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# Software Engineering Analysis of Communication Networks and Determination of Delivery Time

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***ABSTRACT :****Software engineering is one of the most important systems for automation and monitoring all the engineering work related to the networks of communications and management within the operating system linked to software engineering, especially the emergence of Internet networks of large use of software engineering and this was done by software engineers to develop Software Engineering has implemented software engineering methods for networks, operating systems and operating data One of the important tasks arising in the design of communication systems Software Engineering of distributed computer networks is the task of analyzing their survivability indicators. To solve these problems, it is necessary to develop adequate models for calculating and analyzing the corresponding survivability indicators in failure conditions. For the first time this problem was considered which new indicators of survivability of communication systems were introduced and a methodology for their evaluation was developed As an indicator of survivability, it is suggested to use the maximum flow value, which can be transmitted to the network in the event of failures of its elements when limiting to the average delivery time. However, there is a fairly wide class of networks in which there is some hierarchy of network nodes and it is necessary to introduce additional restrictions on the delivery time between the specified pairs of nodes. This requires the development and generalization of the introduced indicators of the survivability of networks and the development of new models and algorithms for their evaluation and analysis. The algorithm of analysis proposed in the dissertation is based on the algorithm for finding the maximum flow in a communication network under additional constraints.*

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## I. INTRODUCTION

Software engineeringConsider the formulation of the problem of finding the maximum flow in a communication network under constraints. The task of the distributed communication network in the form of digraph G = (X, E), the carrying capacity of all branches and the matrix of requirements; It is required to distribute the streams across all branches and to find such a multi-product flow vector, (r, s) E, as well as the values of the transmitted external traffic for which the value of the transmitted stream over the network is maximized

$$H_{\Sigma}^{(k)} = \sum_i \sum_j h_{ij}^{(k)} \rightarrow MAX$$

Under conditions

$$T_{cep} = \frac{1}{h_{\Sigma}} \left( \sum_{(r,s)\in E} \frac{f_{rs}}{k_{\Gamma}\mu_{rs} - f_{rs}} + \sum_{r=1}^{n} \frac{\Lambda_r}{\mu_r k_{\Gamma} - \Lambda_r} \right) \le T_{зад}$$

And additional conditions

$$\overline{T}_{ij} = \frac{1}{h_{ij}} \left( \sum_{(r,s)\in M_{ij}} \frac{f_{rs}^{(i,j)}}{k_{\Gamma}\mu_{rs} - f_{rs}} + \sum_{r\in M_{ij}} \frac{\Lambda_r}{k_{\Gamma}\mu_r - \Lambda_r} \right) \le T_{ijзад}$$

$h_{ij}^{(k)} \le h_{ij}, \ \forall (i,j) = \overline{1,n}$

$f_{rs}^{(k)} \le \mu_{rs}^{э}, \ \forall (r,s) \in E$

The average delay in the network, - the average delay in the delivery of packets from node i in the j box. The difference in this formulation from the known lies in the presence of additional constraints of the form on the delays between the given pairs of node

. The flow of a requirement, that is, is a flow along the shortest path in the metric $\frac{\partial T_{ij}}{\partial f_{rs}}\Big| f_{rs} = f_{rs}^{(k)}$, $\forall (r,s) \in \pi_{i_1 j_1}$

Where it is determined by the relation

The proof of Theorem 1 is analogous to the proof for case 1. Indeed, suppose that the flow of the requirement is distributed along the path in the distribution of the streams, and the shortest path in the metric less -. Consider the flow obtained by the following variation of the flow F *. Let's reduce the component for by an amount, and for channels increase by. That is

$$\Delta F_{r,s}^{(k)} = \begin{cases} +\Delta h_{i_1 j_1}, åñëè(r,s) \in \pi_{i_1 j_1}^{\min} \\ -\Delta h_{i_1 j_1}, åñëè(r,s) \in M_{ij_{11}} \wedge (r,s) \notin \pi_{i_1 j_1}^{\min} \\ 0, \end{cases}$$

