IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received February 21, 2020, accepted March 8, 2020, date of publication March 19, 2020, date of current version March 31, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2981963

Area-Aware Routing and Spectrum Allocation for the Tidal Traffic Pattern in Metro Optical Networks

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This work was supported in part by the National Natural Science Foundation of China (NSFC) under Grant 61822105, in part by the Fundamental Research Funds for the Central Universities under Grant 2019XD-A05, in part by the State Key Laboratory of Information Photonics and Optical Communications of China under Grant IPOC2019ZR01, and in part by BUPT Excellent Ph.D. Students Foundation under Grant CX2019314.

ABSTRACT With the increasing bandwidth requirements for people and the development of urbanization, the movement of the population in the city (especially the supercity) has an increasing influence on the traffic distribution in both space and time dimensions. The imbalanced distribution results in the regional blocking of different areas in different time periods and reduces the spectrum resource utilization in elastic optical networks. To resolve this problem, this paper proposes a tidal traffic model to formulate a kind of tidal traffic phenomenon firstly. Based on the analysis for this model, the area-aware routing and spectrum allocation algorithm that focuses on the traffic adjustment in specific functional areas is proposed. And two benchmark algorithms named min-hop k-shortest path routing algorithm and occupied-slots-as-weight k-shortest path routing algorithm are introduced. The evaluation results show that, compared to the benchmark algorithms, the proposed area-aware algorithm could reduce the blocking probability efficiently from 2% to 47% with low time complexity.

INDEX TERMS Tidal traffic, elastic optical networks, resource, and spectrum allocation.

I. INTRODUCTION

In recent years, the Internet has been achieving rapid development, and its traffic has been increasing exponentially. According to the report of Cisco Visual Networking Index [1], the annual global IP traffic will reach 4.8 ZB per year by 2022, which was only 1.5 ZB per year in 2017. Meanwhile, busy hour Internet traffic is growing more rapidly than average Internet traffic, and smartphone traffic will exceed PC traffic. These two notable trends indicate that the traffic distribution will be influenced by the movement of the population more and more. On the other hand, the urbanization process develops rapidly in developing countries, and the phenomenon of daily population mobility becomes more obvious. Influenced by these factors, the traffic load of the metro network is fluctuant in both space and time dimensions, which is named tidal traffic scenario. Tidal traffic makes traffic load unbalanced, hence reduce the bandwidth resource utilization and the service capability for the operators. Meanwhile, benefit from the emergence of new network applications like 5G, Internet of Things, virtual reality, artificial intelligence, etc. [2]–[6], the requirement for traffic varies, which is a key motivation to make metro optical network expanded and meshed. Therefore, it's important for the meshed metro network to allocate bandwidth resources efficiently under tidal traffic models.

In the past, the study for tidal traffic mainly focused on wireless scenarios on various aspects. The research team [7]–[10] collected the mobile tidal traffic data from some cities, studied the tidal traffic model, analyzed the human urban activities, and analyzed the relationship between cyberspace and the physical world by using big data technology. Li *et al.* [11] proposed an energy-saving schema under tidal traffic prediction. Troia *et al.* [12] studied how to identify the tidal-traffic models by using a matrix factorization-based model in metro mobile networks. Recently, there are also some works studying tidal traffic under the optical network scenario for resource allocation

The associate editor coordinating the review of this manuscript and approving it for publication was Peng-Yong Kong.

problems. Zhong *et al.* [13], [14] considered the balance between both energy efficiency and blocking reduction by using the features of tidal traffic in IP-over-optical networks. Klinkowski *et al.* [15] proposed both Integer Linear Programming (ILP) method and heuristic algorithms to improve the performance of routing and spectrum allocation (RSA) under tidal traffic models. With the introduction of machine learning (ML), some ML-based traffic-predicting algorithms [16]–[19] are proposed to help resource allocation.

All these algorithms that concern the resource allocation efficiency are valuable for only some special tidal traffic models. However, it's rarely mentioned in these papers that how to model the tidal traffic, although some of them are based on real traffic. The concrete definition of the traffic model is the key point when the operators make a choice from various RSA algorithms to optimize network performance under a specific tidal traffic scenario. In our previous work [20], we proposed a tidal traffic model named Onion Tidal Traffic Model (OTTM) with the mathematic definition. OTTM is quite a simple traffic model, which is more applicable to small cities. OTTM divides the city into only one business area and one resident area. In both areas, the traffic model is different. For example, at noon, the traffic load reaches the top in the business area while the traffic load of the resident area remains low level. Because most people are working in the business area. Based on OTTM, two RSA algorithms named Pre-Detour RSA (PD-RSA) and Pre-Detour K-shortest paths RSA (PDK-RSA) algorithms are proposed. These two algorithms consider future traffic trends in optical nodes and make some routing and spectrum adjustment in advance.

