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Online and Offline Scheduling Schemes to Maximize the Weighted DeliveredVideo Packets Towards Maritime CPSs*

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In this paper, the online and offline scheduling schemes towards maritime Cyber Physical Systems (CPSs), to transmit video packets generating from the interior of vessel. During the sailing from the origin port to destination port, the video packets could be delivered via the infostations shoreside. The video packets have their respective release times, deadlines, weights and processing time. The video packets only could be successfully transmitted before their deadlines. A mathematic job-machine problem is mapped. Facing distinguished challenges with unique characteristics imposed in maritime scenario, we focus on the heterogeneous networking and resource optimal scheduling technology to provide valuable insights on the data transmission scheduling via this system. We aim to maximize the weight of delivered packets totally, three algorithms, an offline algorithm, an online ADMISSION Algorithm with no bounded processing times, as well as Exponential-Capacity Algorithm with bounded processing times are developed. Moreover, we induct the approximation ratio and competitive ratios of the proposed algorithms respectively. Finally, we verify the performance of the potential solutions for resource scheduling through comparison simulation

Keywords: Maritime Cyber Physical Systems, time-capacity mapping, job-machine scheduling, approximation algorithm

1. INTRODUCTION

There has been increasing interest in the domain of emerging maritime cyber physical systems(CPSs), which target the incorporation of wireless communications and informatics technologies into the navigation transportation system to revolutionize the navigation pattern to be safer and more efficient. It is envisioned that building up a "maritime highway" system will greatly contribute to the maritime distress, urgency, safety, and general communications, and thereby facilitate a myriad of attractive applications. For example, data with large volume, such as monitoring videos for important spaces of vessel, could be delivered availably through this maritime CPSs with lower cost contrasting with expensive but low-band satellite communications.

The last decade years, a bunch of advanced wireless technologies have been utilized in maritime society to build up this smart system. The work on investigating the new maritime network can be summarized as follows. Zhou *et al.* [1] resorted

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cognitive radio into maritime mesh/ad hoc networks. Worldwide Interoperability for Microwave Access (WiMAX) is utilized to develop wireless-broadband-access for Seaport (WISEPORT) project in Singapore [2]. A novel alternative or complementary solution is store-carry-and-forward data packet delivery in delay tolerant networks (DTNs) [3] is developed to confront the non-contemporaneous end-to-end path due to the characteristics of channel at sea. Therefore, Lin *et al.* developed the WiMAX-based mesh technology with DTN features firstly in [4]. Recent years witnessed the develop of Cyber Physical Systems, which are the emerging research direction for industrial information systems. CPSs incorporate communication and computing technology, could collect data of vessels, compute and deliver it to the authorized session on land. And via analyzing the big data, personnel on land could intelligently control the vessel navigation, cargo loading and discharging, etc. Hence, CPSs extensively integrate computing, communication and control technologies [5], which potentially provide much more smart, efficient and robust communication. In our work, data delivery can be achieved via infostations shore-side, and a WiMAX/store-carry-and-forward interworking maritime CPSs are devised to realize intelligent transportation systems at sea.

In this paper, we focus on the the video data delivery scheduling issue. Videos are divided into packets, with respective release time, deadline and weight. The data packets only be successfully delivered before the deadline. Throughput here is defined as the sum of weights of delivered packets. In the literature, although not in maritime scenarios, vehicle-assisted data delivery has been extensively studied. In [6], Cheng *et al.* propose a vehicle-assisted data delivery method for smart grid applications, based on optimal stoping theory. In [7], 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. And the related literatures on land-based network contribute a solid foundation for our work [8–11]. However, the resource allocation and scheduling issue in online and offline scheduling schemes to maximize the weighted delivered video packets towards maritime CPSs is still an open issue.

In our work, the resource allocation and scheduling problem is formulated by jointly consider the intermittent network connectivity and cooperative transmission scheme. Our target is to guarantee the videos quality as much as possible, i.e., throughput maximization problem. The scheduling problem is converted into mathematic job-machine issue. Moreover, time-capacity mapping is utilized to change the initial intermittent connectivity in maritime CPSs into a single machine scheduling issue. Online and offline algorithms are all proposed. Specially, an ADMISSION algorithm is proposed to maximize the weights of uploaded video packets. Then a proof is given to show the algorithm could achieve a approximation factor $3 C 2 \sqrt{2}$. Additionally, the Exponential Capacity Algorithm with bounded processing times is applied with competitive analysis. Finally, the performance of the proposed algorithm is evaluated, and compared with other classic scheduling algorithms.

Our main results and contributions are summarized as follows:

- Facing distinguished challenges with unique characteristics imposed in maritime scenario, we focus on the heterogeneous networking and resource optimal scheduling technology to provide valuable insights on the data transmission scheduling via this system.
- Online and offline algorithms are all proposed. Specially, an ADMISSION algorithm is proposed to maximize the weights of uploaded video packets. Then a proof is given to show the algorithm could achieve a approximation factor $3 C 2 \sqrt{2}$.
- The Exponential Capacity Algorithm with bounded processing times is applied with competitive analysis.

The remainder of this paper is organized as follows. System model is given in Section 3 and problem formulation is presented in Section 4. Two adopted algorithms are proposed, as well as time complexity is validated in Section 5. In Section 6, simulation results are given employed to demonstrate the performance of our approaches. We conclude this paper in Section 7.

