Towards Video Packets Store-Carry-and-Forward Scheduling in Maritime Wideband Communication

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Abstract—In this paper, we investigate uploading monitoring videos for vessels via a maritime wideband communication network. The Worldwide Interoperability for Microwave Access (WiMAX) technology is utilized to establish a shore-side network infrastructure, and a packet store-carry-and-forward routing mechanism is implemented to address the intermittent network connectivity in maritime communications. A resource allocation problem is formulated to maximize the weights of uploaded video packets, subject to the intermittent network connections and the release time and deadline of each video packet. Time-capacity mapping is applied to transform the original resource allocation problem to a two-machine non-preemptive scheduling problem. As ship routes are relatively stable, the global information in terms of release time, deadline and other time indices of video packets, as well as the schedules of vessels is known a priori. We propose two offline scheduling algorithms, namely Time-capacity mapping based two phase (TMTP) algorithm, and Interval graph theory based job relay selection (IGTJRS) algorithm. Both algorithms achieve a time complexity of \( O(n^2) \). The performance of proposed algorithms is evaluated through simulation based on actual ship route traces obtained from dedicated Navigation software BLM-Ship.

I. INTRODUCTION

It is envisioned that building up a maritime wideband communication system will greatly contribute to the maritime distress, urgency, safety, and general communications. Through this system, large capacity data, such as monitoring videos collected from bridge, engine room or other important regions, can be reliably delivered, which is crucial to maritime authoritative administration. Moreover, ships can also obtain safety related information and multimedia data via the network. In other words, it extends wideband services from land to sea.

Current maritime communication system, denominated as Global Maritime Distress and Safety System, is comprised of terrestrial and satellite systems. The newest Fleet Broadcast satellite system can achieve wideband transmission with data rate up to 432kbps. However, the service fees are very high due to high costs of launching satellites (e.g., voice service costs USD$ 13.75 per minute for Iridium [1]). Hence, the cost for delivery videos could be prohibitive. Meanwhile, current terrestrial maritime communication cannot support wideband communication. Taking the legacy VHF communication as an example, the maximum data rate is merely 9.6kbps [2]. Therefore, it is a imperative demand to construct maritime wideband communication systems at low service cost.

The study of new maritime wideband network has drawn much attention in recent years. In [3], Zhou et al. proposed cognitive maritime mesh/ad hoc networks. In Singapore, wireless-broadband-access for Seaport (WISEPORT) project launches mobile wireless broadband access up to 5Mbps base on Worldwide Interoperability for Microwave Access (WiMAX) [4]. Thus, WiMAX technology is approved to be a favorable candidate to support the explosive growth of mobile data traffic at sea, due to its high data rate and large coverage area. However, its coverage range is still short (e.g., 15km from Singapore’s coastline). In addition, the links at sea are frequently obstructed by sea clutter or suffer from deteriorated channels, and the duration of wireless connection is short (in term of limited amount of information receiver deployed shore-side). Consequently, there will not always be a contemporaneous end-to-end path. A novel alternative or complementary solution is store-carry-and-forward data packet delivery in delay tolerant networks (DTNs) [5], which can exploit node mobility statistics, permitting other nodes to store and carry data messages, and deliver whenever a communication opportunity arises. In [6], Lin et al. explored the WiMAX-based mesh technology for ship-to-ship communications with DTN features firstly to provide less expensive wireless communication services at sea, and compare the performance between regular routing protocols and DTN routing protocols. In our work, data delivery can be achieved via infostations shore-side, while the coverage provided by the infostations may not be seamless due to long coastline and high deployment cost. Hence, we consider a WiMAX/store-carry-and-forward interworking maritime wideband communication system, explicitly devised to overcome above limitations.

Videos are divided into packets, with respective release time, deadline and weight. Weight is assigned to value its contribution to video quality. In order to transmit packets before respective deadline and gain better quality which is determined by weights of delivered packets, cooperative transmission strategy can be exploited [7] [8]. A critical problem is scheduling data packets to be relayed by other vessels. In the literature, although not in maritime scenarios, vehicle-assisted data delivery has been extensively studied. In [9], Cheng et al. propose a vehicle-assisted data delivery method for smart grid applications, based on optimal stopping theory. In [10], Liang and Zhuang investigate on-demand data services for high-
speed trains. An online resource allocation algorithm based on Smith ratio and exponential capacity is proposed.