However, OTTM is not applicable to the big cities that own more functional areas, and more complex traffic distribution. In this paper, we focus on the tidal traffic distribution in supercity's metro Elastic Optical Networks (EONs). In Section II, a new tidal traffic model named Multi-Step Trigonometric Model (MSTM) based on the real traffic of some metro networks is proposed. In Section III, by considering the special optimization using the traffic characteristics, Area-Aware RSA (A2-RSA) algorithm is proposed. Besides, two benchmark algorithms named Min-Hop K-shortest path routing (MHK) algorithm [20] and occupied-Slots-as-Weight K-shortest path routing (SWK) algorithm are also introduced. And the time complexities of the three algorithms are analyzed. In Section IV, we evaluate the performance of these three algorithms on a metro network with 38 nodes and 60 links. Finally, Section V draws a conclusion.

II. MULTI-STEP TRIGONOMETRIC TIDAL TRAFFIC MODEL

With the advancement of the urbanization in the world (especially Asia), the urban functional zoning is becoming more and more refined, especially for those supercities whose population is larger than ten million, for example, Beijing, Tokyo, New Delhi, Shanghai, Seoul, etc. To be simplified, the big city is comprised of three kinds of areas, i.e., the office area (OA) where people work at working hours, the residential area (RA) where people live, and the comprehensive area (CA) that can not be classified into the office area and the resident area [9]. CA includes the narrow transport area where the metro subway runs, the entertainment area where people go shopping and see a movie, and so on. There are distinct tidal traffic models for all these areas every day. According to human activities, one day from 0 a.m. to 24 p.m. could be divided into four periods by four timestamps, i.e., t_1, t_2, t_3, and t_4, as listed:

- $(t_1, t_2]$ - People go to work gradually during this period.
- $(t_2, t_3]$ - People mainly work during this period.
- $(t_3, t_4]$ - People get off work gradually during this period.
- $(t_4, 24 + t_1]$ - People go to sleep during this period.

The optical connection requests include immediate reservation (IR) that needs to be allocated immediately, and advanced reservation (AR) that could be allocated in advance. The adjustable start time of AR is helpful to optimize resource allocation in a time period [21]–[23]. This paper focuses on the performance improvement for the requests whose end time is known. The traffic connection requests follow Poisson process, i.e., both the arrival rate ρ and leave rate μ are negative exponential distributions. We assume that the expected value of holding time for connectivity request keeps unchanged, then the traffic generation will be decided by the expected value of arrival rate ρ. The traffic generations ρ_{RA}, ρ_{OA} and ρ_{CA} for RA, OA and CA respectively are formulated, as Eq. (1-3) show, and the graphical representation is as Fig. 1 shows. This tidal traffic model formulated by Eq. (1-3) is named Multi-Step Trigonometric Model (MSTM) because all these three piecewise functions consist of trigonometric functions and constant functions. Each area maintains a constant value (i.e., β, β' and β'' in RA, OA and CA respectively) as the baseline. And all α-related values (including $\alpha_1, \alpha_2, \alpha'_1$, α'_2, and α'') decide the fluctuation range at different times of the day. Compared to the Onion Tidal Traffic Model (OTTM) proposed in our previous work [20], MSTM introduces CA to explain the traffic for the areas that are neither RA nor OA. Besides, the traffic trends of RA and OA in OTTM are opposite for one day. However, MSTM considers the overlap for different human activities in different areas (for example, the traffic decreases to the valley during the late of the night in all areas), and make the traffic trends of RA, OA, and CA closer to reality.

$$\rho_{RA}(t) = \begin{cases} \alpha_1 \cdot \sin(\frac{t - t_1}{t_2 - t_1}\pi - \frac{\pi}{2}) + \alpha_1 + \beta, \\ \quad t \in (t_1, t_2] \\ \alpha_2 \cdot \sin(\frac{t - t_2}{t_4 - t_2}\pi - \frac{\pi}{2}) + 2\alpha_1 + \alpha_2 + \beta, \\ \quad t \in (t_2, t_4] \\ (\alpha_1 + \alpha_2) \cdot \cos(\frac{t - t_4}{t_1 + 24 - t_4}\pi) + \alpha_1 + \alpha_2 + \beta, \\ \quad t \in (t_4, 24 + t_1] \end{cases} \tag{1}$$

