Leveraging Scheduling to Minimize the Tardiness of Video Packets Transmission in Maritime Wideband Communication

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Abstract. In this paper, we investigated the scheduling issue of the vessel's uploading data to the infostations through the maritime communication network, to optimize the dispatching process by Dynamic Programming. We mapped it as a single-machine minimized total weighted tardiness scheduling problem, subjecting to intermittent network connections in communication, packet generation and due time limitations. The route of the ship, the duration of generation, as well as the due date of the data packet is a priori known. Especially, the time-capacity mapping method is used to convert the problem of intermittent resource scheduling in the sea to continuous scheduling problem. We proposed a Dynasearch algorithm based on time-capacity mapping, and further the proposed algorithm is verified by MATLAB.

Keywords: SDN · Dynasearch scheduling · Maritime communication networks

1 Introduction

In recent years, facing the increasingly scope of the maritime transport systems and complex maritime situation, the maritime communication gradually reflects an important role. Maritime wideband communication system is distinct from the current maritime communication systems, which consists of ground and satellite systems. The newest satellite systems can achieve wideband transmission, whose data rates up to 432 kbps. However, due to the high cost of satellites communication (e.g., voice service costs USD$ 13.75 per minute for Iridium [1]). Taking the legacy VHF communication for an example has the maximum data rate approximately 9.6 kbps [2]. Therefore considering the problem of reducing costs, the establishment of maritime wideband communication system is a fundamental section that we must pay attention. In order to make the system be controlled more finely, Software Define Network (SDN) can be a good solution.

L. Ma et al. (Eds.): WASA 2017, LNCS 10251, pp. 13–22, 2017.
DOI: 10.1007/978-3-319-60033-8_2

Software Defined Networking is a new way of modifying the network. Nearly a decade, the SDN has increasingly became a hot research direction carrying out the separation and control of the network [3]. SDN separates the control and data transmission in network devices and logically centralizes the governing of the network. This paradigm makes the development of new services and applications versatile. Moreover, SDN also has brought certain new concepts in networks such as Network Operating Systems (NOS) which represent a promising approach for realizing the full potential of computer communication networks, High Level Network Operating Languages and Network Functions Virtualization (NFV) [4]. SDN has revolutionized the way which the network built. Based on SDN system, maritime wideband communication systems targets the incorporation of wireless communications and informatics technologies into the navigation transportation system, making the navigation pattern to be safer and more efficient [5]. If a maritime wideband communications system is established, communications will be more convenient in case of maritime distress and safety system, urgency and general communication, and communication performance will be more easily promoted based on SDN field studies [6].

According to the connectivity of maritime wideband communication system is intermittent, a huge number of vessels can not always take part in the communication. So in the limited communication periods scheduling, the schelding is necessary. In this paper, we only concerned the single machine occasion which is about the problem of single-machine total weighted tardiness scheduling [7] to sort the data.

The extensive applications of scheduling in various trades and traffic communication have aroused people's interest [8]. Those are harnessed in the field of operations research, applied mathematics, computer science, production management science, artificial intelligence and engineering science. Study on the problem of single machine scheduling is a guide to research complex problem and provides an approximation algorithm for dealing with complex scheduling problems [9]. For example, many job shop problems can be solved using the decomposition method, and its sub-problems become a single problem.

The plight mentioned above is seldom discussed, easily overlooked, in the scheduling scenario of transport tasks for maritime wideband communications. This is an open issue, and of significance in the maritime efficient scheduling for video transmissions in maritime wireless communication networks area [10]. We have done some basic research in this area, It is more efficient and stable in the area of shipboard and ship interactive information, and provides the theoretical basis for multi-ship cooperative communication in the field of maritime wideband communication system. Considering to find a ductile transmission sequence, which satisfies both the external conditions of delay and the internal conditions of the information classification according to the classification of weights. Since all the constraints are NP-hard problems, we adopt a dynasearch algorithm based on neighborhood searching. In the context of time-depending, dynasearch is a recently proposed neighborhood search technique [11] that allows a series of moves to be performed at each iteration of a local search algorithm, generating in that way an exponential size neighborhood. Congram et al. applied dynasearch to the classical single machine total weighted tardiness problem. In the field of maritime scheduling, due to the multiple, complicated data and which the weight level is a lot in the maritime communication, the similarity of the dynamic search and the characteristic of narrowing the domain scope are particularly suitable for application. We used a lot of ideas on shore-based network scheduling aspects, communications, etc. from below references [13–18].