In this work, we first formulate the resource allocation and scheduling problem by taking account of the intermittent network connectivity and cooperative transmission. The goal is to guarantee the videos quality as much as possible, i.e., throughput maximization problem. We convert the scheduling problem into job-machine issue. Furthermore, time-capacity mapping is applied to transform the original issue to two-machine non-preemptive scheduling problem. As ship routes are relatively stable, the global information in terms of time indices such as release time and deadline, as well as the schedules of vessels is know a priori. We propose two offline scheduling algorithms, namely Time-capacity mapping based two phase (TMTP) algorithm, and Interval graph theory based job relav selection (IGTJS) algorithm depending on maximum weight 2-independent set algorithm. The performance of the proposed algorithm is evaluated and compared with other classic scheduling algorithms under a real ship routes data obtained from dedicated Navigation software BLM-Ship.

The remainder of this paper is organized as follows. System model is given in Section II and problem formulation is presented in Section III. Two adopted algorithms are proposed, as well as time complexity is validated in Section IV. In Section V, simulation results are given employed to demonstrate the performance of our approaches. We conclude this paper with future work in Section VI.

II. SYSTEM MODEL

A vessel generates monitoring videos periodically, sailing from origin port to destination. Videos could be uploaded to content server of administrative agencies by infostations deployed along route line, as well as be stored in a DTN throw box(It is small, stationary and inexpensive device equipped with wireless interfaces and storage, acting as a relay to create more connection opportunities) [11], then be carried and forwarded by another vessel via the encountering infostations.

A. Store-Carry-and-Forward Routing

The network topology is shown in Fig. 1. Several shore-side infostations are deployed along route line, whereas WiMAX network provide seamless coverages within the communication range of infostations. When vessels pass, they correspond with infostations to upload data. A wireline/wireless network can connect the infostations to content servers of administrative agencies. Due to the mobility, vessels only communicate with infostations during the available connecting time. Several vessels may come across the same rendezvous point with DTN throw box, but probably not at the same time. Therefore, the alternative solution is cooperative transmission before deadline of each data. Since vessels sail on predetermined and fixed route lines, the schedule of vessels are relatively stable.

B. Video packet

Monitoring videos are divided into packets, each packet has its release time, deadline, and weight. We utilize weight to value its contribution to the video quality. We can get the weight of packet if deliver it before its deadline. We consider video packets $f = \{c_1, \cdots, c_n\}$ that can be transmitted on vessels $M = \{M_1, \cdots, M_m\}$. Define some parameters as $j, i \in \{1, \cdots, n\}$ for packets, $k \in \{1, \cdots, m\}$ for vessels, $p_j$ for processing time and $s \in \{1, \cdots, t\}$ for starting time.

C. Time-Capacity Mapping

Due to the intermittent network connectivity, a vessel may confront several infostations en route. We map the time indices into virtually cumulative capacity values, as shown in Fig. 2.

Fig. 1. An illustration of the network topology

Fig. 2. Time-capacity mapping

The time-capacity mapping function $f(t) : [T_f, T_a] \rightarrow [0, 1, \cdots, \sum_{h=1}^{H} \sum_{k=1}^{K} A_{hk}]$ is shown as:

$$f(t) = \begin{cases} \frac{(t-T_f)}{T_f} A_{h,m} + \sum_{k=1}^{K} A_{hk} \text{ if } h_t \geq 1 \text{ and } T_{h} \leq t \leq T_{h_t} \\ \sum_{h=1}^{H} \sum_{k=1}^{K} A_{hk} \text{ otherwise} \end{cases} \tag{1}$$

where $A_{hk}$ means the capacity of the $k$th frame within the $h$th infostation, while $T_f(T_a)$ represents the departure (arrival) time. $h_t = \arg \max_{h} T_{h} \leq t$. After time-capacity mapping process, the issue could convert from time based scheduling to capacity based scheduling over a continuous horizon [10], such that the job-machine scheduling theory can be applied to solve the resource allocation problem at a low computational complexity, to be discussed in the following section.

III. PROBLEM FORMULATION

With the goal of achieving better video quality, i.e., maximizing whole profits of accomplished data, the issue is to schedule data conveyed by own vessel and others. The offline problem is considered, on the precise of knowing all the global...
information. A network centralized controller is employed, with the ability to schedule resource allocation problem.