2. RELATED WORK

The related work towards new maritime wideband communication network commenced to be attracted attention recently. Although the research of resource allocation issue on data transmission scheduling at sea is still in the early stage, a bunch of of counterparts on land-based network have laid down a solid foundation for our work [12–21]. A theoretical model to compute the throughput of cooperative content distribution in vehicular ad hoc networks is conceived in [22]. For wireless sensor networks, the authors provided distributed estimation policy based on topology optimization [23]. And advanced utility-Based asynchronous flow control algorithm for wireless sensor networks is exploited in [24]. In [25], a utility-aware data transmission scheme for delay tolerant networks is demonstrated, considering both internal property and external contact of nodes. In [26], Xu *et al.* developed an analytical model through ordinary differential equations to mimic epidemic information dissemination in MSNs, based on pre-immunity and immunity policies. In [27], Liang *et al.* proposed a semi-Markov decision process based service model to schedule the data delivery for mobile cloud networks. In [6], Cheng *et al.* developed a vehicle-assisted data delivery scheme for smart grid context, utilizing optimal stopping theory.

For maritime wideband communication networks, the maritime video transmission scheduling is challenging based on identifying unique characteristics of this dedicated system which could be either one-dimensional (without relay) or two-dimensional (with relay). With respect to maritime data delivery, the ship mobility model considering probability density function of ship velocity is modeled in [28]. Underwater wireless sensor networks are utilized to realize peer-to-peer communication under sea, by exploiting mobility model analysis [29]. The performance of file delivery for maritime DTN networks is investigated in [30]. Meanwhile, in the literature, energy-aware resource management has been extensively studied [31]. In [32], a mathematical framework with regards to video data delivery is developed, based on the observation of the impact of network dynamics. In our previous work [33, 34], the data scheduling issue has been transformed to job-machine scheduling problem, and efficient algorithms are proposed based on time-capacity mapping method [35].

However, the existing literatures have not considered listing the offline and online algorithms towards maritime scenario. Facing distinguished challenges with unique characteristics imposed in maritime scenario, we focus on the heterogeneous networking and resource optimal scheduling offline and online algorithms to provide valuable insights on the data transmission scheduling via this system.

3. SYSTEM MODEL

In this paper, we only consider the single-machine scenario. A vessel sails on the way from the origin port to destination port within time duration $[T_I, T_O]$. It generates surveillance videos periodically during the sailing. Videos are splited into packets and try the best to be delivered to content server of the competent authority via infostations deployed along route line, where LTE network could provide seamless coverages within the communication range of infostations. While the infostations play the role as base station to connect to the maritime authorities on land via wire network. The framework is belonging to heterogeneous network structure. We both consider large vessels (a.k.a., passenger vessels and cargo vessels) which are sailing on predetermined and fixed route lines, and also the small vessels (a.k.a., fishing vessels) which are sailing on unpredetermined route lines. Thus both offline scheduling and online scheduling scenarios are discussed in this paper. The network topology is illustrated in Fig. 1.

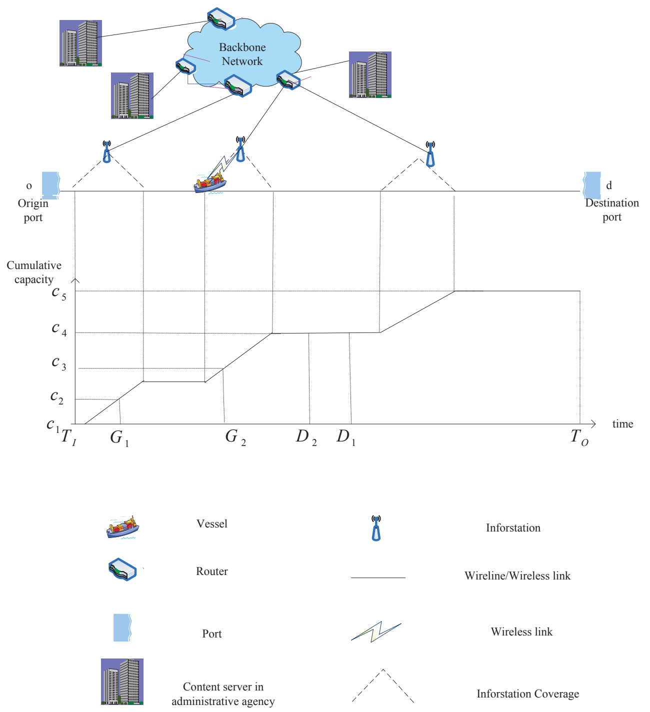

Figure 1 An illustration of the network topology

3.1 Video packet

We consider the videos chunks are splited into packets. And each packet has its own release time, deadline, and weight. The packets only could be successfully delivered before the respective deadlines. We denote r_j, d_j, b_j, e_j, w_j and p_j as the release time, deadline, beginning time, ending time, weight and processing time for job j respectively. Denote $i, j \in \{1, \cdots, n\}$ as jobs, n the number of job. The scenario of multiple jobs being scheduled simultaneously on single machine is avoided. Definitely, the time indices should be integers complying with $r_j \le b_j$ and $b_j + p_j \le d_j$.

3.2 Time-Capacity Mapping

Due to the intermittent network connectivity scenario, one vessel will encounter several infostations en route. The time indices are mapped into virtually cumulative capacity values which is shown in Fig. 1. We define the time-capacity mapping function as $f(t) : [T_I, T_o] \rightarrow [0, 1, \cdots \sum_{h=1}^{H} \sum_{k=1}^{K} A_{h,k}]$ [36] which is shown as:

$$f(t) = \begin{cases} \sum_{m=1}^{(t-T^i_{h_t})/T_F} A_{h_t,m} + \sum_{l=1}^{h_t-1} \sum_{m=1}^{K_l} A_{l,m} \\ \qquad if\ h_t \ge 1\ and\ T^i_{h_t} \le t \le T^o_{h_t} \\ \sum_{l=1}^{h_t} \sum_{m=1}^{K_l} A_{l,m} \qquad otherwise \end{cases} \tag{1}$$

Here, $A_{h,k}$ is denoted as the capacity of the kth frame within the hth infostation, $T_I(T_O)$ is denoted as the beginning (ending) time of the vessel. $h_t = \arg\max_h \{T^i_h \le t\}$. Via this time-capacity mapping conversion, the issue could change from time based scheduling to capacity based scheduling over a continuous horizon. Then the job-machine scheduling theory will be applied to solve the resource allocation problem with low computational complexity. Fig. 1 indicates the network topology based on the time-capacity mapping.