The remainder of this paper is organized as follows. System model is given in Sect. 2 and problem formulation is presented in Sect. 3. Actual dynamic programming algorithms are proposed in Sect. 4. In Sect. 5, simulation results are given employed to demonstrate the performance of our approaches. We conclude this paper with future work in Sect. 6.

2 System Model

The vessel's route is from the origin port to the destination port, during which the ship will generate a monitor video randomly and discontinuously, the task in order to transmit the monitor video is considered as a job. Videos could be uploaded to content server of administrative agencies by infostations deployed along route line. In the process of transmission, the packet type is based on the weight, the start time and the end time of the transmission, and the time required for the transmission. The infostations distributed along the navigation path, each infostation has coverage. The vessel in the infostations' coverage transmit monitoring video, in the outside of infostations' coverage sort the data. In order to optimize the result, we use dynamic programming to solve the scheduling problem, such as swapping the sequence of the jobs instead of the traditional search method. The vessels running route within the communication system is shown as followed (Fig. 1):

2.1 Time-Capacity Mapping

In our previous work, Dr. Yang put forward this idea in the information scheduling of maritime wideband network. The time is regarded as discrete and intermittent. In contrast, the capacity is continuous. This paper is based on the scheduling problem of this model, 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.

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

$$f(t) = \begin{cases} \sum_{m=1}^{(t-T_{h_t}^i)/T_F} A_{h_t,m} + \sum_{l=1}^{h_t-1} \sum_{m=1}^{K_l} A_{l,m} \\ \qquad if\ h_t \geq 1\ and\ T_{h_t}^i \leq\ t \leq T_{h_t}^o \\ \sum_{l=1}^{h_t} \sum_{m=1}^{K_l} A_{l,m} \qquad otherwise \end{cases} \tag{1}$$

where $A_{h,k}$ means the capacity of the kth frame within the hth infostation, while $T_I(T_O)$ represents the departure (arrival) time. $h_t = \arg\max_h \{T_h^i \leq t\}$.

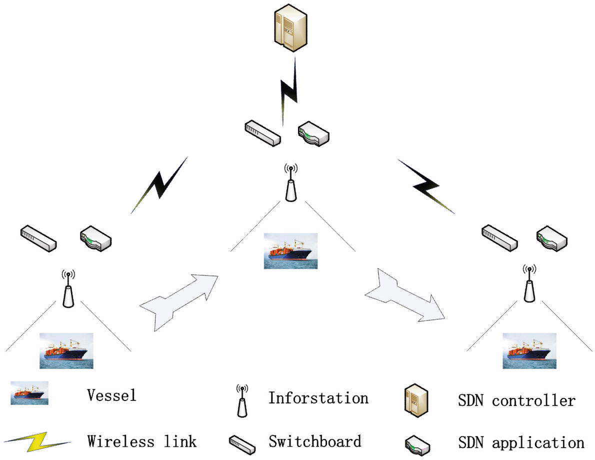

Fig. 1. An illustration of the network topology

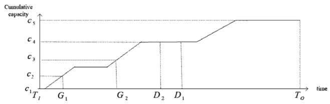

Fig. 2. Time-capacity mapping

After time-capacity mapping process, the issue could convert from time based scheduling to capacity based scheduling over a continuous horizon [12], 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. Since the parameters t are used in the subsection Time-capacity mappings, in order to distinguish them, we use t' for the relationship of $t \xrightarrow{f(t)} t'$.