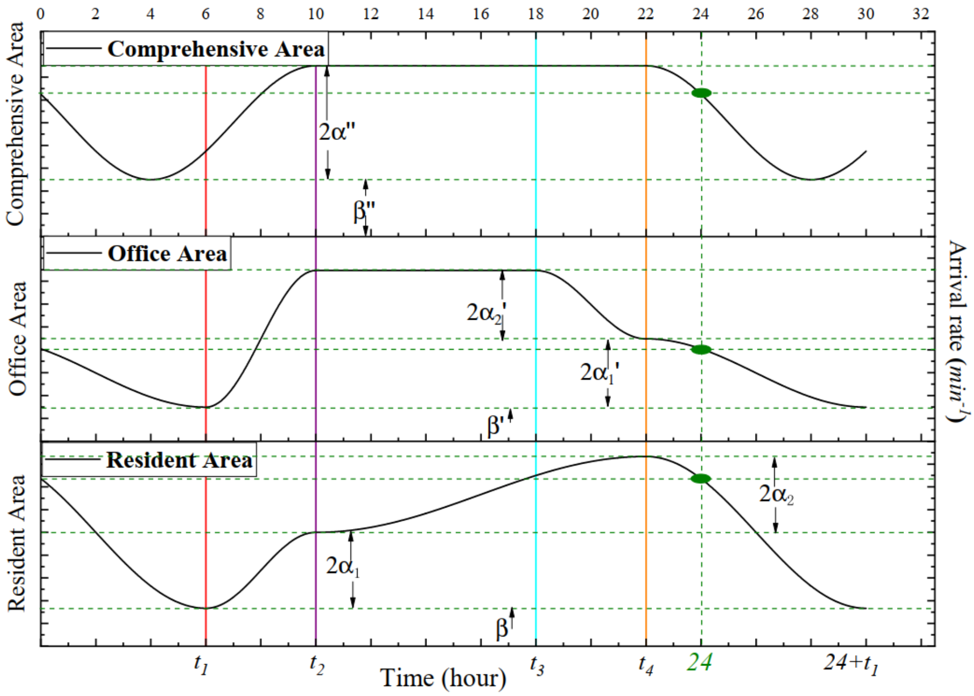

FIGURE 1. Demonstration of multi-step trigonometric model.

$$\rho_{OA}(t)=\begin{cases}(\alpha_1'+\alpha_2')\cdot\sin(\frac{t-t_1}{t_2-t_1}\pi-\frac{\pi}{2})+\alpha_1'+\alpha_2'+\beta', & t\in(t_1,t_2]\\ 2\alpha_1'+2\alpha_2'+\beta', & t\in(t_2,t_3]\\ \alpha_2'\cdot\cos(\frac{t-t_3}{t_4-t_3}\pi)+2\alpha_1'+\alpha_2'+\beta' & t\in(t_3,t_4]\\ \alpha_1'\cdot\cos(\frac{t-t_4}{t_1+24-t_4}\pi)+\alpha_1'+\beta' & t\in(t_4,24+t_1]\end{cases} \tag{2}$$

$$\rho_{CA}(t)=\begin{cases}2\alpha''+\beta'', & t\in(t_2,t_4]\\ \alpha''\cdot\cos(\frac{t-t_4}{t_2+24-t_4}\cdot 2\pi)+\alpha''+\beta'', & t\in(t_4,24+t_2]\end{cases} \tag{3}$$

Figure 1 shows a demonstration of three traffic models. In all three traffic models in $(t_4, 24+t_1]$, the traffic decreases to a low level because people need to sleep. The traffic model of CA is simplified, which remains unchanged at all daytime in $(t_2, t_4]$. The traffic model of OA contains four segments. Except for the sleep time, the traffic remains the top in the working hours of $(t_2, t_3]$. And then people go home after t_3. However, there are still some people working or living in OA, so the traffic decreases again since t_4. The traffic model of RA contains two climbing segments in $(t_1, t_2]$ and $(t_2, t_4]$ respectively, and one decreasing segment in $(t_4, 24+t_1]$. At t_4, most people have arrived at home, so the traffic reaches a peak.

The city zoning is quite a complex problem, which is influenced by many factors. We evaluate MSTM on the real aggregated traffic collected from some 4G base stations of Shanghai in one month, by adjusting all parameters in Eq. (1-3). The results show that in the most workdays, MSTM is able to explain the traffic expectation distribution for RA and OA, and has a relatively low performance for CA. Because CA actually includes many kinds of areas whose traffic patterns are different notably. For the weekends, holidays and the days with sudden events, the traffic distribution is hard to analyze. According to the collected real traffic data, there are also several simple rules inside, which are shown in Fig. 2. The topology in Fig. 2 shows a metro optical network with 38 nodes and 60 undirected links. Firstly, the OA and the RA are generally small because of high population density. Secondly, some big cities own more than one OA/RA area. For example, Beijing owns several office areas like Wangjing area, Wudaokou area, Wangfujing area, etc. Thirdly, the CA is usually located at the border of the city, and the gap between OAs and RAs. Besides, the traffic peaks that different areas could reach is quite different. The traffic peak of CA is lower than the peaks of OA and RA.

III. ROUTING AND SPECTRUM ALLOCATION ALGORITHMS UNDER TIDAL TRAFFIC MODEL

Compared to the basic and general routing algorithms like shortest-path algorithm [24] and k-shortest-paths algorithm [25], the heuristic algorithms applied to specific scenarios could improve the performance by using the uneven distribution in different aspects. In the MSTM tidal traffic

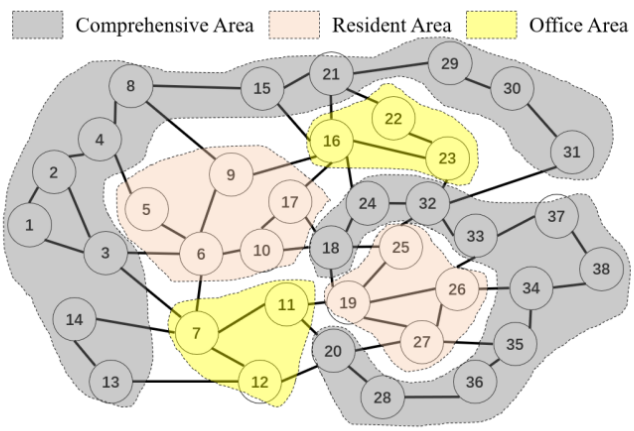

FIGURE 2. Demonstration of city zoning.

scenario, the uneven characters in both space dimension and time dimension are considered.

