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SLA Constraint Quickest Path Problem for Data Transmission Services in Capacitated Networks

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Abstract

In this paper, an extension has been made on the quickest path problem (QPP) with a constraint of service level agreements and energy required for the data transmission services. This new variant of QPP strengthens the applicability of QPP with criticality of data transmission service. The criticality of service is measured in terms of the requested service completion time and mean time of failure of service. The selection of the values of the constraint plays an important role in the computation of the SLA constraint quickest path problem (SLAQPP) for the data transmission services. The variation of SLA has been analysed to obtain the pattern of selection of number of SLAQPP paths. The proposed algorithm is tested on serval benchmark networks and random networks, providing results after computation of SLAQPP. The results show that the proposed algorithm outperforms several existing algorithms in terms of selection of paths and computation time.

Keywords: quickest path problem; service level agreements constraint; reliability; minimization problem; computer communication network

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1. Introduction

In the past decades, the advancement of technology [1] has made it possible to utilize computer communication networks (CCN) resources for the data transmission services of several applications. These data transmission services are sometime denoted as missions and divided into certain categories such as general mission, moderate mission, and critical mission [2]. Each mission is associated with different requirements. Some applications are associated with CCN requests for data transmission services [3]. These services fall under the category of mission critical services [4]. For mission critical services, data transmission services must be quick, and hence the quickest path problem (QPP) emerged [5]. The QPP is the path problem that minimizes the transmission time of a data transmission service. This transmission time depends mainly on two terms: the additive function of delay along the path and the bottleneck function of the path, which is the minimum capacity along the path. This problem of data transmission services in CCN was pioneered first by [5], but before this, [6] had proposed this type of model for convoy-type traffic. The authors in [7] proposed the evacuation problem model with the single evacuation path.

Certain extensions and different variants of QPP have been taken account by various researchers, such as the constrained QPP [8-15] k-QPP [16-18] and QPP in stochastic-flow networks [19-20]. An exhaustive literature survey of QPP has been explored by [21]. Various extensions of QPP have been made into reliable QPP [22], energy QPP [23], QoS QPP [24], fast and fine QPP [25], and residual energy QPP [26-27]. Although these papers presented the constraint QPP model, its complexity would be the same as the QPP models proposed for the computation of QPP. This concept is also extended with the reliability; therefore, extensions of QPP have been made by the authors in [28-29] and [30]. The problem QPP is also deeply studied in different application fields such as transportation [31-34] cargo shipments [35], healthcare [36-37], and evacuation [38].

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1.1. Motivation

This paper addresses the general existing QPP model of data transmission services with the consideration of SLAs. When QPP was formulated, it was thought that if transmitted from a source end, it should be received at the destination end. There was no provision for data transmission services with boundaries. However, as different applications became integrated with CCN, some of the mission critical applications requested for assured data transmission services [24]; therefore, SLAs came into consideration for the assurance [27]. These SLAs are the certain rules, terms, and conditions that are signed between service users and service providers. For the CCN, these SLAs are drawn in terms of the requested service time and service mean time between failure [38]. In this paper, we introduced the SLA constraint quickest path problem (SLAQPP), which computes the quickest path where each node, computer, switch, or router is able to satisfy the SLAs for the data transmission service. We formulate the problem and propose a polynomial time algorithm that is based on the computation of the shortest path with minimum time in different sub-networks of the original network.

1.2. Research Contributions

The main outcomes of the proposed model are listed as below:

- The SLA constraint QPP model is a good indicator of satisfying the SLAs; therefore, using SLAs before transmitting data between two ends saves resources.
- The SLA constraint gives only the nodes that can take part for the specific nodes.
- The analysis of SLA satisfaction to the QPP allows us to explore the certain issues in the different fields.
- The variation pattern of the set of SLAQPP paths shows the impact of choosing SLAs on the selection of SLA satisfied paths.

1.3. Organization

The paper is divided into sections and sub-sections. Section 2 presents the background of the proposed model. The mathematical modeling of the proposed model is explained in Section 3. A theoretical illustration of an example is presented in Section 4 to promote understanding of the concepts, followed by the performance analysis in Section 5. An algorithm and its complexity are discussed in Section 6. Results are dictated in Section 7. Finally, in the last section, conclusions are drawn.