2.2 Ds-swap Neighborhood

The dynasearch neighborhood we use is based on the swap neighborhood which gives the best results compared to other ones for the $1||\sum_{j=1}^{n} w_j T_j$ problem, and probably for the generalized problem that we consider. We shall represent a solution by a permutation $\sigma = (\sigma(1), ..., \sigma(n))$ of the set $\{1, 2, ..., n\}$, meaning that job $\sigma(j)$ is the jth job to be scheduled. Given a permutation $\sigma = (\sigma(1), ..., \sigma(i), ..., \sigma(j), ..., \sigma(n))$ the swap neighbor consists of all $\frac{n(n-1)}{2}$ permutations $\sigma' = (\sigma(1), ..., \sigma(j), ..., \sigma(i), ..., \sigma(n))$, with $1 \leq i < j \leq n$, that can be obtained from r by swapping two jobs. The ds-swap neighborhood, introduced in [11], it is not difficult to see that this neighborhood has size $2^{n-1} - 1$.

3 Problem Formulation

Our goal is to let the infostations on the shore receive data more efficiently, that is, minimize the product of weights and delays by rescheduling the data task. A network centralized controller is employed, with the ability to schedule resource allocation problem.

In this section, we give the formal expression of the vessel weight tardiness minimization problem (VWTMP) for scheduling problems. The problem can be stated as follows. There are a set of n jobs seem as the transmission of monitor video, each job j has a due date d_j and a positive weight w_j. The processing time $f_j\left(t'\right)$ of each job j depends on its starting time of execution t' and is given by a function f_j. We shall denote $f_j\left(t'\right)$ by $p_j^{t'}$. So, if a job j immediately starts after a job i, its duration is $p_j^{c_i}$, where c_i represents the completion time of job i. We denote by c_j the completion time and by $T_j = \max\left\{C_j - d_j, 0\right\}$ the tardiness of job j. The objective is to find a schedule which minimizes the total weighted tardiness.

$$\begin{aligned} &\exists N sequence\left\{\sigma_1(1), ..., \sigma_1(\mathrm{n})\right\}, ..., \left\{\sigma_n(1), ..., \sigma_n(\mathrm{n})\right\}, \\ &result[x] = \sum_{j=1}^{n} W_{\sigma_x(j)} T_{\sigma_x(j)} \\ &\sigma_* = \arg\min result[x], 1 \leq x \leq 2^{n-1} - 1 \end{aligned} \tag{2}$$

This problem is strongly NP-hard since it is a generalization of the single-machine total weighted tardiness problem. Indeed we use dynasearch programming. The method of neighborhood search is used to obtain the solution of an approximate optimal solution, which greatly reduces the computational cost.

4 Proposed Algorithms

In order to achieve effective resource allocation with low computational complexity, We propose a dynamic programming algorithm based on sequence scheduling, which combines the parameters of time-dependment processing and the idea of ds-swap (here we consider only a single swap).