Let us calculate the change in the delay value for such a variation

$$\Delta T_{i_1 j_1}(F^*) = T_{i_1 j_1}(F_1) - T_{i_1 j_1}(F^*) = \sum_{(r,s)} \frac{\partial T_{i_1 j_1}}{\partial f_{rs}} \Delta f_{rs} = \Delta h \Big( \sum_{(r,s)\in\pi_{i_1 j_1}} \frac{\partial T_{i_1 j_1}}{\partial f_{rs}} \Delta f_{rs} - \sum_{(r,s)\in M_{i_1 j_1}} \frac{\partial T_{i_1 j_1}}{\partial f_{rs}} \Delta f_{rs} \Big) =$$

$$= \Delta h \, [\mathrm{l}(\pi_{i_1 j_1}^{\min}) - \mathrm{l}(M_{i_1 j_1})]$$

Because of the assumption

**$\mathrm{l}(\pi_{i_1 j_1}^{\min}) < \mathrm{l}(M_{i_1 j_1})$, то $\Delta T_{i_1 j_1}(F^*) < 0$**

Thus, after this deviation of the flow F *, we reduce the delay compared to. And we get (F1) <. This means that you can

$$\Delta F = F_1 - F^* = \begin{cases} +\Delta h_{i\,j}, \text{ if } (r,s) \in \pi_{i\,j}^{\min} \\ -\Delta h_{i\,j}, \text{ if } (r,s) \in M_{i,j} \\ +\Delta h_{i_k j_k}, \text{ if } (r,s) \in \pi_{i_k j_k}^{\min} \\ -\Delta h_{i_k j_k}, \text{ if } (r,s) \in M_{i_k j_k} \\ 0, \text{ в other cases.} \end{cases}$$

**We find the increment of the criterion**

$$\Delta T_{cp}(F^*) = T_{cp}(F_1) - T_{cp}(F^*) = \sum_{(r,s)\in E} \frac{\partial T_{cp}}{\partial f_{rs}} \Delta f_{r,s} = \Delta h_{i\,j} \sum_{\substack{(r,s)\in\pi_{ij} \\ (r,s)\in M_{ij}}} \frac{\partial T_{cp}}{\partial f_{rs}} + \Delta h_{i_k j_k} \sum_{\substack{(r,s)\in\pi_{i_k j_k} \\ (r,s)\in M_{i_k j_k}}} \frac{\partial T_{cp}}{\partial f_{rs}} =$$

$$= \Delta h_{i\,j} \, (\mathrm{l}(\pi_{i\,j}^{\min}) - \mathrm{l}(M_{ij})) + \Delta h_{i_k j_k} \, (\mathrm{l}(\pi_{i_k j_k}^{\min}) - \mathrm{l}(M_{i_k j_k}))$$

And by virtue of (2.15) $\Delta T_{cp}(F^*) < 0$.

Similarly

$$\Delta T_{ij}(F^*) = T_{ij}(F_1) - T_{ij}(F^*) = \sum_{(r,s)\in M_{i_k j_k}} \frac{\partial \mathrm{T}_{cp}}{\partial f_{rs}} \Delta f_{rs} = \Delta\ h_{i_k j_k}\ (\mathrm{l}(\pi_{i_k j_k}^{\min}) - \mathrm{l}(M_{i_k j_k})) < 0.$$

Consequently, by changing the flow from F * to F1, we ensure a decrease of u. Thus, there is an additional reserve for the PS, and it follows that the flow is not optimal. Thus, the condition that the maximum flow
Consequently, by changing the flow from F * to F1, we ensure a decrease of u. Thus, there is an additional reserve for the PS, and it follows that the flow is not optimal. Thus, the condition that the maximum flow is a flow along the shortest paths is a necessary condition

**The generalized maximum flow problem**

Let us consider a more general case of the maximum flow problem, which takes into account the value of the transmitted information. Let wij be the relative value of the information that must be transferred from node i to node j. Required
for a given set of MSs of the CS and a matrix of requirements, to find such transmission and distribution paths for the flows under which the