4. PROBLEM FORMULATION

This paper targets to maximize the total weight of transmitted packets successfully via the infostations along the route line during the sailing process. This problem is nominated as data transmission throughput maximization issue, which is a 0-1 integer programming problem obviously. A mathematic job-machine scheduling method is utilized to schedule the different packets to be transmitted during the exact frames of infostations, for sake of solving this issue simply. In this scenario, we define the vessels and packets playing the role of machines and jobs, respectively. Jobs $\mathcal{J} = \{J_1, \cdots, J_n\}$ that can be assigned on machines $\mathcal{M} = \{M_1, \cdots, M_m\}$. For an random job, which corresponding to a family. A family is a set of job cases implemented within release time and deadline [37]. Quadruplicate variables (family, weight, beginning time, ending time) are utilized to express job instance S_i, i.e., (i, w_i, b_i, e_i). We only consider the single-vessel delivery scenario, which is shifted into a single-machine scheduling problem applying time-capacity mapping method. We denote binary variable x_{jb_j} whether job j is assigned at interval $\mathcal{T} b_j, b_j \, C \, p_j \mathcal{U}$ as follows:

$$x_{jb_j} \, \mathcal{D} \begin{cases} 1, & \text{if job } j \text{ is scheduled at interval } \mathcal{T} b_j, b_j \, C \, p_j \mathcal{U} \\ 0, & \text{otherwise.} \end{cases}$$

Then, the single-vessel data transmission scheduling issue is formulated as follows:

$$\max \quad \sum_{j\mathcal{D}1}^{n} \sum_{b_j \mathcal{D} r_j}^{d_j - p_j} w_j \cdot x_{jb_j} \tag{2}$$

$$s.t. \quad \sum_{j\mathcal{D}1}^{n} \sum_{b_j \mathcal{D} u - p_j C 1}^{u} x_{jb_j} \leq 1, \forall u \tag{3}$$

$$\sum_{b_j \mathcal{D} r_j}^{d_j - p_j} x_{jb_j} \leq 1, \forall j \tag{4}$$

$$x_{jb_j} \in \{0, 1\} \tag{5}$$

where n denotes the total number of jobs executed on single-machine. Constraint (3) is designed to avoid multiple jobs to interfere with each other on a single machine. Constraint (4) is meant that each job could only be assigned at most once.

5. SOLUTIONS

In this section, a combinatorial algorithm is proposed to solve this weighted job maximization formulation. A single-machine model will be presented in the following paper. In order to provide the novel sight of resource allocation with low computational complexity, three algorithms are presented to address the data transmission scheduling issue, i.e., a offline TMTP algorithm for single machine, an ADMISSION Algorithm for online scheduling scenario with bounded processing times, as well as an Exponential Capacity Algorithm for online scheduling scenario with bounded processing times.

5.1 Offline TMTP Algorithm

In this part, we provide an offline Time-Capacity Mapping Based Two Phase Algorithm for Single Machine, which comes out with a stack based scheme with two phases (a.k.a., evaluation phase and selection phase). In the first phase, the job cases are pushed in sequence of non-decreasing ending time into a stack, and only those job cases with large enough weight compa [37]red to overlapping job cases already in the stack could can get into the stack. In the second phase, the job cases are popped and arranged into a non-competition schedule in the inverted order. According to this law, the highest weight job instances with the earliest ending times are adopted. Thus we could get the maximized total weight of scheduled packets.

Some necessary definitions are provided as following shown. $\mathcal{S}$ is an originally empty stack storing intervals, which is utilized in the TMTP scheme as illustrated above; $\mathcal{L}$ is a array that involving an job case $\triangleright i, w_i, b_i, e_i \triangleleft$, for every integer $i \in \mathcal{T} 1, n \mathcal{U}$; $TOTAL \triangleright i, b_i' \triangleleft$ is the total sum of weights of those job cases other than i on the stack $\mathcal{S}$ that have $ending > b_i'$, where *ending* depicted the ending time of job case; $total \triangleright i, b_i' \triangleleft$ is the total weight of job cases that $ending < b_i'$ of family i. The latest deadline on machine 1 is t and t' in time and capacity horizon, respectively. **Algorithm 1** shows a pseudo-polynomial algorithm of TMTP solution.