4.1 Ds-swap-Neighborhood with Dynasearch Programming

To search this exponential neighborhood in an efficient way, i.e. to find the best neighboring permutation of job among the $2^{n-1} - 1$ candidate permutations (i.e. we use steepest descent local search), We use a backward enumeration scheme in which jobs are appended to the beginning of the current partial sequence and are possibly swapped with jobs already scheduled in the partial sequence. We denote $(x)^+ = \max\left\{x, 0\right\}$ for any integer x. Let $\sigma = \left(\sigma\left(1\right), ..., \sigma\left(i\right), ..., \sigma\left(j\right), ..., \sigma\left(n\right)\right)$, be a permutation. We denote $\left(\sigma_i, t'\right)$ the best possible way to schedule jobs $\sigma\left(i\right), \sigma\left(i+1\right), ..., \sigma\left(n\right)$ by applying a series of independent swaps on the subpermutation $\left(\sigma\left(i\right), \sigma\left(i+1\right), ..., \sigma\left(n\right)\right)$, assuming that the first job scheduled in that sub-permutation (which is not necessarily $\sigma\left(i\right)$) is scheduled at time t'. We take only into account the total weighted tardiness of jobs $\sigma(i), \sigma(i+1), ..., \sigma(n)$ and forget jobs $\sigma(1), \sigma(2), ..., \sigma(i-1)$ when dealing with (σ_i, t'). We note $F(\sigma_i, t')$ the corresponding total weighted tardiness of jobs $\sigma(i), \sigma(i+1), ..., \sigma(n)$ in the state (σ_i, t'). We shall put $(\sigma_{n+1}, t') = \phi$ and $F(\sigma_{n+1}, t') = 0$ for any time t' to simplify the description of the algorithm below. Now the state (σ_i, t') must be obtained either by appending the job $\sigma(i)$ in front of the state $(\sigma_{i+1}, t' + p^{t'}_{\sigma(i)})$ or by appending the sequence $(\sigma(j), \sigma(i+1), ..., \sigma(j-1), \sigma(i))$, obtained by swapping jobs $\sigma(i)$ and $\sigma(j)$, in front of the state (σ_{j+1}, t'') for some job $i+1 < j \leq n$ and time t'' (to be determined later). We have for the first case

$$F(\sigma_i, t') = w_{\sigma(i)}\left(t' + p^{t'}_{\sigma(i)} - d_{\sigma(i)}\right)^+ + F\left(\sigma_{i+1}, t' + p^{t'}_{\sigma(i)}\right) \tag{3}$$

For the second case, let t'_k be the starting time of the kth scheduled job for $i \leq k \leq j$ after having swapped $\sigma(i)$ and $\sigma(j)$. By definition of $F(\sigma_i, t'), t'_i = t'$. Then since jobs $\sigma(i)$ and $\sigma(j)$ have been swapped, $t'_{i+1} = t'_i + p^{t'_i}_{\sigma(j)}$. Finally, $t'_k = t'_{k-1} + p^{t'_{k-1}}_{\sigma(k-1)}$ for $i+1 < k \leq j$. Thus we have

$$\begin{aligned} F(\sigma_i, t') = {} & w_{\sigma(j)}\left(t'_i + p^{t'_i}_{\sigma(j)} - d_{\sigma(j)}\right)^+ \\ & + \sum_{i<k<j} w_{\sigma(k)}\left(t'_k + p^{t'_k}_{\sigma(k)} - d_{\sigma(k)}\right)^+ \\ & + w_{\sigma(i)}\left(t'_j + p^{t'_j}_{\sigma(i)} - d_{\sigma(i)}\right)^+ \\ & + F\left(\sigma_{j+1}, t'_j + p^{t'_j}_{\sigma(i)}\right) \end{aligned} \tag{4}$$

If $j = i+1$, the sum is empty.

We want to calculate $F(\sigma_1, 0)$. Notice that a forward enumeration scheme is not possible in ourcase, since we do not know what is the completion time of the last job in an optimal solution. In our implementation of the dynamic programming algorithm, an array stores the values of F already computed in order to reduce the number of recursive calls. The optimal set of independent swaps can be retrieved by examining an array which stores, for each job j and each time t' for which a value $F(\sigma_j, t')$ was computed, the position of $\sigma(j)$ in the state (σ_j, t'). The algorithm is given as followed.

We obtain the time complexity of the result is $\theta(n^4)$, so as to obtain the optimal solution in the case where the complexity is as small as possible, and give the most feasible job permutation.

5 Performance Evaluation

In this part, We consider the comparison between dynamic search algorithm and some common algorithms. In simulation comparison, we choose some significant parameters such as processing time, task waiting time and the number of tasks.

In the three simulation diagram, the vertical axis is expressed as the sum of the delay times the weight.