**under conditions**

$$\mathrm{T}_{cp}\left(\mathrm{H}^{(k)}\right) = \frac{1}{h_\Sigma}\left( \sum_{(r,s)} \frac{f_{rs}^{(k)}}{\mu_{rs}^{э} - f_{rs}^{(k)}} + \sum_{r} \frac{\lambda_r}{\mu_r k_r - \lambda_r} \right) \le \mathrm{T}_{зад}$$

$$\mathrm{T}_{ij}\left(\mathrm{H}^{(k)}\right) = \frac{1}{h_{ij}}\left( \sum_{(r,s)\in M_{ij}} \frac{f_{rs}^{i,j}}{\mu_{rs}^{э} - f_{rs}^{(k)}} + \sum_{r\in M_{ij}} \frac{\lambda_r^{\,i}}{\mu_r k_r - \lambda_r} \right) \le \mathrm{T}_{ijзад},\ \forall (i,j) \in \mathrm{P}_{зад}$$

The following theorem establishing the priorities in the transfer of claims is valid.
Theorem 3. A requirement dominates the transfer of a requirement if and only if the relations

$$h_{ij} \succ h_{rt} \leftrightarrow \frac{l(\pi_{ij}^{\min})}{w_{ij}} \le \frac{l(\pi_{rt}^{\min})}{w_{ij}}$$

where the sign denotes the dominance of the flow of claims over (i.e., priority transmission).
Proof of Theorem.
So, let the restriction be active. Then, by Theorem 1, the requirements of the packets are transmitted along the shortest paths and in the metric.

$$l_{rt} = \frac{\partial \mathrm{T}_{ij}}{\partial f_{rs}} \Big| f_{rs} = f_{rs}^{(k)}\ .$$

$$\delta(\sum_i \sum_j h_{ij} w_{ij}) = \Delta h_{ij}\ (\mathrm{w_{ij}} - \mathrm{w_{rt}} \frac{l(\pi_{ij})}{l(\pi_{rt})})$$

In addition, let $h_{ij}^{\ (k)} < h_{ij}^{\ зад}$ и $h_{rt}^{\ (k)} < h_{rt}^{\ зад}$ and besides

$$\pi_{ij}^{\min} \cap \pi_{rt}^{\min} \ne \varnothing\ \frac{l(\pi_{ij}^{\min})}{w_{ij}} < \frac{l(\pi_{rt}^{\min})}{w_{rt}}$$

We denote by $F^* = \left[f_{rs}^{\ *}\right]$ the current flow and derive the conditions for its optimality. To do this, consider a new flow F1, which is obtained by varying the flow F * as follows:

$$h_{ij}^{\ \mathrm{k}} = h_{ij} + \Delta h_{ij},\quad h_{rt}^{\ \mathrm{k}} = \Delta h_{i\,j} \sum_{(r,s)\in\pi_{ij}} \frac{\partial \mathrm{T}_{cp}}{\partial f_{rs}} - \Delta\ h_{rt} \sum_{(r,s)\in\pi_{rt}} \frac{\partial \mathrm{T}_{cp}}{\partial f_{rs}} = \Delta h_{i\,j}\ (\mathrm{l}(\pi_{i\,j}^{\min}) - \Delta\ h_{rt}\ (\mathrm{l}(\pi_{rt}^{\min})) = 0\ h_{rt} -$$

$$\Delta h_{rt}\ \Delta f_{r,s}^{(k)} = \Delta T_{cp} = T_{cp}(F_1) - T_{cp}(F^*) = \sum_{(r,s)\in E} \frac{\partial \mathrm{T}_{cp}}{\partial f_{rs}} \Delta f_{r,s} = 0$$

$$\Delta h_{rt} = \Delta h_{ij}\frac{l(\pi_{ij})}{l(\pi_{rt})} = \Delta h_{ij}\, w_{ij} - \Delta h_{rt}\, w_{rt}$$