Algorithm 1 : *Time-Capacity Mapping Based Two Phase Algorithm for Single Machine*

```
Phase one: Evaluation
S ← an empty stack
for each ▹i, w_i, b'_i, e'_i◃ from L do
    v ← w_i − total▹i, b'_i◃
    −TOTAL▹i, b'_i◃
    if v > 0 then
        push ▹▹i, v, b'_i, e'_i◃, S◃
    end if
end for
Phase two: Selection
for each job instance i do
    occupied T 1 U ← t'
    done T i U D false
end for
while S is not an empty do
    ▹i, v, b'_i, e'_i◃ ← pop▹S◃
    if done T i U D false and e'_i ≤ occupied T 1 U then
        insert ▹i, w, b'_i, e'_i◃ to
        solution
        done T i U ← true,
        occupied T 1 U ← b'_i
    end if
end while
```

5.2 Online Algorithm

There are a plenty of methods to conduct the online algorithm actually. Generally, the packet job cases (or intervals) in the order could be pointed out, and then the packets could be accepted or refused according to our rules defined before. It is noted that the decision of rejection is an irreversible determination, however, the acceptance process is also a temporary commitment. From the later point of time if the job is not the priority of others, the accepted job case could be still rejected finally. Then the approximation factor should be inducted instead of a constant competitive factor in this online scheduling scenario. In this specific online scheduling scenario, accordingly, the order of release time of each job instance must be considered, under the online labeled nature. All the feasible packets intervals on the time axis could be checked out, in the order of ending times during the period of sailing from the original port to the destination port along the shore-side. We define $\mathcal{S}$ as the currently accepted job cases, while $\mathcal{I}$ as a new interval belongs to a packet that already has an instance in $\mathcal{S}$. Thus it is immediately rejected according to the sorted order. In another case of not overlapping with any other interval in $\mathcal{S}$, then it could be immediately accepted. Interval $\mathcal{I}$ is inserted to $\mathcal{S}$ in the accepting situation. And its weight is larger than $\beta(\beta > 1$ times the total of the weights of all overlapping intervals if it has one or more overlaps in $\mathcal{S}$, which is to be determined in following context. Hence, we define that $\mathcal{I}$ "preempts¡± these overlapping intervals. Interval $\mathcal{I}$ is added to $\mathcal{S}$ in the accepting case and given up all the overlapping intervals in $\mathcal{S}$. The ADMISSION Algorithm with no bounded processing times is described in detail as follows.

5.2.1 ADMISSION Algorithm With No Bounded Processing Times

Firstly, the parameters here are described in detail as follows.

1. The set of accepted packet instances is $\mathcal{S}$. therefore, $\mathcal{S}\ \mathcal{D}\ \emptyset$.

2. The $\mathcal{I}$ is presented the unprocessed packet instances. Initially, $\mathcal{I}$ is the set of all feasible packet instances.

3. While $\mathcal{I}$ is not empty, repeat the following procedure: Let $I \in J_i$ be the packet instance, and finishes first among all packet instances in $\mathcal{I}$ and the weight of packet is ω_i. Let W be the total of the weights of all instances $\{I_1, \cdots, I_h\}$ in $\mathcal{S}$ which overlap I.

Algorithm 2 : *Algorithm ADMISSION*

```
I VD I\{I}
if J_i ∩ S ≠ ∅ then
    reject I
end if
if W D 0 then
    accept I; S VD S ∪ {I}
else
    if ω_i/W > β then
        accept I and preempt {I_1, ··· , I_h};
        S VD S ∪ {I}\{I_1, ··· , I_h}
    end if
else
    reject I
end if
```

It is reveals that the interval I and another interval J have closer association with each other. When $h \geq 2$, it is not hard to see that $I\ \mathcal{D}\ I_0, I_1, ..., I_h\ \mathcal{D}\ J$ sequence of intervals in the sequence that I_i preempted I_{iC1} to $0 \leq i \leq h-2$, and I_{h-1} rejected or preempted the interval I_h. To make sense of the online algorithm, we must prove the connection of the sum weights of these intervals and accept interval I. It is at most $f(\beta)$ times. In the following, we give the induction of the best β, $3\,C\,2\sqrt{2} \approx 5.828$ bounded of the online algorithm.

Theorem 1 *The approximation factor of Algorithm ADMISSION is* $3\,C\,2\sqrt{2}$.

Proof 1 *Define $\mathcal{C}$ as the optimal intervals which is chosen by the algorithm. And for each interval $I \in \mathcal{A}$, we could define all the intervals as $R(I)$ and occupied by I in $\mathcal{C}$. On the basis of the above laws, we define $I \in \mathcal{C}$ and all the intervals in $\mathcal{C}$ no matter rejected or preempted [38]. Thus, the following situations is discussed further:*

1. *Assume that $J \in \mathcal{C}$ but is rejected by rule of (If $J_i \cap \mathcal{S} \neq \emptyset$ then reject I) . J is rejected which caused by the I, and $I \in \mathcal{A}$. Both I and J are part of the same packet, then add J to $R(I)$ accordingly.*

2. *Assume that I conforms to the rule of (if $W\ \mathcal{D}\ 0$ accept I). In the case of $I \in \mathcal{C}$, set $R(I)$ which is occupied by I.*

3. *Assume that I conforms to the rule of (if $\frac{\omega_i}{W} > \beta$ then accept I and preempt $\{I_1, \cdots, I_h\}$). All intervals are denoted as $R(I)$ and preempted by I in $\mathcal{C}$. Set all intervals as $R(I')$ and preempted by I. Then in the case of I in $\mathcal{C}$, $R(I)$ contains I.*

4. *Assume that $J \in \mathcal{C}$ but is rejected by rule of ($\frac{\omega_i}{W} < \beta$ reject I). Let $I_1, ..., I_h$ overlap with J in$\mathcal{S}$. The weight of J is ω and the ω_j is the weight of I_j ($1 \leq j \leq h$). Then there are $J_1, ..., J_h$ for $1 \leq j \leq h$, and the weight of J_j is $\frac{\omega_j \cdot \omega}{\sum_{i\mathcal{D}1}^{h} \omega_i}$. And set $R\left(I_j\right) \mathcal{VD}\ R\left(I_j\right) \cup \left\{J_j\right\}$. Note that the weight of J_j is no more than $\beta \cdot I_j$.*

