel noise in ATL-CRDSA.

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