A. PROBLEM STATEMENT

RSA is an important problem in EON. To explain the RSA algorithm proposed in this paper, the following variables are defined:

- $G(V, E, S)$: the metro EON, where V is the set of nodes including the nodes of RA, OA, and CA, i.e., $V = RA \cap OA \cap CA$. E is the set of fiber links, and S is the total available slot number in each fiber link.
- $v_i \in V - v_i$ is the i-th node in V.
- $e_{i,j}(w_{i,j}, \{s_{i,j,k}|k = 1, \ldots, S\}) \in E$: $e_{i,j}$ is the link between v_i and v_j in E. $w_{i,j}$ means the weight value of $e_{i,j}$. $\{s_{i,j,k}\}$ is the set of the slot in $e_{i,j}$, where $s_{i,j,k}$ is a boolean value that indicates whether this slot has been occupied now.
- C: the connection queue, in which the connections are sorted in ascending order of t_b.
- $c(v_s, v_d, r, t_b, t_e)$: a connection request of C, where v_s and v_d are the source and the destination, r is the required slot number, t_b and t_e are the timestamps when this connection plan to begin and stop respectively.
- R_k: the set of feasible routing paths for connection c_k.
- $r(V_r, E_r, s_a)$: an available RSA solution of R_k. V_r and E_r are the passed nodes and edges from the source to the destination. And s_a is the beginning slot index to be occupied.

B. THE BENCHMARKS AND AREA-AWARE RSA ALGORITHM

The universality and efficiency are two conflicting indicators for RSA algorithms. The efficiency improvement introduces more certain impact factors and reduces the range of applications. The algorithm PD-RSA and PDK-RSA proposed in our previous work [20] could be only applied to the tidal traffic scenario with only two kinds of areas, but not be applied to the MSTM scenario in this paper. In order to evaluate the proposed algorithm in this paper, we introduce two traditional algorithms as the benchmarks, i.e., Min-Hop K-shortest path routing (MHK) algorithm [20] and occupied-Slots-as-Weight K-shortest path routing (SWK) algorithm, as Algorithm I shows. In the beginning, the values of all weights are initialized as 1.0. At Step 3, for the arriving connection request, k feasible routing paths are calculated by using Yen's algorithm [25]. Then in two embedded **FOR** loops between Step 4 to Step 11, each slot index of each path option is checked in order to meet the requirements of the continuity constraint and the contiguity constraint in EONs [26]. The spectrum resource policy between Step 5 to Step 10 is called First-Fit (FF), that means to select the first available slot index from bottom to top. Once the available solution is found, this connection is built at Step 13. Otherwise, it's blocked at Step 16.

Algorithm 1 The Benchmark (MHK&SWK With k Value)

1. Initialize $G(V, E, S)$ with $w_{i,j} = 1.0, \forall e_{i,j} \in E$.
2. FOR $\forall c_k(v_s, v_d, r, t_b, t_e) \in C$ in order:
3. Calculate k feasible routing paths as R_k by using Yen's algorithm.
4. FOR $\forall r(V_r, E_r) \in R_k$ in order:
5. FOR $\forall i \in [1, S]$ in order:
6. IF the spectrum resource that begins from i-th slot satisfies the requirement r:
7. $s_a \leftarrow i$
8. GO TO Step 12.
9. END IF
10. END FOR
11. END FOR
12. IF $\exists r(V_r, E_r, s_a)$:
13. Allocate the spectrum resource.
14. Update all weights if this algorithm is SWK.
15. ELSE
16. c_k is blocked.
17. END IF
18. END FOR

In most steps, the performances of MHK and SWK are the same. The only difference happens in Step 14. MHK aims to find the min-hop path as the routing path, so the weights remain 1.0 to indicate that one link is one hop. But in SWK, the occupied slot number is considered as the weight to indicate the traffic load briefly [27], which follows the least-loaded path strategy that aims to minimize the occupied spectrum resource in a routing path. Therefore, only SWK needs to update the weights in Step 14. Besides, the steps in Algorithm I only show the process of request arriving events. In the events of request leaving, the weights also need to be updated under SWK algorithms, while the resources for the allocated connection are released.

Under the tidal traffic model, the blocking always happens at the time when the traffic is higher. In the OTTM scenario proposed in our previous work, the business area and the resident area reach their traffic peak at different times without overlap. So our heuristic algorithm could only consider both the current traffic and the predicted future traffic. However, in MSTM, the RAs, CAs, and OAs have overlapped peak moments, as Fig. 1 shows. In another way, the holding time for the optical connection is quite long (several hours) because of its large bandwidth. Therefore, the influence of an allocated connection may cross multiple time periods. By considering these two characters, the algorithm named Area-Aware RSA (A2RSA) algorithm is proposed, as Algorithm II shows.