Now we set an interval $R(I)$, and let ω_i and W are the weight of I and the total of weights of all job cases in $R(I)$. Set $\rho\ \mathcal{D}\ \frac{W}{\omega}$, and we are targeting to get the bound ρ of the algorithm in the following context. From $\mathcal{C}$, the interval I may reject no more than one. Then define job cases $I_r \in \mathcal{C} \cap R(I)$ was rejected by I with weight ω_r. Otherwise $\omega_r\ \mathcal{D}\ 0$. In that case, $\omega_r \leq \beta\omega$, otherwise I_r may be accepted. Let I and I' belong to the same packet, if the case exists. According to that ω is the weight of I', let $W' \geq W - \omega - \omega_r$ be the total weights of the other job cases in $R(I)$. Define $\alpha\ \mathcal{D}\ \frac{W'}{\omega}$, then $\rho \leq \alpha C \beta C\, 1$. The sum weights of the packets no more than ω/β, thus we could obtain $\frac{\omega}{\beta} \cdot \rho \geq \alpha \cdot \omega$, which indicates that $\frac{\alpha C \beta C 1}{\beta} \geq \alpha$. Finally $\alpha \leq \frac{\beta C 1}{\beta - 1}\ \mathcal{D}\ 1\ C\ \frac{2}{\beta-1}$, then $\rho \leq 2\ C\ \beta\ C\ \frac{2}{\beta-1}$. Thus, we get $\beta\ \mathcal{D}\ 1\ C\ \sqrt{2}$ and implies $\rho \leq 3\,C\,2\sqrt{2}$. Finally, the value of the optimal solution could be obtained, at most ρ times. Therefore, the approximation factor is $3\,C\,2\sqrt{2}$.

5.2.2 Exponential Capacity Algorithm With Bounded Processing Times

Next, we take into consideration of the job cases with arbitrary weights with bounded processing times scenario. The online algorithm named Exponential Capacity Algorithm [39] could be utilized to schedule the job j which aims to maximizes the total weights of $\omega_j \cdot \alpha^{q_j - 1}$. All job cases processing time is denoted as y.

Theorem 2 *The online Exponential Capacity Algorithm with* ▹3 C *o*▹1◃◃ · *y*/*lny-competitive*

Proof 2 *We apply General charging scheme here to faciliate our proof. Now we define the value of $\alpha(y)$, $\alpha(y)\ \mathcal{D}\ 1 - c^2 \cdot \ln y/y$, and definey as the time of processing time for all job cases. And the processing times are all integers. $c\ \mathcal{D}\ 1 - \varepsilon$ for $\varepsilon > 0$. The algorithm is called α-sort monotone. To prove that $p \cdot \alpha^{p-1} \geq 1$ and all $p \leq y$, we get $\omega_j/p_j \leq \omega_j \cdot \alpha^{p-1}$ for any job case j at t. When job case h is delivered by the Exponential Capacity algorithm at t, the first job case i_0 delivered from $t\ C\ 1$ is π monotonicity.*

$$\omega_j \cdot \alpha^{p_j - 1} \leq \pi \cdot \left(j, q_j(t)\right) \leq \pi\left(h, q_h(t)\right) \leq \pi\left(i_0, 1\right)\ \mathcal{D}\ \omega_{i_0} \tag{6}$$

According to the characteristics of function $f(x)\ \mathcal{D}\ x \cdot \alpha^{x-1}$, it could be enhanced and extended to any lager y and $x \in \{1, 2, ..., y\}$ as follows,

$$f(x) \geq 1, 1 \leq x \leq \frac{y}{c^2 \cdot \ln y} \tag{7}$$

$$f(x) \geq \ln y, \frac{y}{c^2 \cdot \ln y} \leq x \leq y \tag{8}$$

In the case of $f(x) \geq 1$ *for* $x \in \{1, 2, ..., y\}$*, according to equation (9). The type when job instance* j*, which is not pending any more. And let* z *be the critical time and charge* ω_j/p_j *to* i_0 *from the time* $z\, C\, 1$*. According to above, charge to* i_0*. And for each* (j, a)*,* ω_j/p_j*, implies* $\omega_j \alpha^{p_j - 1} \leq \omega_{i_0}$*, it is learned that* $\omega_j/p_j \leq \omega_{i_0}/\left(p_j \cdot \alpha^{p_j - 1}\right) \mathcal{D}\ \omega_{i_0}/f\left(p_j\right)$*. Then for the processing time* $p \leq y$ *the number of* (j, a)*, it is known that* $p_j \leq p$ *is at most* $p - 1$*. And applying that to* $p\ \mathcal{D}\ y/\left(c^2 \cdot \ln y\right)$ *and* $p\ \mathcal{D}\ y$*, applying above equation we could obtain that*

$$\sum_{(j,a)} 1/f\left(p_j\right) \leq \frac{y}{c^2 \cdot \ln y}\ C\ \frac{y}{\ln y}\ \mathcal{D}\ \frac{y}{\ln y}\left(1\ C\ \frac{1}{c^2}\right) \tag{9}$$

Each job i_0 *executed by this online algorithm which is* j *by time* t *charge of no more than* ω_{i_0}*. But for* $\rho\ \mathcal{D}\ \alpha$*, it can accept no more than* $\omega_{i_0} \cdot y/c^2 \cdot \ln y$*, where* i_0 *is the next job executed from time* $t C 1$*. For a large enough* y*, at most* $\omega_{i_0} \triangleright 1 C 1/c^2 \triangleleft y/\ln y$ *in total. Then we get* $\omega_{i_0} \triangleright 1 C 2/c^2 \triangleleft y/\ln y\ \mathcal{D}\ \omega_{i_0} \triangleright 3 C o \triangleright 1 \triangleleft\triangleleft \cdot y/lny$*. For the constant* $c < 1$ *and a large enough parameter* x*,*

$$\left(1 - \frac{c}{x}\right)^x \geq \frac{1}{e} \tag{10}$$

when x *is large enough, it obtains that* $e^{-c} > e^{-1}$*. When* y *is large enough, it obtains* $f(1)\ \mathcal{D}\ 1$*,*

$$f(y)\ \mathcal{D}\ y \cdot \left(1 - \frac{c^2 \cdot \ln y}{y}\right) \mathcal{D}\ y\left(1 - \frac{c^2 \ln y}{y}\right)^{\frac{y}{c \cdot \ln y} \cdot (y-1) \cdot \frac{c \cdot \ln y}{y}} \tag{11}$$