In this section, we give the formal formulation for Vessel Throughput Maximization Problem (VTMP) based on 0-1 Integer Programming problem. The objective is to maximize the total throughput of delivered data before their deadlines based on different rewards. The VTMP problem of how to allocate resource, i.e., infostations to different data, and which data should be relayed by other vessels, can be induced into a mathematic job-machine scheduling problem. In this interpretation, infostations play the role of machines, and partitioned video packets can be recast without loss of generality as jobs. The weight of the data packet is stated as the weight of the job.

Multi-vessel scenario takes advantage of different infrastructures to deliver. It corresponds to the multi-machine fashion, resource, i.e., infostations to different data, and which data should be relayed by other vessels, can be induced into a mathematic job-machine scheduling problem. In this interpretation, infostations play the role of machines, and partitioned video packets can be recast without loss of generality as jobs. The weight of the data packet is stated as the weight of the job.

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Algorithm 1: Time-capacity mapping based two phase algorithm

1: Phase one: Evaluation
2: \( S \leftarrow \) an empty stack
3: In machine 1
4: for each \((i, w_i, b_i', e_i')\) from \(\mathcal{L}\) do
5: \( v \leftarrow w_i - \text{TOTAL}(i, b_i') - \text{TOTAL}(b_i') \)
6: \( v > 0 \) then
7: push \(((i, v, b_i', e_i'), S)\)
8: end if
9: end for
10: In machine 2 do
11: for each \((i, w_i, b_i', e_i')\) from \(\mathcal{L}\) do
12: \( v \leftarrow w_i - \text{TOTAL}(i, b_i') \)
13: \( v > 0 \) then
14: push \(((i, v, b_i', e_i'), S)\)
15: end if
16: end for
17: Phase two: Selection
18: for each job instance \(i\) do
19: \( \text{occupied}[k] \leftarrow i \)
20: \( \text{done}[i] = \text{false} \)
21: end for
22: while \( S \) is not an empty do
23: In machine 2 do
24: \( (i, v, b_i', e_i') \leftarrow \text{pop}(S) \)
25: if \( \text{done}[i] = \text{false} \) and \( e_i' \leq \text{occupied}[2] \) then
26: \( \text{insert}((i, v, b_i', e_i')) \) to solution
27: \( \text{done}[i] \leftarrow \text{true}, \text{occupied}[2] \leftarrow b_i' \)
28: end if
29: end for
30: end for
31: end while

Proof: To prove the lemma, we need to consider the intersections of an arbitrary number of jobs. Because of space limitation, we only show the case of three jobs intersecting with each other, and \( w_3 > w_2 > w_1 \). In Figure 3, we consider each job has two job instances. The calculation process is described in Table I. We judge whether the job instances should be enter into stack in left column, alternatively exploiting the calculation value process in right column. * means the job instance is selected in phase two. Then Lemma 1 is proved, and it will be applied in the following section.

<table>
<thead>
<tr>
<th>TABLE I The two phase process of Two machine Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter into stack</td>
</tr>
<tr>
<td>((t_1, w_1, b_1', e_1'))</td>
</tr>
<tr>
<td>((i_2, w_2 - w_1, b_2', e_2'))</td>
</tr>
<tr>
<td>((i_3, w_3 - w_2, b_3', e_3'))</td>
</tr>
<tr>
<td>((i_2, w_1, b_1', e_1'))</td>
</tr>
<tr>
<td>((i_3, w_3, b_3', e_3'))</td>
</tr>
</tbody>
</table>

B. Interval graph theory based job relay selection algorithm

Based on the observations in Lemma 1, we propose more effective Interval Graph Theory based Job Relay Selection (IGTJSR) algorithm to choose jobs be delivered to vessel 2. Time-capacity mapping also plays a role in intermittent connectivity scenario firstly. Firstly, in step 3-7 of Algorithm 2, detect whether job instances with each other. It is deemed that if the ending time of interval with earliest beginning time is greater than the beginning time of interval with latest ending time, that the two intervals must be intersect with each other. If jobs intervals in vessel 1 could non-intersect with each other, it can directly schedule the jobs on vessel 1, while choose the intervals with minimum beginning times that guarantee non-overlapping. It is shown in step 12-13. However, the key point is the inevitable overlapping of several jobs that could not be totally scheduled for vessel 1. In step 8-10, we choose two sets of job intervals, one set transmit by vessel 1 and another set threw to rendezvous point, looking forward vessel 2 to carry. In each collection, the job intervals are non-overlapping.