Algorithm 2 The A2RSA Algorithm With k

1. The same as Step 1-3 in Algorithm I.
2. Filter R_k using First-Fit policy in min-hop order.
3. $r_b \leftarrow r_1, p \leftarrow |OA \cap V_r^1|, q \leftarrow |RA \cap V_r^1|$
4. IF $t_b < t_2$ and $t_e \in [t_2, t_3]$:
5. FOR $\forall r_m(V_r^m, E_r^m, s_a^m) \in R_k$ in order:
6. IF $|OA \cap V_r^m| < p$:
7. $r_b \leftarrow r_m, p \leftarrow |OA \cap V_r^m|$
8. END IF
9. END FOR
10. ELSE IF $t_b \in [t_2, t_3]$ and $t_e > t_3$:
11. FOR $\forall r_m(V_r^m, E_r^m, s_a^m) \in R_k$ in order:
12. IF $|OA \cap V_r^m| < p$:
13. $r_b \leftarrow r_m, p \leftarrow |OA \cap V_r^m|, q \leftarrow |RA \cap V_r^m|$
14. ELSE IF $|OA \cap V_r^m| == p$ and $|RA \cap V_r^m| < q$:
15. Same as Step 13.
16. END IF
17. END FOR
18. END IF
19. The same as Step 12-18 in Algorithm I.

A2RSA is based on SWK algorithm. So at Step 19 in Algorithm II, A2RSA follows the weight updating policy as SWK does. In the beginning, A2RSA filters all available paths to find the feasible solution set R_k in Step 2. Then in Step 3, A2RSA initializes the best solution r_b as the first element of R_k, and records the node number of OA and RA as p and q in the routing path of r_b. According to the traffic variation in different areas, A2RSA introduces two special path selection methods, i.e., the first segment between Step 4 and Step 9, and the second segment between Step 10 and Step 18. Table 1 shows the path selection cases for two source-destination requests to explain these two segments. In the first segment, A2RSA handles the connection requests who arrive before t_2 and leave in $[t_2, t_3]$. In $[t_1, t_2]$, the traffic increases from the valley in all areas. There is enough spectrum resource at this time. However, in $[t_2, t_3]$ when both the OA and the CA reach its traffic peak, the blocking occurs. These requests handled in the first segment have continuous influence from t_1 to t_3. Therefore, A2RSA considers using the best solution r_b which goes through the minimum of OA nodes, as the IF statement at Step 6 shows. For example, the paths with 1.1 and 1.2 in Tab. 1 have the same hop counts from node 3 to node 32, which is on the topology of Fig. 2. A2RSA would choose path 1.1 as the best option because its p value is less than path 1.2. In the second segment, A2RSA handles the connection requests who arrive in $[t_2, t_3]$ and leave after t_3. After t_3, the traffic in OA begins to decrease, but the traffic in RA is coming to its peak. Therefore, A2RSA needs to consider both the current heavy traffic load in OA and future heavy traffic load in RA by comparing p and q at the IF statement from Step 12 to Step 16. As two paths 2.1 and 2.2 in Tab. 1 show, when the p values of these paths are the same, A2RSA will choose the one with minimal q value. Because RA will reach the peak after t_3.

TABLE 1. Path selection in A2RSA.

ID	Source-Destination	Routing Path	p	q
1.1	3→32	3→6→10→18→24→32	0	2
1.2	3→32	3→7→11→19→25→32	2	2
2.1	28→37	28→20→27→26→33→37	0	2
2.2	28→37	28→36→35→34→38→37	0	0

C. TIME-COMPLEXITY ANALYSIS

In this subsection, we analyze the average time complexity of the MHK, SWK, and A2RSA.

1) Time Complexity of MHK and SWK: The time complexity depends on Yen's algorithm at Step 3 in Algorithm I, and the FOR loop between Step 4 and Step 11. As proved by Bouillet [28], the time complexity of path calculation using Yen's algorithm is $O(k|V|(|E| + |V| \log |V|))$. In the FOR loop, S slots should be checked on each link of the k paths. The max hop count for the routing path is $|V| - 1$. Therefore, the average time complexity of MHK and SWK is:

$$\begin{aligned} T_{MS} &= O(k|V|(|E| + |V| \log |V|)) \\ &\quad + O(k \cdot S(|V| - 1)) \\ &= O(k|V|(S + |E| + |V| \log |V|)) \end{aligned} \tag{4}$$

2) Time Complexity of A2RSA: Compared to SWK algorithm, A2RSA adds the comparison for k paths for two kinds of connection requests. In comparison, A2RSA counts the number of passed nodes in OA and CA. Therefore, the average time complexity of A2RSA is:

$$T_{A2} = T_{MS} + O(k|V|) = T_{MS} \tag{5}$$

IV. NUMERICAL EVALUATION

In this section, the proposed tidal traffic model MSTM and heuristic algorithm A2RSA are implemented on the metro optical network shown in Fig. 2. Also, the benchmarks MHK and SWK are introduced for comparison.