2. Preliminaries

A CCN has been modeled as a graph G, which has N number of nodes and E number of links. Each node is connected with the consecutive node u to another node v and forms a link (u, v). Every link (u, v) of the CCN is associated with certain performance parameters, such as delay $d(u, v)$ and capacity $c(u, v)$. A data transmission service σ is requested to transmit between two specific ends source s and destination t nodes.

For the data transmission services with constant flow rate ρ along the links (u, v), the link capacity is requested to be greater than or equal to the constant flow rate, i.e., $\rho \leq c(u, v)$. Using the definition of QPP [5, 9], the minimum transmission time along a link (u, v) calculated with the maximum flow rate is

$$T_\sigma(u, v) = d(u, v) + \left\lceil \frac{\sigma}{c(u, v)} \right\rceil \tag{1}$$

For a loop-less path P from a node $s = u_1$ to a node $t = u_k$, the path P is $(s = u_1, \cdots, u_k = t)$, $\exists\, u_i \in N, i = 1,2, \cdots, k$, and $(u_i, u_{i+1}) \in E, i = 1, 2, \cdots, k - 1$.

By using the definition of terms present in Equation (1), the minimum transmission time occurring while path P is computed is given as

$$T_\sigma(P) = d(P) + \frac{\sigma}{c(P)} \tag{2}$$

In Equation (2), the term $d(P)$ is the delay of a path P calculated as

$$d(P)=\sum_{i=1}^{k-1} d(u_i,u_{i+1})$$

and the term is the capacity given as $c(P)=\min_{i=1,2,\cdots,k-1} c(u_i,u_{i+1})$. By using all this terminology in Equation (2), the minimum transmission time along path P is given as

$$T_\sigma(P)=\sum_{i=1}^{k-1} d(u_i,u_{i+1})+\left\lceil\frac{\sigma}{\underset{i=1,2,\cdots,k-1}{min} c(u_i,u_{i+1})}\right\rceil \tag{3}$$

Equation (3) is useful to demonstrate the QPP formulations, as below [9]:

$$\underset{P}{min}\, T_\sigma(P) \\ \text{s.t. } P \text{ is a } s-t \text{ path in the network } G \tag{4}$$

In general, the optimality of a path has a great influence on data transmission services, which is the general characteristic. When the data transmission service is very small, then the data transmission time mainly depends on the delay parameter, which can be a good solution. If the request for data transmission services is very large, then the transmission time is controlled by the maximum capacity, where the path has to follow the maximum capacity of the path [23]. Also, it is worth mentioning that QPP does not follow the principle of optimality; if a path (P) is the optimum, then it is not necessary that its sub-path will be the optimum.

3. Proposed System Model

The list of assumptions is given as follows:

- Capacity and delay are uniformly generated from the uniform distribution, and they are statistically independent.
- The traffic follows the law of conservation.
- Each node and link of network is perfect during data transmission services.

Consider that $G(N,E)$ as discussed in the previous section has been requested for a (σ) unit data transmission service, which is initiated with requested SLAs [39]. These SLAs are quantified in terms of the requested service time (t_s) and mean time to failure $(MTTF_s)$. As data transmission services occur within seconds, units for both SLAs are considered in seconds (sec). These SLAs play a very important role in the criticality of data transmission services; therefore, it is necessary to model all the performance parameters of the link, data transmission service, and SLAs into a single link performance parameter [40]. This parameter is called the service performance factor (SPF) of a link (u,v), i.e., $SPF(u,v)$. It is derived as

$$SPF(u,v)=e^{-\left[\frac{d(u,v)+\frac{\sigma}{c(u,v)}}{MTTF_s}\right]} \tag{5}$$

A CCN can be a combination of different number of nodes, where each node can be represented either with nodes, users, switches, or service providers. For a data transmission service, a path is formed by combination of links (u,v). Each node is associated with the requested service performance factor $(RSPF_u)$ derived from the requested SLAs. The RSPF is given as below:

$$RSPF_u=e^{-\frac{t_s}{MTTF_s}} \tag{6}$$

To satisfy the SLAs, it is worth considering the consecutive link or nodes rather than the completion of the data transmission services. For the SLA satisfaction, $SPF(u,v)$ must be greater than $RSPF_u$, i.e., $SPF(u,v)\geq RSPF_u$ is denoted by the residual service performance factor $\left(RRSPF_u(\sigma,P)\right)$ and defined as the value of $RSPF_u$ left at node (u) after the data transmission service with the value of $SPF(u,v)$. Therefore, using Equations (5) and (6), the residual service performance factor $(RRSPF_u(\sigma,P))$ is calculated as below:

$$RRSPF_u(\sigma, P) = \begin{cases} -ln[RSPF_u] - \{-ln[SPF(u_i, u_{i+1})]\}, & \text{if } u = u_i, i = 1,2,\cdots,k-1 \\ -ln[RSPF_u], & \text{otherwise} \end{cases} \quad (7)$$