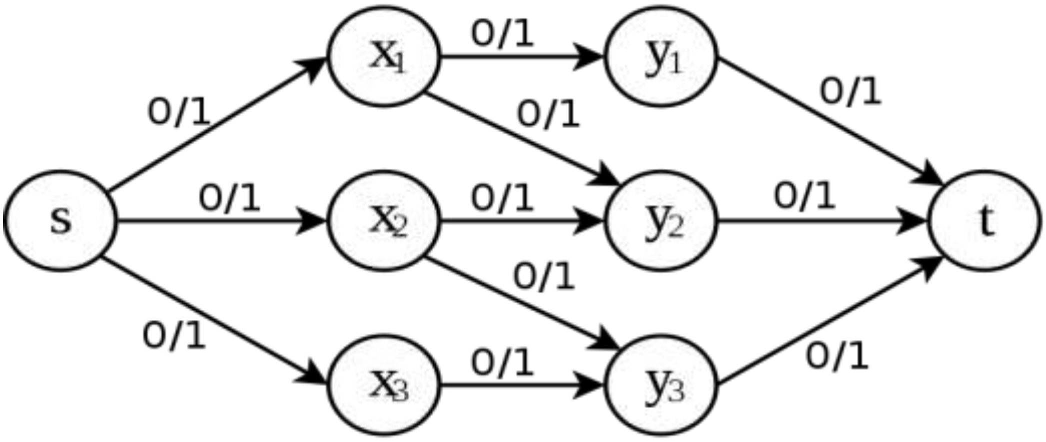
$$\delta(\sum_i \sum_j h_{ij} w_{ij}) = \Delta h_{ij}\ (w_{ij} - w_{rt}\frac{l(\pi_{ij})}{l(\pi_{rt})})\,\Delta h_{ij}\ (w_{ij} - w_{rt}\frac{l(\pi_{ij})}{l(\pi_{rt})})>0$$

$$\frac{w_{ij}}{l(\pi_{ij}{}^{\min})} > \frac{w_{rt}}{l(\pi_{rt}{}^{\min})} \text{ или } \frac{l(\pi_{ij}{}^{\min})}{w_{ij}} < \frac{l(\pi_{rt}{}^{\min})}{w_{ij}}$$

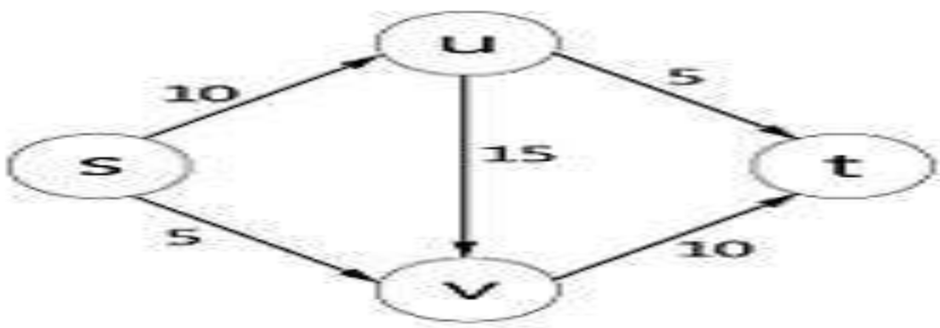
Thus, if condition is satisfied, increasing the flow of requirement (i, j) by, we increase the value of the criterion. Theorem is proved.
Hence we obtain the following optimality conditions. Let be the optimal flow in the problem - Then if

$$\frac{l(\pi_{i_1 j_1}{}^{\min})}{w_{i_1 j_1}} \le \frac{l(\pi_{i_2 j_2}{}^{\min})}{w_{i_2 j_2}} \le \ldots \le \frac{l(\pi_{i_k j_k}{}^{\min})}{w_{i_k j_k}}$$

то $h_{i_1 j_1} \succ h_{i_2 j_2} \succ \ldots \succ h_{i_k j_k}$ ,




**A network with an example of maximum flow. The source is s, and the sink t. The numbers denote flow and capacity**.




A flow network, with source s and sink t. The numbers next to the edge are the capacities.

| Method | Complexity | Description |
|---|---|---|
| Linear programming | | Constraints given by the definition |
| Ford–Fulkerson algorithm | O(E max\| f \|) | As long as there is an open path through the residual graph, send the minimum of the residual capacities on the path. |

| | | |
|---|---|---|
| Edmonds–Karp algorithm | $O(VE^2)$ | A specialization of Ford–Fulkerson, |