According to the mobile traffic data collected in Shanghai, the four key timepoints t_1, t_2, t_3 and t_4 in MSTM are set as 6, 10, 18, and 22, respectively. In the connection requests, the expected value of the average holding time for the connections is set as 2 hours, and the required slot number is random between $[1, 2]$. Figure 3 shows the demonstration of

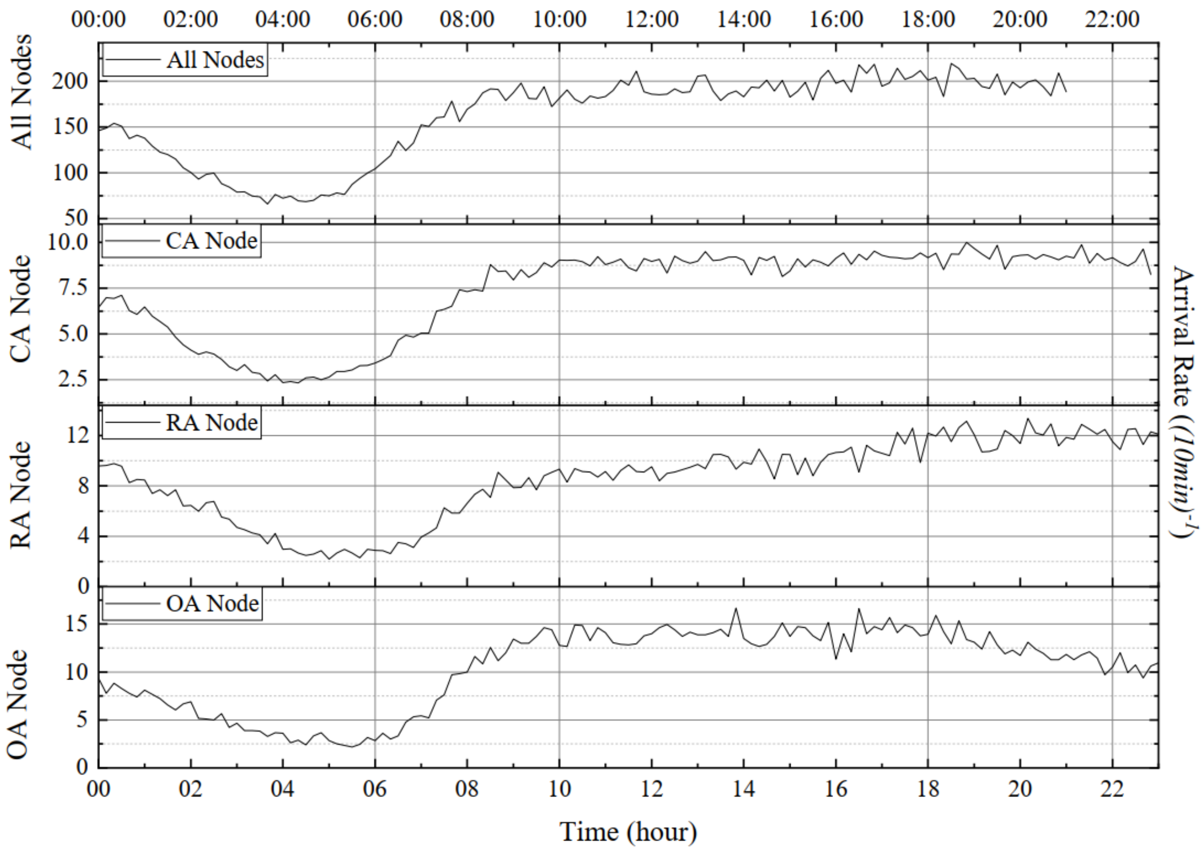

FIGURE 3. Demonstration of the traffic load in MSTM.

the traffic load (arrival rate) in MSTM scenario. The period to summary the traffic is set as 10 minutes to smooth the curves, hence the unit of traffic load is $(10\,\min s)^{-1}$ in all four subgraphs of Fig. 3. The baseline in all areas is set as $\beta = \beta' = \beta'' = 0.1$, and the coefficients of the trigonometric segments are set as $\alpha_1 = \alpha'' = \alpha_2 = \alpha'_2 = 0.15$ and $\alpha'_1 = 0.25$. The first subgraph of all nodes shows the traffic load for the whole network, which is the sum of all connection requests. This subgraph explains the universal traffic fluctuation for the whole metro network, i.e., the traffic load reaches the valley in the dead of night, and remains high level in the rest of the day. The rest of the three subgraphs show the average traffic load on each node. The values of the traffic load are not equal to the baseline, for example, the β' shown in the fourth subgraph is about 2.35 $(10\,\min s)^{-1}$, i.e., 0.235 $\min^{-1}$, but not the definition of 0.1. Because all the connections are bidirectional, and the target nodes of the requests are randomly selected.