Algorithm 2: Job relay selection algorithm

1: Definition: the same as Algorithm 1, and \( M = \emptyset \)
2: Detection two jobs whether intersect with each other:
3: for \( \forall J_i \in \psi \), \( \forall J_j \in \psi \), do
4: \( b_i = \{b_i', b_i', \ldots b_i\} \) express beginning time of job \( i \), \( b_i = \{b_i', b_i', \ldots b_i\} \) express beginning time of job \( j \) intervals
5: Job instance \( k^i_{\text{max}} = \min\{b_i'^j\}, k^j_{\text{max}} = \max\{e_i'^j\} \). \( \alpha = k^i_{\text{max}}, \beta = k^j_{\text{max}} \)
6: \( e_i'^j > b_j \) \( \beta \) ?
7: Then Job \( i \) and \( j \) mutually intersect. \( J_i \leftarrow (j, w_j, b_{\text{min}}, e_{\text{min}}), J_j \leftarrow (i, w_i, b_{\text{min}}, e_{\text{min}}) \)
8: draw relative interval graph \((G(V,E))\), then use Algorithm 3 to obtain two maximum weight interval sets \( Q_{\text{u}} \) and \( Q_{\text{v}} \) to be delivered in vessel 1 and vessel 2
9: Let \( Q = \{Q_u, Q_v\}, Q' = \{Q_s e_{\text{min}}\} \)
10: vessel 2 \( \leftarrow \) DTN throw box \( \leftarrow \) the set \( Q' \)
11: Else Job \( i \) and \( j \) not mutually intersect, Find \((j, w_j, b_{\text{u}}, e_{\text{u}}), (i, w_i, b_{\text{v}}, e_{\text{v}}) \leftrightarrow M \) with minimum \( b \)
12: \( M = M \cup (j, w_j, b_{\text{u}}, e_{\text{u}}) \cup (i, w_i, b_{\text{v}}, e_{\text{v}}) \)
13: end if

From the aspect of a series intersecting jobs, in order to obtain the maximum total weights, we utilize the concept of maximum weight 2-independent set (MW2IS) in interval graph [13]. Interval graph is the intersection graph of a multiset of intervals on the real line. It has one vertex for each interval in the set, and an edge between every pair of vertices corresponding to intervals that intersect [14]. According to the intersection between job intervals, a interval graph \((G(V,E))\) is obtained. Hence, intersecting jobs selection issue could be transformed to set selection in interval graph issue.

In [13], the MW2IS algorithm only gives a collection of the two sets with maximum weights, but not indicates which elements each set contains. Here, we extend the algorithm to get the exact elements of two independent sets \( Q_u \) and \( Q_v \), with maximum weights. The algorithm 3, an modified MW2IS on interval graph algorithm, further considers the two sets classification that the intervals in each set are non-overlapping.

For any 2-independent set \( Q \) of intervals \( I \), \( MW(Q, u, v) \) denotes an MW2IS. \( w(u, v) \) denotes the weight of MW \((Q(u, v); \psi(I)) \) stores \( w(u, v) \). Algorithm 3 is based on the equation

\[
w(u, v) = \psi(I) + \max[w(x, v) | b_v > e_x and v < x] \cup [w(x, v) | b_v > e_x and x < u].
\]
In step 1 of Algorithm 3, initial values are set; In step 2, it computes each value of \( w(u,v) \); An back-selection intervals procedure is described in step 4; In step 4, a simple judgement and comparison procedure is shown to demonstrate the list of \( Q_1 \) and \( Q_2 \) of MW2IS to be delivered by two vessels. We choose the set with the latest deadline to deliver to vessel 2.

Algorithm 3: Modified maximum weight 2-independent set on interval graph algorithm