Now, a path is said to be feasible if and only if $RRSPF_u(\sigma, P) \geq 0, \forall\, u \in N$; therefore, feasibility of the path (P) is calculated in terms of supporting the requested service performance factor $(RSPF_u)$ of the nodes to transmit the data service using path capacity $c(P)$. In this paper, the capacity of path $c(P)$ has been considered rather than the link capacity $c(u, v)$, because the path capacity $c(P)$ is the minimum capacity of the links in the path (P), which takes part in the data transmission services to support the constant flow rate without any buffer.

Hence, the SLA constraint quickest path problem (SLAQPP) can be formulated to find an $s - t$ path, and it is given as

$$\begin{gathered} \min_{P} T_\sigma(P) \\ \text{Subject to constraint} \\ RRSPF_u(\sigma, P) \geq 0, u \in N \\ P \text{ is a } s - t \text{ path in the network } G \end{gathered} \quad (8)$$

The main characteristic of the SLA constraint on the residual requested service performance parameter allows us to develop an algorithm to find the SLA constraint quickest path problem for data transmission services on the different sub-networks of the original network (G), which guarantees the SLA satisfaction.

Without loss of generality, let us assume that there are r number of different link capacities sorted in the increasing order, i.e., $c_1 < c_2 < c_3 < \cdots < c_r$ in the network (G).

To transmit data with SLA satisfaction, data need to be transmitted with a constant flow rate and without a loss of generality. The label of the minimum SLA satisfaction capacity of link $c_{\min}(u, v)$ is given as

$$c_{min}(u, v) = \min_{i=1,\cdots,r} \{c_i \; : \; -ln[RSPF_u] - \{-ln[SPF(u_i, u_{i+1})]\} \geq 0\} \quad (9)$$

Equation (9) gives the label of a minimum SLA satisfaction capacity of the link (u, v) for the data transmission service over the $s - t$ path (P). Therefore, by satisfying the $(RSPF_u)$, the path (P) has also been satisfied.

Here, one point has to note down that a link (u, v) constituting the $s - t$ path P is said to be feasible if and only if it follows the condition shown in the equation below:

$$c(P) \geq c_{min}(u, v) \quad (10)$$

A CCN is divided into different sub-networks (G_j) equal to the number of distinct link capacities (c_j). The SLA satisfied links are sorted in the sub-networks (G_j) and are given as

$$c_{min}(u, v) \leq c_j \leq c(u, v); \text{ where value of } j = 1, \cdots, r \quad (11)$$

4. Theoretical Illustration

An illustration of the theoretical results has been given to provide insight into the concepts, which are useful for the proposal of an algorithm with the help of a benchmark topology [5, 9, 20, 41].

The data transmission service of 100 Mb is sent from node 1 to node 5 with the requested service time ($t_s = 240$) and mean time to failure of service ($MTTF_S = 1500$). The value of link delay and link capacity has been associated to each link and shown in Figure 2(a).

The given network has been associated with distinct capacities, and the number of different capacities present in the network is equal to five.

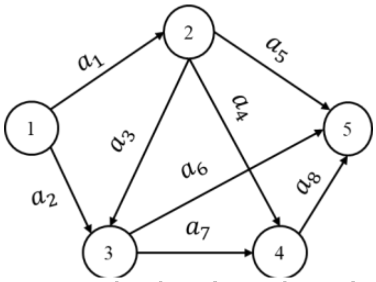


Figure 1. Benchmark topology with arc values

Illustration of theoretical results has been given for the insight understanding of the concepts which are useful for the proposal of an algorithm with the help of a benchmark topology [7,8,14,24] as shown in Figure 1. To understand the concepts, we have illustrated the theoretical results with the help of a simple example explained in certain steps. The benchmark topology has been used to explain and strengthen the concepts.