Thus the following formula is no more than the above formula

$$y \cdot \left(\frac{1}{e}\right)^{(y-1) \cdot \frac{c \cdot \ln y}{y}} \mathcal{D}\ y \cdot y^{(1-y) \cdot \frac{c}{y}}\ \mathcal{D}\ y^{\frac{1 - \varepsilon C y \cdot \varepsilon}{y}} \geq \ln y \tag{12}$$

Now we could conclude that, for $x \leq y/\left(c^2 \cdot \ln y\right)$*,* $(f(x))^y_{x \mathcal{D} 1}$ *is non-decreasing, and for* $x > y/\left(c^2 \cdot \ln y\right)$*,* $(f(x))^y_{x \mathcal{D} 1}$ *is decreasing. Therefore, the ratio could be obtained* $f(x)/f(x-1)\ \mathcal{D}\ \alpha \cdot x/(x-1)$*, which is at least 1 only if* $x \geq y/\left(c^2 \cdot \ln y\right)$*. Hence, the algorithm with* $\triangleright 3\ C\ o \triangleright 1 \triangleleft\triangleleft \cdot y/lny$*-competitive.*

6. SIMULATION RESULTS

In this session, the proposed algorithms are verified using simulations. In the simulation, we consider the trace of vessel YangTZE extracted from BLM-Shipping navigation software [40]. The time-position information could be easily obtained from this software, which is shown partly in Fig. 2. Simulation parameters are listed in Table 1.

In the simulation part, we compare the proposed schemes with some other classic scheduling algorithms, i.e., Deadline (the job with the earliest deadline is scheduled first), First-input-first-output (FIFO) (the job with the earliest release time is scheduled first), Weight (the job with the largest weight is scheduled first). When online algorithms is simulated, preemption mechanism is considered in the current job queue. Normalized throughput is used to evaluate the performance uniformly.

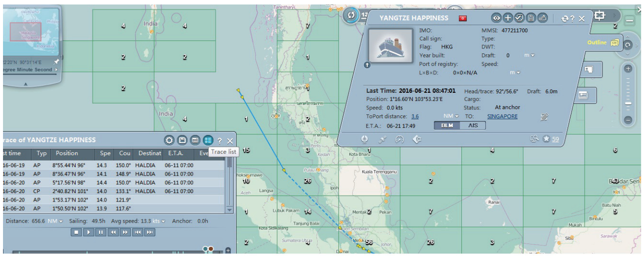

Figure 2 The traces of vessel YangTZE.

Table 1 Simulation parameters.

Name	Value
Packet size S_p	100 bytes
System bandwidth	10 MHz
Noise spectral density	174 dBm/Hz
Transmit antenna height h_{tx}	10 m
Video bitrate	0.47 Mbps
Frame duration T_F	5 ms
UE transmit power P_{tx}	23 dBm
Receive antenna height h_{rv}	50 m

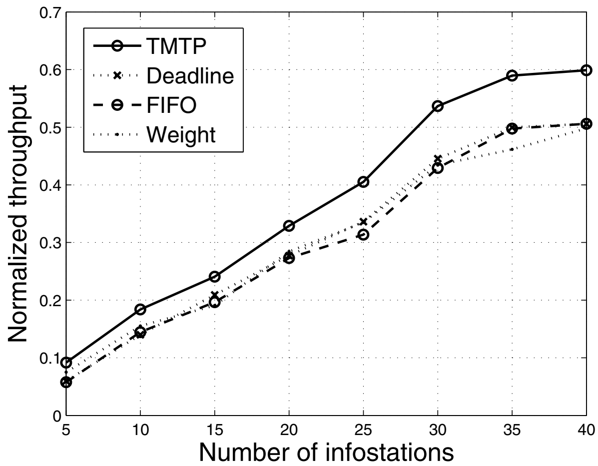

Figure 3 Number of infostations versus Normalized throughput for Offline algorithm .

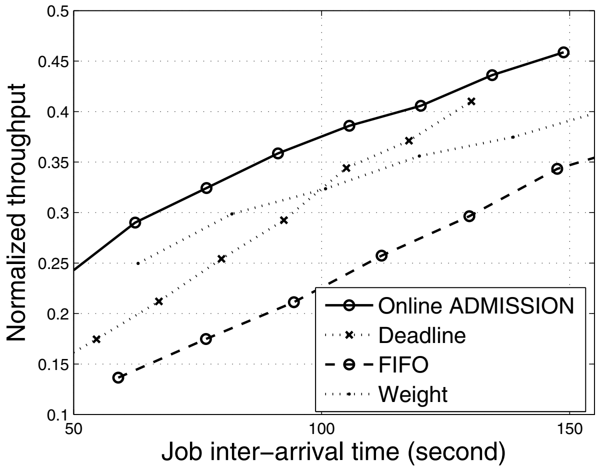

Figure 4 Job inter-arrival time versus the normalized throughput for Online algorithm.