A. BLOCKING PROBABILITY

Figure 4 shows the variation of the blocking probability (BP) for all algorithms per day. In Fig. 4(a), the x-axis is the multiple coefficients for the baseline configuration of MSTM model. For example, for the multiple value c, the configuration of MSTM is $\beta = \beta' = \beta'' = 0.1c$, $\alpha_1 = \alpha'' = \alpha_2 = \alpha'_2 = 0.15c$, and $\alpha'_1 = 0.25c$. With the increasement of the k, the BP increases for all algorithms. Because more calculated routing paths provide more options for resource allocation. However, when k becomes larger, the difference between the BP of k and the BP of k-1 is smaller. Because the resource potential gets weaker. In the comparison among different algorithms with the same k (2, 3, 4, and 5), SWK and A2RSA perform better than MHK obviously. And the BP of A2RSA is lower than the BP of SWK. Because A2RSA adjusts the path selection policy for the daytime. The difference between A2RSA and SWK becomes smaller with the increase of k, which is because the path selection policy becomes less influential. Fig. 4(b) shows the performance improvement for A2RSA compared to SWK with the same k, which is the BP ratio of the difference to SWK. When the traffic load is relatively light, the performance improvement becomes significant. The best improvement could reach 47%, and bad improvement is at least 2%.

In the tidal traffic scenario, the phenomenon of connection blocking happens mainly in $[t_2, t_4]$, as Fig. 5 shows. In the traffic peak at about t_3 (18:00), the BPs of A2RSA are not always lower than the BPs of SWK. They are almost the same at that time. Because the path selection policy of A2RSA doesn't work when the blocking is serious. However, at both ends when the blocking happens as the green blocks and the yellow blocks show, the BPs of A2RSA are always lower than the BPs of SWK. In these green blocks, A2RSA benefits from the policy at Step 4-9 in Algorithm II, which remains

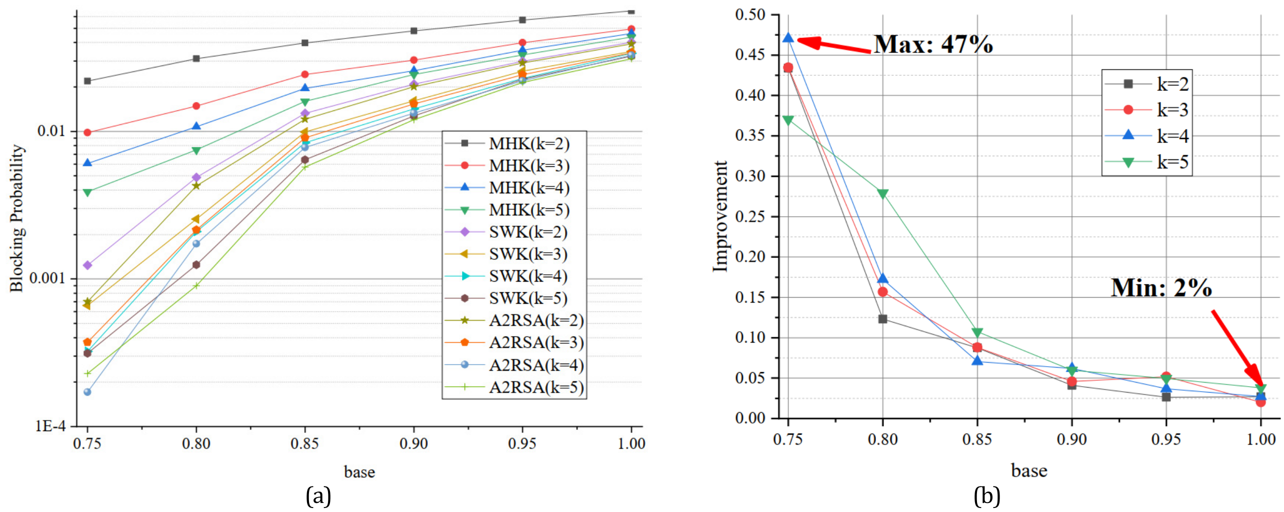

FIGURE 4. **(a) Blocking probability of the algorithms with different k and base; (b) The performance improvement of the algorithms with different k and base.**