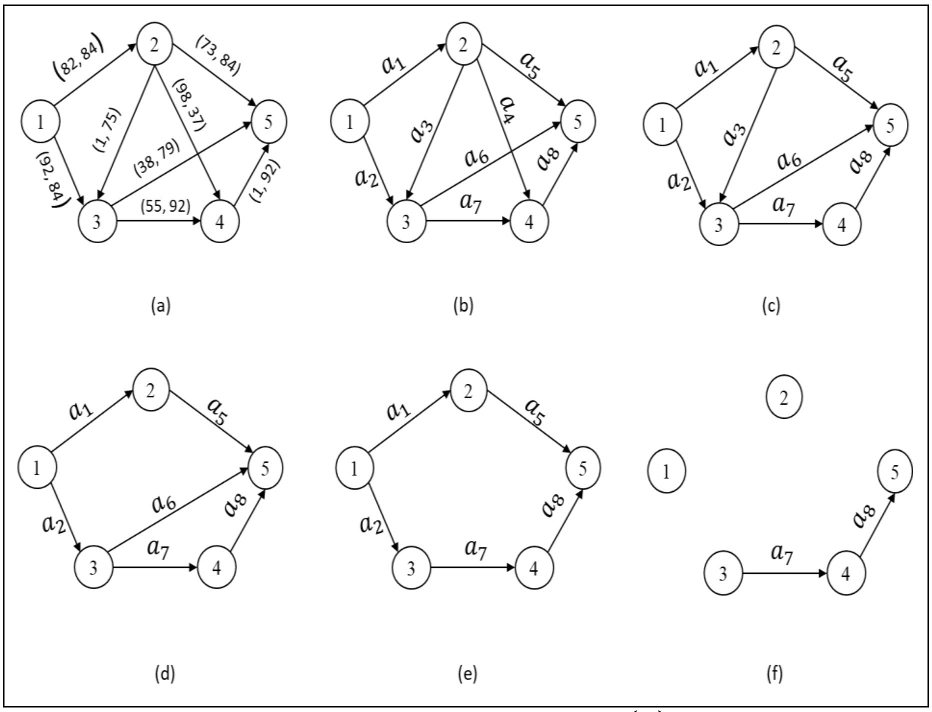


Figure 2. The SLA satisfied sub-networks (G_j)

Therefore, the network is divided into five different sub-networks, as shown in Figure 2. Also, each node is associated with the RSPF computed using Equation (6); therefore, theoretical results of different paths are given in Table 1.

Table 1. Theoretical results of the SLAQPP

Capacity	Selected Path	Transmission Time $T_\sigma(P)$	Comment
37	$1-2-3-5$	123.7027	No
75	$1-2-3-5$	122.3333	Minimum
79	$1-3-5$	129.2658	No
84	$1-3-4-5$	147.1905	No
92	No Path	INF	No path

The results show that the path having a capacity of 75 $Mbpsec$ is the path with the minimum transmission time, which is an SLA satisfied path for $\sigma = 100\ Mb$ data transmission services.

After presenting the results, it is necessary to state certain lemmas and theorems with their proofs, which are required for the feasibility of a path in the given topology.

5. Performance Analysis

Lemma 1: Let path $P = (s = u_1, u_2, \cdots, u_k = t)$ be an SLA satisfied $s - t$ path (P) in sub-network (G_j), and then path (P) is said to be an $s - t$ feasible path computed for SLAQPP.

***Proof*:** The proof of Lemma 1 is given as if an $s - t$ path (P) is an SLA satisfied $s - t$ path in the computer network (G_j), and then the capacity of the path follows $c(P) \geq c_j \geq c_{\min}(u_i, u_{i+1})$, where $i = 1, \cdots, k-1$. Therefore,

$$RRSPF_{u_i}(\sigma, P) = e^{\frac{-\left[\sum_{i=1}^{k-1} d(u_i,u_{i+1}) + \frac{\sigma}{c(P)}\right]}{MTTF_S}} - \prod_{i=1}^{k} r_{u_i} \geq e^{\frac{-\left[\sum_{i=1}^{k-1} d(u_i,u_{i+1}) + \frac{\sigma}{c_{\min}{}_{i=1}^{k-1}(u_i,u_{i+1})}\right]}{MTTF_S}} - \prod_{i=1}^{k} r_{u_i} \geq 0$$

Lemma 2: The Lemma 2 states that if an $s - t$ path (P) is said to be a feasible path having path capacity $c\,(P) = c_j$, then the path (P) is said to be a path (P) in network (G_j).