Algorithm 1. *Ds-swap Dynasearch*

phrase 1 : Time-capacity Mapping

$$f(t) = \begin{cases} \sum_{m=1}^{(t-T_{h_t}^i)/T_F} A_{h_t,m} + \sum_{l=1}^{h_t-1} \sum_{m=1}^{K_l} A_{l,m} \\ \quad if\ h_t \geq 1\ and\ T_{h_t}^i \leq\ t \leq T_{h_t}^o \\ \sum_{l=1}^{h_t} \sum_{m=1}^{K_l} A_{l,m} \quad otherwise \end{cases}$$

$t \xrightarrow{f(t)} t'$

phrase 2 : Ds-swap Neighbourhood

Initially:alreadycomputed$[i][t']$ =false,swaps$[k][t'] = k$ $\quad \forall i \in \{1, ..., n\}, t' \in \{0, ..., (n-1)p\max\}$ $\quad \forall k \in \{1, ..., n\}, t' \in \{0, ..., (n-1)p\max\}$

function $ds - swap - neighborhood(\sigma)$
function $dyna(i, t')$
if $i = n$ then
return $w_{\sigma(n)} * (t' + p_{\sigma(n)}^{t'} - d_{\sigma(n)})^+$
else if computed$[i][t']$ then
return dynacomputed$[i][t']$
end if
result$[i] := w_{\sigma(i)} * (t' + p_{\sigma(i)}^{t'} - d_{\sigma(i)})^+ + dyna(i+1, t + p_{\sigma(i)}^{t'})$
for $j = i + 1$ to n do

result$[j]$=: $$\begin{aligned} & w_{\sigma(j)} * (t' + p_{\sigma(j)}^{t'} - d_{\sigma(j)})^+ \\ & + \sum_{i<k<j} w_{\sigma(k)} * (t'_k + p_{\sigma(k)}^{t'_k} - d_{\sigma(k)})^+ \\ & + w_{\sigma(i)} * (t'_j + p_{\sigma(i)}^{t'_j} - d_{\sigma(i)})^+ \\ & + dyna(j+1, t'_j + p_{\sigma(i)}^{t'_j}) \\ & /* t'_{i+1} = t' + p_{\sigma(j)}^{t'} \end{aligned}$$ and $t'_k = t'_{k-1} + p_{\sigma(k-1)}^{t'_{k-1}}$ for

$i + 1 < k \leq j */$
end for

phrase 3 : Generate The Sequence

$j*$:=arg min$i \leq j \leq n$ result$[j]$
swaps$[i][t'] := j*$
alreadycomputed$[i][t']$ =true
dynacomputed$[i][t']$ =result$j*$
return dynacomputed$[i][t']$
end function
$dyna(1, 0)$
$time := 0$
for $k = 1\ \ to\ n - 1$do
if swaps$[k][time]! = k$ then
$swap\ job\ \sigma(k)\ with\ job\ \sigma(swaps[k][time])$
k:=swaps$[k][time]$
end if
$time := C_k$
end for
return σ
end function

In Fig. 3 the processing axis can be seen as independent variables indicates the number of tasks, it varies from 30 to 50, with the increase of the number of tasks. The total delay weight multiplied by the three algorithms are increasing, but the increase of the dynamic search algorithm is the slowest. That is to say when the task increases when the algorithm is still very stable.

In Fig. 4, AHT is equal to average processing time. The average processing time requires for horizontal variables task processing, it varies from 10 to 14 second. Increasing the average processing time will make the task delay increase,