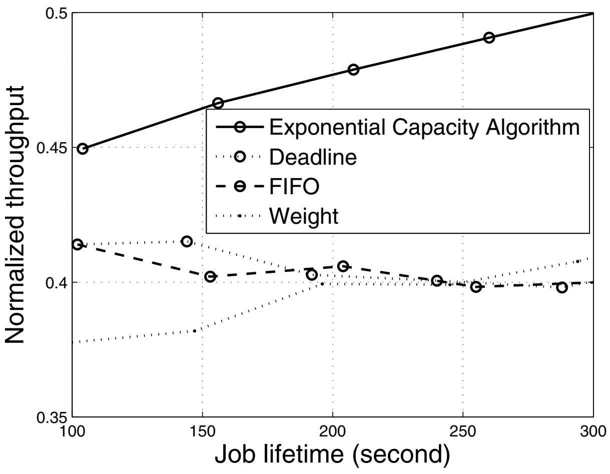

Figure 5 Job lifetime versus the normalized throughput for Online algorithm.

The single-vessel scenario is simulated. Fig. 3 indicates the normalized throughput versus the number of infostations. The number of infostations varies from 5 to 40 along the shore-side route line. We find that the normalized throughput increases along with the increasing number of the infostations. It is obvious that the network performance of TMTP algorighm is better. In Fig. 4, the normalized throughput versus the job inter-arrival time is executed. With a larger inter-arrival time, the number of overlapping packets is decreased, and sequently the overall throughput could be increased. Admission Algorithm is obviously better than the other algorithms. Fig. 5 shows the comparison related to Job lifetime versus the normalized throughput. And Exponential Capacity Algorithm is obviously better than the other algorithms.

7. CONCLUSION

In this paper, we take into consideration of data transmission scheduling issues in maritime CPSs. A shore-side network framework is established, while we solve the problem into job-machine issue. Utilizing the time-capacity-mapping, an offline algorithm, ADMISSION algorithm as well as Exponential-Capacity Algorithm are proposed to maximize the total weight of dat packets transmission. Simulation verified our schemes, based on the data extracted from dedicated BLM-Shipping navigation software. For the future work, more intelligent and greater performance online and offline scheduling should be designed further, considering fairness issue.

REFERENCES

1. M. T. Zhou and H. Harada, "Cognitive maritime wireless mesh/ad hoc networks," *Journal of Network and Computer Applications*, vol. 35, no. 2, pp. 518–526, Mar. 2012.
2. Cellular-news, "Maritime wimax network launched in Singapore," http://www.cellular-news.com/story/29749.php, Mar. 2008.
3. K. Fall, "A delay-tolerant network architecture for challenged internets," in *Proc. ACM Applications, technologies, architectures, and protocols for computer communications*, Aug. 2003.
4. H.-M. Lin, Y. Ge, A.-C. Pang, and J. S. Pathmasuntharam, "Performance study on delay tolerant networks in maritime communication environments," in *Proc. IEEE OCEANS*, 2010, pp. 1–6.
5. K.-D. Kim and P. R. Kumar, "Cyber–physical systems: A perspective at the centennial," *Proceedings of the IEEE*, vol. 100, no. Special Centennial Issue, pp. 1287–1308, 2012.
6. N. Cheng, N. Lu, N. Zhang, J. Mark, and X. Shen, "Vehicle-assisted data delivery for smart grid: An optimal stopping approach," in *Proc. IEEE ICC*, Jun. 2013.
7. H. Liang and W. Zhuang, "Efficient on-demand data service delivery to high-speed trains in cellular/infostation integrated networks," *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 4, pp. 780–791, May 2012.
8. S. Liu, H. Zhu, R. Du, C. Chen, and X. Guan, "Location privacy preserving dynamic spectrum auction in cognitive radio network," in *Proc. IEEE ICDCS*, 2013, pp. 256–265.
9. R. Deng, Y. Zhang, S. He, J. Chen, and X. Shen, "Maximizing network utility of rechargeable sensor networks with spatiotemporally-coupled constraints," *IEEE Journal on Selected Areas in Communications*, DOI: 10.1109/JSAC.2016.2520181, to appear.
10. J. Ren, Y. Zhang, N. Zhang, D. Zhang, and X. Shen, "Dynamic channel access to improve energy efficiency in cognitive radio sensor networks," *IEEE Transactions on Wireless Communications*, DOI:10.1109/TWC.2016.2517618.
11. Z. Gao, H. Zhu, Y. Liu, M. Li, and Z. Cao, "Location privacy in database-driven cognitive radio networks: Attacks and countermeasures," in *Proc. IEEE INFOCOM*, 2013, pp. 2751–2759.
12. M. Dong, T. Kimata, K. Sugiura, and K. Zettsu, "Quality-of-experience (QoE) in emerging mobile social networks," *IEICE Transactions*, vol. 97, no. 10, pp. 2606–2612, 2014.
13. H. Zhang, P. Cheng, L. Shi, and J. Chen, "Optimal denial-of-service attack scheduling with energy constraint," *IEEE Transactions on Automatic Control*, DOI:10.1109/TAC.2015.2409905.
14. K. Ota, M. Dong, H. Zhu, S. Chang, and X. Shen, "Traffic information prediction in urban vehicular networks: A correlation based approach," in *Proc. IEEE WCNC*, 2011, pp. 1021–1025.
15. D. Fang, Z. Su, and Q. Xu, "Analysis of data transmission based on the priority over grid structures," *ICIC Express Letters, Part B: Applications*, vol. 5, no. 3, pp. 751–755, June 2014.
16. H. Zhang, P. Cheng, L. Shi, and J. Chen, "Optimal dos attack policy against remote state estimation," in *Proc. IEEE CDC*, 2013, pp. 5444–5449.
17. M. Dong, K. Ota, M. Lin, Z. Tang, S. Du, and H. Zhu, "Uav-assisted data gathering in wireless sensor networks," *The Journal of Supercomputing*, vol. 70, no. 3, pp. 1142–1155, 2014.
18. Q. Xu, Z. Su, K. Zhang, P. Ren, and X. Shen, "Epidemic information dissemination in mobile social networks with opportunistic links," *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 3, 2015.
19. A. Shahzad, M. Sajjad A., and K. Atta Ur Rehman, "Routing protocols for mobile sensor networks: a comparative study," *International Journal of Computer Systems Science & Engineering*, vol. 29, no. 2, pp. 183–192, March 2014.
20. C. Yangjie, S. Hongyang, and Q. Depei, "Scalable hierarchical scheduling for malleable parallel jobs on multiprocessor-based systems," *International Journal of Computer Systems Science & Engineering*, vol. 29, no. 2, pp. 169–181, March 2014.
21. R. Ying, Z. Huachun, and G. Deyun, "Pcndn: Proactive caching for efficient mobility support in ndn," *International Journal of Computer Systems Science & Engineering*, vol. 29, no. 6, pp. 437–450, Nov. 2014.
22. Q. Yan, M. Li, Z. Yang, W. Lou, and H. Zhai, "Throughput analysis of cooperative mobile content distribution in vehicular network using symbol level network coding," *IEEE Journal on Selected*