***Proof*:** The proof of Lemma 2 relies on Lemma 1 so we must use Lemma 1. Let path (P) be a feasible path:

$$RRSPF_u(\sigma, P) = e^{\frac{-\left[d(u_i,u_{i+1}) + \frac{\sigma}{c(P)}\right]}{MTTF_S}} - RSPF_{u_i} \geq 0,\ i = 1, 2, \cdots, k-1$$

Hence, using Equation (11), Lemma 2 is proven as $c_{min}(u_i, u_{i+1}) \leq c(P) = c_j \leq c(u_i, u_{i+1})$, where $i = 1, 2, \cdots, k-1$, and therefore we conclude here that $(u_i, u_{i+1}), i = 1, 2, \cdots, k-1$ are the sorted links existing in (E_j). Hence, path (P) is an $s - t$ path in the network (G_j).

Here, in this paper, it is worth mentioning that an $s - t$ feasible path (P) for the SLAQPP with capacity $c(P) > c_j$ is not necessarily an $s - t$ path in the network (G_j). It can also be mentioned that the network (G_j) contains the $s - t$ paths (P) that are feasible for the SLAQPP having the capacity greater than or equal to c_j, for which Lemma 2 is proven, i.e., nodes that are SLA satisfied will take part in the data transmission services. If there is no $s - t$ path in the network (G_j) taking part in the data transmission services, then there is no optimal solution with capacity (c_j) in the network (G_j).

In this paper, the main priority of routing is to transmit the data services in minimum time, i.e., quick with SLA constraint. Therefore, SLAQPP computes the shortest path problem (SPP) with respect to the delay time $(d(u, v))$ in the network (G_j).

$$\begin{gathered} \text{SPP}_j \quad : \quad \min_P d(P) \\ \text{Subject to constraint} \\ \text{Path } P \text{ is an } s - t \text{ path in the network } (G_j) \end{gathered} \tag{12}$$

Equation (12) allows us to prove Lemma 3 immediately for the optimal solution of SPP_j, as shown above.

Lemma 3: Let path (P) be an optimal solution for the path commutated for the SLAQPP using SPP_j, and the path capacity is given as $c(P) = c_h > c_j$. Then, there is no other optimal solution for the SLAQPP having the capacity (c_j).

***Proof*:** To prove Lemma 3, let us assume that another path (Q) is an $s - t$ feasible path for the SLAQPP path having a capacity of (c_j), and then path (Q) is a path in network (G_i), as illustrated below:

$$T_\sigma(P) = d(P) + \frac{\sigma}{c_h} < d(Q) + \frac{\sigma}{c_j} = T_\sigma(Q)$$

Thus, path (Q) cannot be an optimal solution for the SLAQPP, as $T_\sigma(P) < T_\sigma(Q)$.

Theorem 1: Let a path $(\tilde{P})$ be an optimal solution for the SLAQPP, and the path has a capacity of $(\tilde{P}) = c_h$. Then, the path $(\tilde{P})$ is an optimal solution of (SPP_h), and any optimal solution of (SPP_h) is an optimal solution.

***Proof*:** Since the path $(\tilde{P})$ is an $s-t$ feasible path for the SLAQPP having a capacity of $c(\tilde{P})=c_h$), then path $(\tilde{P})$ is an $s-t$ path in the network (G_h). Let path (Q) be an $s-t$ feasible path in the network (G_h), then $c(Q)\geq c_h$. If $d(Q)<d(\tilde{P})$, then

$$T_\sigma(Q)=d(Q)+\frac{\sigma}{c(Q)}<d(\tilde{P})+\frac{\sigma}{c_h}=T_\sigma(\tilde{P})$$

This contradicts the above dictated equation of the proof of optimality of solutions of path $(\tilde{P})$. Furthermore, by applying Lemma 3, the capacity of any $s-t$ shortest path (P^*) in the network (G_h) is $c(P^*)=c_h$. Hence, path (P^*) is an $s-t$ feasible path for the SLAQPP such that $T_\sigma(P^*)=T_\sigma(\tilde{P})$, and so it is an optimal solution of the SLAQPP.

6. Algorithm and Time Complexity

In this section, an algorithm is proposed for the computation of the SLA satisfied quickest path problem (SLAQPP) followed by the time complexity analysis.