The following table lists algorithms for solving the maximum flow problem
The length of the shortest path of the transfer of the requirement in the metric, is the dominance condition.
The task of estimating the survivability parameters under additional constraints

The most important indicator that characterizes the functioning of the network in case of failures is survivability. The problem of the survivability of information systems has been most fully studied in the monograph by A.G. in which survivability is interpreted as the ability of the system to sustainably perform its basic functions in the failure of elements and the impact of unfavorable environmental factors, but with reduced efficiency

In this case, the total number of A0 functional tasks that the system performs in a fail-safe state is considered, and a subset of the tasks that it is able to perform for failures A1 (where A0 □ □ A1) is determined. The power of the subset A1 determines the survivability of the system. At the same time, the authors distinguish between functional viability and structural survivability. A similar approach can be used in the analysis of the survivability of the CS.

This approach was first realized According to under the survivability we will understand the ability of the network to maintain its functioning in the event of element failures. We will evaluate the survivability by an indicator of a decrease in the total throughput (or an equivalent decrease in the maximum value of the flow) in the event of failures in the elements of the channel and node network. In comparison with the state in which all nodes and communication channels are in good order. Path is some state of the network in which the communication channel has failed, and its probability, let the maximum value of the stream transmitted through the network into the state is equal to. This value can be estimated with the aid of the above-described algorithm. Then the survivability of a distributed communication network (CS) can be characterized by the following probability distribution, namely

$$\mathrm{P}\left(\mathrm{H}_{зад}\right)=\mathrm{P}\left(\mathrm{H}_{\Sigma}^{\phi}\geq\mathrm{H}_{зад}\right)=1-\mathrm{P}\left\{\mathrm{H}_{\Sigma}^{\phi}\langle\mathrm{H}_{зад}\right\}$$

Here 0, 1; 0, 2;. . . . . ; 1, 0 and - the value of the maximum flow transmitted in an intact network (without failures), - actual values

The following are suggested as the basic values of the survivability index:

$$P(H_{\Sigma}^{\phi}=H_{\Sigma}^{0});$$

$$P(H_{\Sigma}^{\phi}\leq 0.9H_{\Sigma}^{0})$$

$$P(H_{\Sigma}^{\phi}\leq 0.8H_{\Sigma}^{0})$$

$$P(H_{\Sigma}^{\phi}\leq 0.7H_{\Sigma}^{0})$$

$$P(H_{\Sigma}^{\varphi}\leq 0.6H_{\Sigma}^{0})$$

$$P(H_{\Sigma}^{\phi}\leq 0.5H_{\Sigma}^{0})$$

In contrast to here, in estimating the survivability indicators, additional constraints are taken into account. This circumstance required the creation of a new algorithm for calculating and analyzing the survivability indices, which is based on the method for solving the generalized maximum flow problem.

The following methodology for estimating the survivability of the network is proposed

1. Consider various network failures: (failures of one or more communication channels and nodes). Assuming the probability of failure-free state
2. Separate channels and nodes by statistically independent random variables, we calculate the probabilities.
3. For each of the states using the NLM algorithm, we find the maximum flow in the network.

$$\mathrm{P}\left(\mathrm{H}_{зад}\right)=\sum_{\mathrm{Z}_j:\mathrm{H}\left(\mathrm{Z}_j\right)\geq\mathrm{H}_{зад}}\mathrm{P}\left(\mathrm{Z}_j\right)=1-\sum_{\mathrm{Z}_j:\mathrm{H}\left(\mathrm{Z}_j\right)\langle\mathrm{H}_{зад}}\mathrm{P}\left(\mathrm{Z}_j\right)$$

## II. CONCLUSIONS

1. The problem of finding the maximum flow in a CS under additional constraints
2. A number of theoretical statements (theorems) are established that establish the properties of the maximum flow in a communication network.
3. An algorithm is developed for finding the maximum flow in a network under additional constraints.
4. The problem of analyzing the survivability of communication networks is considered and an algorithm for determining the survivability index is proposed, which is based on the algorithm

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