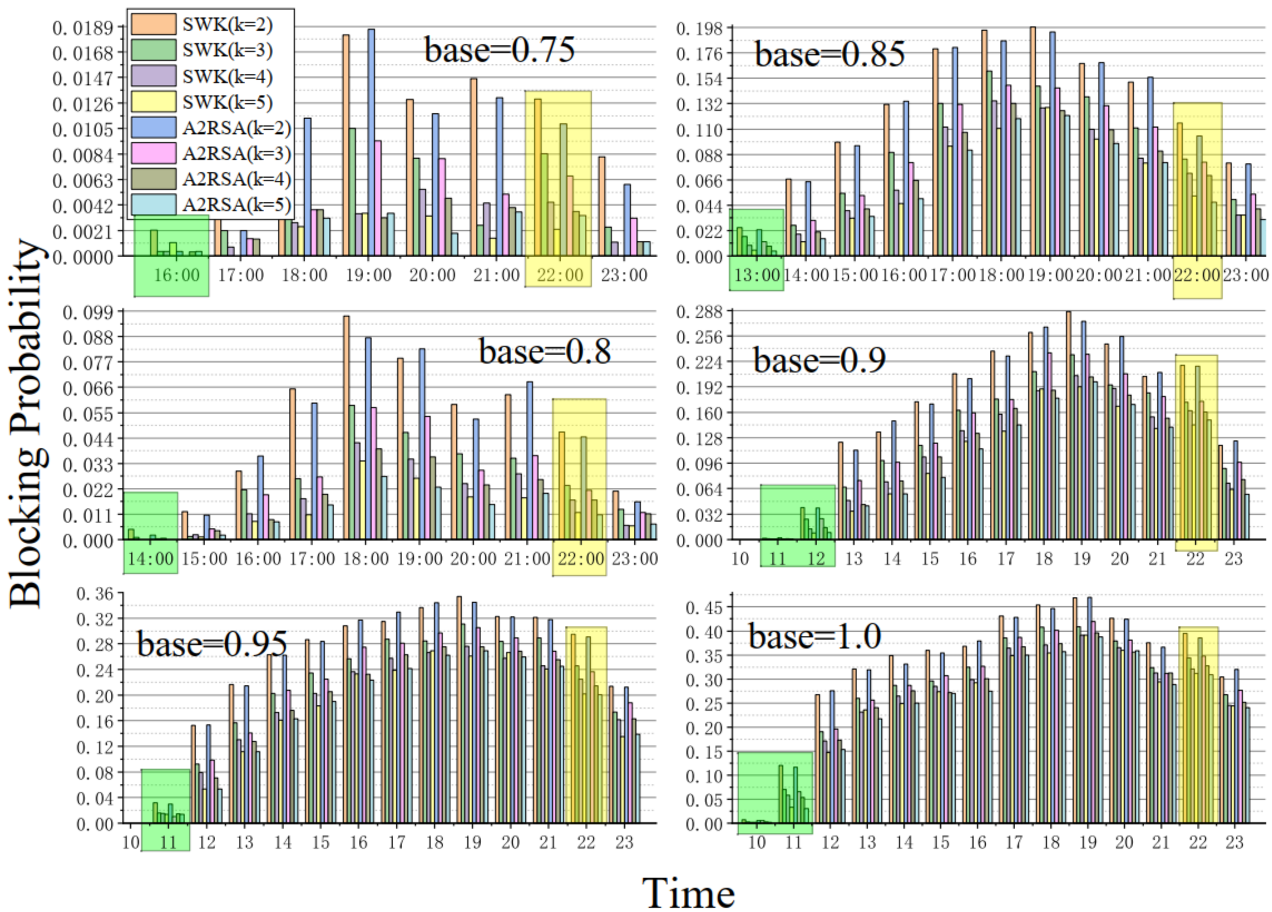

FIGURE 5. **Blocking probability in one day with different k and base.**

more resources for the rising traffic loads. In these yellow blocks (i.e. at about t_4), A2RSA benefits from the policy at Step 10-18 in Algorithms II. Because the adjustment for those requests that leave after t_3 influences on the resource allocation when the traffic load decreases after t_4.

B. RUNNING TIME

Figure 6 shows the average time cost of each algorithm in millisecond. According to section III.C, the average time complexities of all algorithms are the same. However, the differences among them in the simulation are still obvious. The

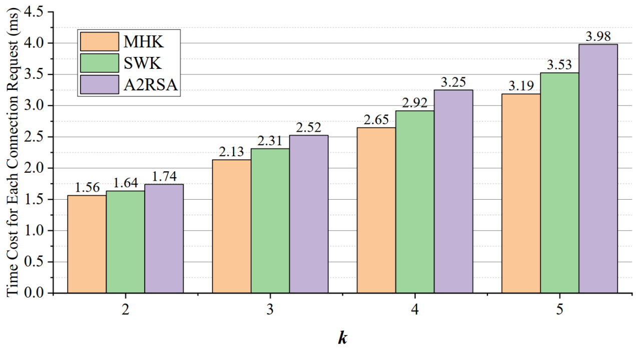

FIGURE 6. Running time for different algorithms.

time cost of A2RSA is always larger than the time cost of SWK, and the time cost of MHK is always the minimal one. The reason is that compared to MHK, the weights updating in SWK cost additional time. In reality, the developer could calculate all minimal-hop routing paths for all possible source-destination pairs, and store them in advance. In this case, MHK only needs to get the existed paths, which reduces the path calculating time, and makes the time cost of MHK lower. Compared to SWK, A2RSA needs to search for all feasible solutions on all calculated k routing paths at Step 2 in Algorithm II. And SWK only needs to search the first feasible one, and jump to the end at Step 8 in Algorithm I. That's the reason that A2RSA costs a little more time than SWK. Additionally, with the increment of k, the time cost of all algorithms increases in a linear way. This trend conforms to the analysis in Section III.C.

V. CONCLUSION

This paper proposes a tidal traffic model named Multi-Step Trigonometric Model (MSTM) for metro elastic optical networks. MSTM divides the city into three kinds of areas (office area, residential area, and comprehensive area), and defines the traffic trends for different time periods. By using the characteristics of MSTM, the area-aware RSA (A2RSA) algorithm is proposed to improve the network performance. Compared to the benchmark algorithms, A2RSA considers the different path selection policies for those connection requests that cross multiple time periods. The simulation results show that A2RSA is able to reduce the blocking probability while keeping the time complexity.

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