1. **Input:** A set of weighted maximum intervals \( I = \{i_1, i_2, \ldots, i_q\} \) and the sorted endpoints list \( L = \{e_1, e_2, \ldots, e_{2n}\} \).
2. **Output:** The MW2IS \( \mathcal{Q}_{\max} \) of I, two sets \( \mathcal{Q}_1, \mathcal{Q}_2 \).
3. Step 1: \( \mathcal{Q}_{\max} \leftarrow \emptyset; \mathcal{Q}_1 \leftarrow \emptyset; \mathcal{Q}_2 \leftarrow \emptyset; \) Set the initial value of \( w(u,v) \leq u, v \leq n \), to be 0.
4. Step 2: Compute each value of \( w(u,v) \), \( 0 \leq u, v \leq n \), beginning from \( w(0,v) \), \( 0 \leq v \leq n \), then \( w(1,v) \), \( 0 \leq v \leq n \), \( \ldots \), \( w(n,v) \) \( 0 \leq v \leq n \), by algorithm MWIS. In INTERVALS and formula \( w(u,v) = w(i,j) + \max\{w(u,x)\} \).
5. Step 3: Let \( u(n-1,v_n) = \psi(I); \mathcal{Q}_{\max} \leftarrow \mathcal{Q}_{\max} \cup \{i_n, i_n\}; \)
6. \( \psi(I) = \psi(I) - (w(i_n,x_n) + w(i_n,y_n)); u(n-1) \leftarrow u; v_n \leftarrow v_1 \)
7. While \( \psi(I) \) \( > \) 0 do
8. Select intervals pair \( (i_2, i_2) \) with constraints \( \max\{e_2, e_2\} \) \( < \) \( \max\{b_3, b_3\}, \min\{e_2, e_2\} \) \( < \) \( \min\{b_3, b_3\}, w(a, a) = \psi(I) \).
9. \( \mathcal{Q}_{\max} \leftarrow \mathcal{Q}_{\max} \cup \{i_1, i_1\}; \psi(I) = \psi(I) - (w(i_1,x_1) + w(i_1,y_1)); u \leftarrow u_2; v_1 \leftarrow v_2; \mathcal{Q}_2 \leftarrow \mathcal{Q}_2 \cup \{i_1\}; \mathcal{Q}_1 \leftarrow \mathcal{Q}_1 \cup \{i_1\} \).
10. end while
11. Step 4: Let \( \mathcal{Q}_0 = \{\mathcal{Q}_2, \mathcal{Q}_1, \cdots, \mathcal{Q}_n\}; \mathcal{Q}_2 = \{\mathcal{Q}_2, \mathcal{Q}_1, \cdots, \mathcal{Q}_n\}; '\n12. \mathcal{Q}_0 = \emptyset; \mathcal{Q}_1 = \emptyset; \mathcal{Q}_2 = \emptyset; \mathcal{Q}_1 \leftarrow \mathcal{Q}_1 \cup \{i_1\}; \mathcal{Q}_2 \leftarrow \mathcal{Q}_2 \cup \{i_1\} \)
13. For \( i = 1 \) to \( n \) do
14. \( \mathcal{Q}_0 \leftarrow \mathcal{Q}_0 \cup \{i_0\}; \mathcal{Q}_2 \leftarrow \mathcal{Q}_2 \cup \{i_0\}; \mathcal{Q}_1 \leftarrow \mathcal{Q}_1 \cup \{i_0\} \)
15. end if
16. end for
17. end

C. Multi-vessel algorithm of TMP

Since vessel may encounter multiple other vessels, we further consider multi-vessel-relay transmission. It will be more practical and efficient. If vessel 1 is the main ship, confronting other \( m \) ships. It permits to easily extend this scenario into \( m \) Two-machine scheduling issue. We can apply the TMTP or IGTJRS algorithm \( m \) times to solve this issue.

D. Complexity analysis

**Theorem 1:** The IGTJRS Algorithm for VMTP has an approximation ratio of 2 and runs in \( O(n^2) \) time.

**Proof:** By listing all the intersecting job cases and comparing TMTP algorithm with IGTJRS algorithm, we find they have the same scheduling results, i.e., the same set of jobs are selected by the two algorithms. Then they all achieve approximation ratio 2 [12]. Due to the page limitation, we omit the details of the proof. Time complexity calculation process of IGTJRS algorithm is dissolved into three components:

**Insert families:** Sort list \( L \) of all the families, according to the earliest ending time of interval belonging to the family. We adopt method of binary search on \( L \) in \( O(\log n) \) time.

**Judge the intersect relationship:** Exploring linear search, we achieve a time \( O(n) \) for judgement operation.

**Job Relay Selection:** Maximum weight 2-independent set algorithm is adopted, which is solved in \( O(n^2) \).

Therefore, the IGTJRS algorithm runs in \( O(n^2) \) for the worst case. Contrastively, TMTP algorithm runs in \( O(2m \log \log(2t)) \), where \( t \) is the largest job deadline. In practical communication, one job cross multiple timeslots, then \( t \gg n \). Hence, IGTJRS algorithm we proposed has favorable time complexity performance than TMTP algorithm.

V. Performance Evaluation

In this section, we conduct simulation considering Singapore Harbor surrounding area. We obtain the trace of vessel Rainbow1, from specific BLM-Ships Navigation software [15]. The following simulations are based on the trace of vessel Rainbow1. TABLE II list the time-position information of vessel Rainbow1 and vessel Secret which acts the role of relay.