6.1. Algorithm

Algorithm: SLA satisfied quickest path problem (SLAQPP) data transmission service

Input: A network $\boldsymbol{G(N,E)}$ link delay and capacity $(\boldsymbol{d},\boldsymbol{c})$, respectively, connection request $\boldsymbol{s-t}$, requested SLA $\boldsymbol{t_s}$, and $\boldsymbol{MTTF_s}$.
Output: SLAQPP data transmission service or null.
Begin {
1. Sort the links of network graph to satisfy the SLA parameters using Equation (11).
2. Sort the sub-networks as $\boldsymbol{G_j(N,E_j)}$ using (12).
3. Use Dijkstra's algorithm to find the $\boldsymbol{s-t}$ path using delay of links $\boldsymbol{d(u,v)}$.
4. Find **min** $\{\boldsymbol{T_\sigma(P)}\}$ for each $\boldsymbol{s-t}$ path $\boldsymbol{P}$ in each sub-network $\boldsymbol{G_j(N,E_j)}$.
5. If a $\boldsymbol{s-t}$ path exists, then the path is SLAQPP or null.

}
End

6.2. Complexity Analysis

The performance of an algorithm relies on its time complexity, so time complexity analysis of the proposed algorithm is presented as Theorem 2.

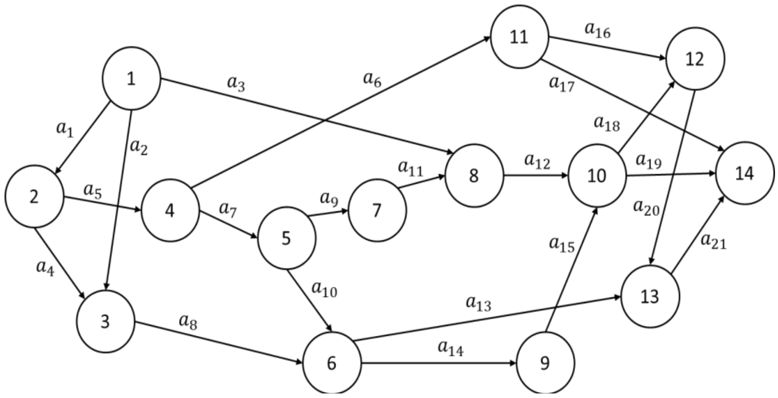
Theorem 2: The time complexity of SLAQPP is given as $O(r(m+n(\log(n)))$.

***Proof*:** The time complexity of the proposed algorithm SLAQPP is explained step by step using the algorithm presented in the previous section. Step 1 is used to sort the links after satisfying the SLA constraint with a time complexity of $O(1)$. In step 2, different sub-networks are sorted, which are equal to the (r) number of distinct link capacities with a time complexity of $O(r)$. For the computation of SLA satisfying the $s-t$ path for data transmission, the Dijkstra algorithm SPP_j is used in step 3 with a time complexity of $O(m+n(log\ (n))$ [42]. There are r different sub-networks present; therefore, the time complexity is given as $O(r(m+n(log\ (n)))$. Step 4 is used to find the minimum transmission time of a path (P) from the complete set of solutions. Step 5 gives either a SLAQPP or null set.