Areas in Communications, vol. 30, no. 2, pp. 484–492, Feb. 2012.

23. J. Yan, C. Chen, X. Luo, and H. Liang, "Topology optimization based distributed estimation in relay assisted wireless sensor networks," *IET Control Theory & Applications*, pp. DOI: 10.1049/iet–cta.2014.0163, 2014.
24. J. Chen, W. Xu, S. He, Y. Sun, P. Thulasiramanz, and X. Shen, "Utility-based asynchronous flow control algorithm for wireless sensor networks," *IEEE Journal on Selected Areas in Communications*, vol. 28, no. 7, pp. 1116–1126, 2010.
25. F. Xiao, X. Xie, Z. Jiang, L. Sun, and R. Wang, "Utility-aware data transmission scheme for delay tolerant networks," *Peer-to-Peer Networking and Applications*, DOI: 10.1007/s12083-015-0354-y.
26. Q. Xu, Z. Su, K. Zhang, P. Ren, and X. Shen, "Epidemic information dissemination in mobile social networks with opportunistic links," *IEEE Transactions on Emerging Topics in Computing*, DOI: 10.1109/TETC.2015.2414792.
27. H. Liang, L. X. Cai, D. Huang, X. Shen, and D. Peng, "An smdp-based service model for interdomain resource allocation in mobile cloud networks," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 5, pp. 2222–2232, Jun. 2012.
28. J. Shankar Pathmasuntharam, P.-Y. Kong, M.-T. Zhou, Y. Ge, H. Wang, C.-W. Ang, W. Su, and H. Harada, "TRITON: High speed maritime mesh networks," in *Proc. IEEE PIMRC*, 2008, pp. 1–5.
29. K. Kalkan and A. Levi, "Key distribution scheme for peer-to-peer communication in mobile underwater wireless sensor networks," *Peer-to-Peer Networking and Applications*, vol. 7, no. 4, pp. 698–709, 2014.
30. P. Kolios and L. Lambrinos, "Optimising file delivery in a maritime environment through inter-vessel connectivity predictions," in *Proc. IEEE WiMob*, 2012, pp. 777–783.
31. L. X. Cai, H. Poor, Y. Liu, T. H. Luan, X. Shen, and J. W. Mark, "Dimensioning network deployment and resource management in green mesh networks," *IEEE Wireless Communications*, vol. 18, no. 5, pp. 58–65, Oct. 2011.
32. T. H. Luan, L. X. Cai, and X. Shen, "Impact of network dynamics on user's video quality: Analytical framework and qos provision," *IEEE Transactions on Multimedia*, vol. 12, no. 1, pp. 64–78, Jan. 2010.
33. T. Yang, Z. Z., H. Liang, R. Deng, N. Cheng, and X. Shen, "Green energy and content aware data transmissions in maritime wireless communication networks," *IEEE Transactions on Intelligent Transportation System*, DOI: 10.1109/TITS.2014.2343958.
34. T. Yang, H. Liang, N. Cheng, and X. Shen, "Efficient scheduling for video transmissions in maritime wireless communication networks," *IEEE Transactions on Vehicular Technology*, DOI: 10.1109/TVT.2014.2361120.
35. ——, "Towards video packets store-carry-and-forward scheduling in maritime wideband communication," in *Proc. IEEE GLOBECOM*, Dec. 2013, pp. 1–6.
36. ——, "Efficient scheduling for video transmissions in maritime wireless communication networks," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 9, pp. 4215–4229, Sept. 2015.
37. P. Berman and B. DasGupta, "Multi-phase algorithms for throughput maximization for real-time scheduling," *Journal of Combinatorial Optimization*, vol. 4, no. 3, pp. 307–323, Sep. 2000.
38. A. Bar-Noy, S. Guha, and J. Naor, "Approximating the throughput of multiple machines in real-time scheduling," *Journal of Computing*, vol. 31, no. 2, pp. 331–352, 2001.
39. C. Durr, L. Je, and K. Thang N, "Online scheduling of bounded length jobs to maximize throughput," *Journal of Scheduling*, vol. 15, no. 5, pp. 653–664, 2012.
40. B. I. G. Ltd, "User manual," http://www.boloomo.com/shippingMain.