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**Fig. 4. The trace of a vessel Rainbow1**

<table>
<thead>
<tr>
<th>Time(1)</th>
<th>Rainbow1 Position(1)</th>
<th>Time(2)</th>
<th>Secret Position(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19:56</td>
<td>1°13’54”N103°53’32”E</td>
<td>19:37</td>
<td>1°05’45”N103°44’01”E</td>
</tr>
<tr>
<td>20:05</td>
<td>1°12’20”N103°52’16”E</td>
<td>19:52</td>
<td>1°08’23”N103°46’20”E</td>
</tr>
<tr>
<td>20:28</td>
<td>1°10’31”N103°47’57”E</td>
<td>19:58</td>
<td>1°08’51”N103°46’46”E</td>
</tr>
<tr>
<td>20:40</td>
<td>1°09’10”N103°45’34”E</td>
<td>20:01</td>
<td>1°09’31”N103°47’38”E</td>
</tr>
<tr>
<td>20:46</td>
<td>1°08’51”N103°44’27”E</td>
<td>20:19</td>
<td>1°10’26”N103°49’35”E</td>
</tr>
</tbody>
</table>

For the sake of simplicity simulation, we assume the vessels sail in straight line between the two position points. So we exploit the distance between any two sequential the two points, and do curve fitting on the route. Since the earth is round, the following formulas are engaged in calculation the great circle distance \( D \) in Navigation science. We set the two position of vessels \((\varphi_1, \theta_1)\), \((\varphi_2, \theta_2)\). Here, \( \varphi \) and \( \theta \) indicate latitude and longitude respectively. The calculation formulas are:

\[
\cos S = \sin \varphi_1 \cdot \sin \varphi_2 + \cos \varphi_1 \cdot \cos \varphi_2 \cdot \cos D \cdot \theta \tag{12}
\]

\[
D \cdot \theta = \theta_2 - \theta_1 \tag{13}
\]

Then applying \( S = \arccos(\cos S) \), we can get the great circle distance [16]. Afterwards, we can exploit \( D \) to do route fitting. In the simulation, we compare the proposed algorithms with three classic scheduling algorithms, i.e., Deadline (job with earliest deadline is scheduled firstly), First-input-first-output (FIFO) (job with earliest release time is scheduled firstly), and Weight (job with heaviest weight is scheduled firstly).
In Figure 5(a), we depict Normalized Throughput versus infostation coverage. Normalized Throughput determines the ratio of the accomplished jobs profits compared to total weight of jobs. Infostations coverage varies from 10% to 80% coverage of the whole route line, to study the effect of infostations density. It can be observed that the Normalized Throughput increase with the increase of infostations density. And IGTJRS algorithm has nearly the same performance with TMTP algorithm, and obviously better than other three schemes, which coincide with the performance analysis.

Figure 5(b) shows the normalized throughput versus size of job (in packet), with infostations coverage of 60%. Without exception, the IGTJRS algorithm has almost the same performance with TMTP algorithm, with the throughput decreasing following with the size of job increasing. Along with the jobs size increasing, the amount of scheduled job decreases.

In Figure 5(c), the granularity of release times varies from 20 to 41 packets in capacity horizon for vessel 1, with the parameter of infostation coverage set 80%. We show normalized throughput of the network with increase of granularity. It is indicated that when the granularity becomes bigger, which leads to an increase of the amount of non-overlapping jobs, the network throughput will increase. And the IGTJRS algorithm has almost the same performance with TMTP algorithm.

Through the simulations, it is verified the IGTJRS algorithm can effectively solve the VTMP problem with almost the same performance, but with a lower computation complexity.

VI. CONCLUSION

In this paper, we have studied the scheduling issues in maritime wideband system, which is set up by combining Wimax and store-carry-and-forward mechanism. With the objective of throughput maximization, we effectively convert the videos uploading issue into job-machine issue. Based on time-capacity-mapping, two offline scheduling algorithms, TMTP algorithm, and IGTJRS algorithm, concerning cooperatively deliver, are proposed. We also validate IGTJRS algorithm runs in $O(n^2)$ time. Simulation results demonstrate the performance of our approaches, based on practical data from dedicated navigation software BLM-Ship. For the future work, we will study efficient scheduling for normal or non-emergent services. Additionally energy-constrained infostation and DTN throw box will also be considered.

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