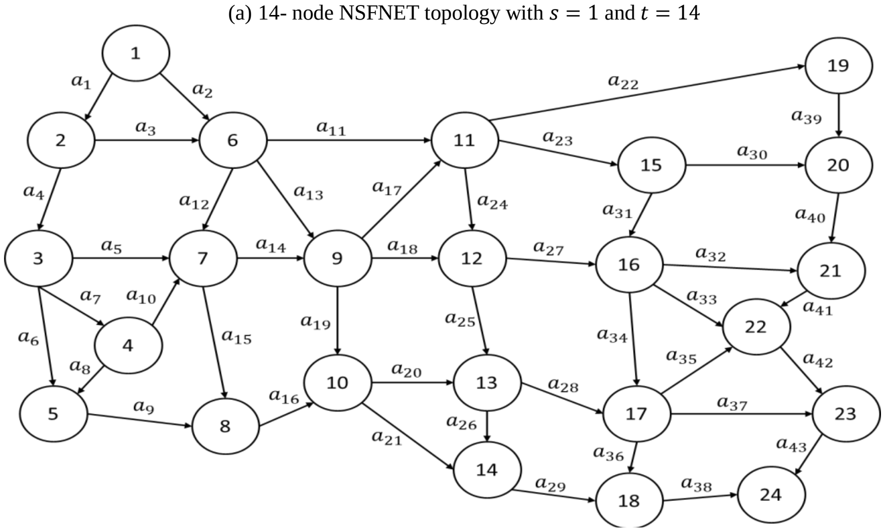
7. Simulation and Results

7.1. Experiment Setup

The experimental results are performed on a personal computer with Intel(R) CoreTMi5–7400, CPU@ 3.00 GHz, 8-GB RAM, and Windows 10 operating system in MATLAB 2013a. The SLAQPP involves the Dijkstra's algorithm, which is solvable in polynomial time. To conduct the simulation experiment, values of the capacities in $Mbpsec$ and delay in sec are generated from the uniform distribution in the range of [1, 100], respectively. Three different data transmission services are requested to send between two specific ends to analyze the performance of the SLAQPP. A service promising contract SLA is drawn between the user and service provider in terms of the requested service time (t_s) in sec and service $MTTF_s$ in sec. The impact of the selection of SLAs has been seen for different values of SLAs. The illustration of the results is performed over different topologies 14-nodes NSFNET directed network with 21 links [43] and 24-nodes USANET directed network with 43 links [44], as shown below in Figures 3(a)-3(b).



(a) 14- node NSFNET topology with $s = 1$ and $t = 14$



(b) 24-node USNET topology with $s = 1$ and $t = 24$

Figure 3. Network topologies

In the above figures, each link is labeled with a link number, and their corresponding fixed values have been given in Tables 2 and 3. The results have been simulated for the 10 Mb amount of data transmission service. Here, the values of SLA considered for the simulations are $t_s = 240$s and $MTTF_s = 1500$s to obtain the path that has the minimum transmission time.

Table 2. Data values for 14-nodes NSFNET associated with each link

Link	$d(u,v)$	$c(u,v)$	Link	$d(u,v)$	$c(u,v)$
a_1	18	87	a_{12}	96	4
a_2	27	99	a_{13}	35	44
a_3	6	46	a_{14}	6	17
a_4	20	17	a_{15}	73	31
a_5	38	46	a_{16}	59	59
a_6	63	46	a_{17}	5	17
a_7	59	99	a_{18}	19	12
a_8	84	59	a_{19}	24	17
a_9	88	87	a_{20}	55	17
a_{10}	37	59	a_{21}	64	34
a_{11}	43	84			

7.2. Results Discussion

In the first column of Table 4, different capacities present in the networks are listed, and $s - t$ is shown in the second column. The third column presents their respected total transmission time, and the last column is used to comment on the selected $s - t$ path. For the topology NSFNET, there are 11 distinct capacities in the selected $s - t$ paths for the NSFNET, which means our algorithm must run 11 times. By analyzing the second column of results of SLAQPP for NSFNET, it is observed that only five distinct capacities provide the $s-t$ paths for the data transmission services. The column third shows that the $s-t$ path ($P=1-3-6-13-14$) is the path with the minimum transmission time, with a path capacity of $c(P)=34\ Mbpsec$.

Table 3. Data values for 24-nodes USANET associated with each link

Link	$d(u,v)$	$c(u,v)$	Link	$d(u,v)$	$c(u,v)$
a_1	14	93	a_{23}	9	99
a_2	42	53	a_{24}	66	87
a_3	30	53	a_{25}	6	49
a_4	19	14	a_{26}	55	37
a_5	61	57	a_{27}	15	25
a_6	6	19	a_{28}	34	49
a_7	37	67	a_{29}	17	57
a_8	99	11	a_{30}	20	49
a_9	44	67	a_{31}	44	18
a_{10}	63	52	a_{32}	96	25
a_{11}	55	87	a_{33}	17	97
a_{12}	58	96	a_{34}	41	52
a_{13}	17	25	a_{35}	54	53
a_{14}	17	87	a_{36}	72	42
a_{15}	15	42	a_{37}	77	66
a_{16}	89	50	a_{38}	34	25
a_{17}	63	50	a_{39}	52	93
a_{18}	40	3	a_{40}	10	42
a_{19}	73	52	a_{41}	88	2
a_{20}	100	53	a_{42}	95	87
a_{21}	42	42	a_{43}	66	97
a_{22}	52	67			