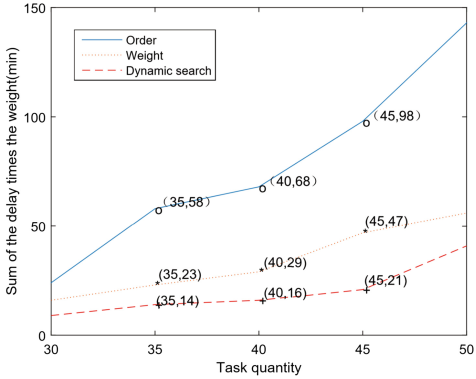

Fig. 3. Delay times weight versus task quantity

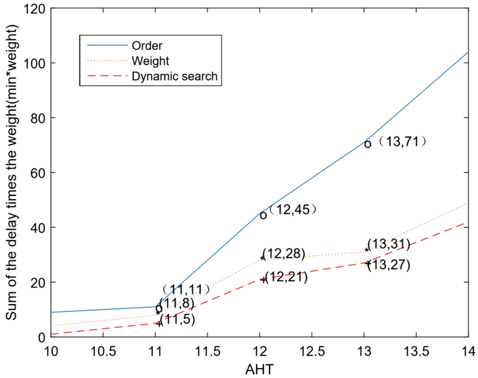

Fig. 4. Delay times weight versus task AHT

and the dynamic search algorithm index still increased most slowly. The weight sorting algorithm and dynamic search algorithm will be relatively close to the average processing time.

In Fig. 5 indicates the influence of the average waiting time on the results. The task average waiting time varies from 320 to 440 second. Task average waiting time is longer, the delay will be shorter, so the value of the variable will be reduced. The increase in the average waiting time will reduce the number of tasks that exceed the deadline. The cumulative effect of delay does not occur, thus reducing the weight of the impact of the results. By comparing with other algorithms, the dynamic search algorithm is still the best method, which shows that the algorithm is very stable.

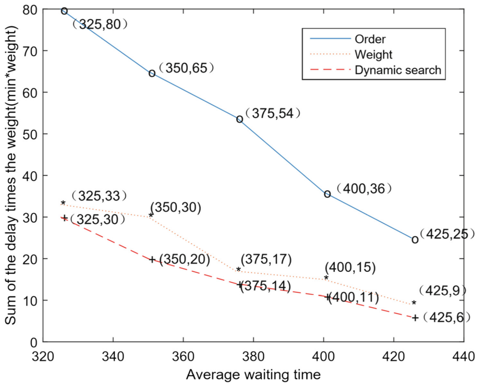

Fig. 5. Delay times weight versus average waiting time

6 Conclusion

In this paper, we done a deep exploration of the scheduling problem of uploading data to infostations in marine environment. In order to minimize the total weighted tardiness, time-capacity mapping based dynamic search algorithm is proposed. In simulation part, we compared our schemes with the other two traditional transmission methods. The simulation results showed that the dynamic search algorithm has a more effective consequence in transferring time, which has an extremely prefect time complexity that nearly $\theta(n^4)$. All in all this potential field also has a flamboyant future, we have a strong wish to devote in the collaboration of multi-ship and valid scheduling tasks of multi-transfer mode. In addition, priority options for maritime emergency missions such as search and rescue and certain information of diabolic accidents will also be pondered.

Acknowledgement. This work was supported in part by Research Project for FY2017 of International Association of Maritime Universities, China Postdoctoral Science Foundation under Grant 2015T80238, Natural Science Foundation of China under Grant 61401057, Natural Science Foundation of Liaoning Province under Grant 201602083, Science and technology research program of Liaoning under Grant L2014213, Dalian science and technology project under Grant 2015A11GX018, Research Funds for the Central Universities 3132016007 and 01760325. Dalian high-level innovative talent project under Grant 2016RQ035, Open Research Project of the State Key Laboratory of Industrial Control Technology of Zhejiang University, China under Grant ICT170310.

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http://www.springer.com/978-3-319-60032-1

Wireless Algorithms, Systems, and Applications
12th International Conference, WASA 2017, Guilin, China, June 19-21, 2017, Proceedings
Ma, L.; Khreishah, A.; Zhang, Y.; Yan, M. (Eds.)
2017, XVII, 912 p. 405 illus., Softcover
ISBN: 978-3-319-60032-1