Table 4. Set of the SLAQPP paths for the 14-node NSFNET

Capacities	Selected path	$T_\sigma(P)$	Comment
4	$1-2-4-11-14$	149.0000	No
12	$1-2-4-11-14$	132.3333	No
17	$1-2-4-11-14$	129.8824	No
31	$1-3-6-13-14$	213.2258	No
34	$1-3-6-13-14$	212.9412	Minimum
44	No Path	INF	No path
46	No Path	INF	No path
59	No Path	INF	No path
84	No Path	INF	No path
87	No Path	INF	No path
99	No Path	INF	No path

For the topology USANET, there is a slight increase in the number of nodes and links, so the number of distinct capacities associated to each node in the network is 21. A total of ten distinct capacities are capable for finding the $s-t$ paths for the data transmission services.

Finally, the third column is used to comment on the path with minimum transmission time, and it is shown that the $s-t$ path ($P=1-6-9-10-14-18-24$) with the path capacity of $c(P)=25\ Mbpsec$ has the minimum transmission time.

Table 4 and 5 are used to explain the results for 14-node NSFNET and 24-nodes USANET standard topologies. Furthermore, the SLAQPP results for both topologies have been extended for the three different values of data transmission services $(10, 100, 1000)$ Mb and the three different SLA requested service times $(100, 105, 110)s$. The experiment for SLAQPP has been performed 1000 times to get the relation and pattern of the SLA requested service time and data transmission services.

Table 5. Set of the SLAQPP paths for the 24-nodes USANET

Capacities	Selected path	$T_\sigma(P)$	Comment
2	$1-6-9-12-13-14-18-24$	261.0000	No
3	$1-6-9-12-13-14-18-24$	244.3333	No
11	$1-6-9-10-14-18-24$	234.0909	No
14	$1-6-9-10-14-18-24$	232.1429	No
18	$1-6-9-10-14-18-24$	230.5556	No
19	$1-6-9-10-14-18-24$	230.2632	No
25	$1-6-9-10-14-18-24$	229.0000	Minimum
37	$1-6-11-12-13-17-23-24$	348.7027	No
42	$1-6-11-12-13-17-23-24$	348.3810	No
49	$1-6-11-12-13-17-23-24$	348.0408	No
50	No Path	INF	No path
52	No Path	INF	No path
53	No Path	INF	No path
57	No Path	INF	No path
66	No Path	INF	No path
67	No Path	INF	No path
87	No Path	INF	No path
93	No Path	INF	No path
96	No Path	INF	No path
97	No Path	INF	No path
99	No Path	INF	No path

Table 6. Selection of SLAQPP set of paths for NSFNET with different data transmission services and SLAs

10 Mb data			100 Mb data			1000 Mb data		
100s	240s	400s	100s	240s	400s	100s	240s	400s
5.6	6.1	6.4	3.4	5.0	5.2	1.8	4.0	4.5

Table 7. Selection of SLAQPP set of paths for USANET with different data transmission services and SLAs

10 Mb data			100 Mb data			1000 Mb data		
100s	240s	400s	100s	240s	400s	100s	240s	400s
5.7	6.5	8.0	5.1	5.8	7.4	1.4	5.5	7.1

Further, in Table 6 and 7, SLAQPP results for the both topology have been extended for the three different values of data transmission services $(10, 100, 1000)$ Mb and the three different SLA requested service times $(100, 105, 110)$ secs. The results show that for any fixed value of data transmission service, if we increase the value of the requested service time (t_s) from 100s to 400s, the possibility of getting a number of SLAQPP $s-t$ paths is increased. Also, it has been observed that for a given selected value of the requested service time (t_s), the number of selected SLAQPP $s-t$ paths decreases as we increase the value of the data transmission time from 10 Mb to 1000 Mb.

8. Conclusions

In this paper, we have proposed and introduced the concept of service level agreement satisfaction in the quickest path problem, which is another variant of the quickest path problem that has a side constraint of node availability for the requested data transmission services. By using the properties of constraint, various numbers of shortest paths are computed using the delay function from different sub-networks, which fulfills the SLA constraints. A polynomial algorithm has been proposed to solve the problem with the same time complexity found in existing algorithms. Additionally, the SLAs are varied over a range to analyze the impact of selection of SLAs. The random experiment conducted shows the effectiveness of SLAs in the selection of sets of paths. Finally, it has also been seen that with the variation of data transmission services, there is a variation pattern in the selection of sets of paths.

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