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# OSPF-based model of adaptive routing and possibility for stable network operations

NIHAD BOROVINA
Faculty of Electrical Engineering
University of Sarajevo
Zmaja od Bosne bb
BOSNIA AND HEZEGOVINA
http://www.etf.unsa.ba

SEAD KRESO
Faculty of Electrical Engineering
University of Sarajevo
Zmaja od Bosne bb
BOSNIA AND HEZEGOVINA
http://www.etf.unsa.ba

*Abstract:* This paper deals with adaptive routing based on OSPF protocol. The main goal of adaptive routing is to provide network distribution of IP traffic so that links are as evenly as possible loaded without loosing IP packets in the network. This paper presents the routing model which collect the parameters from the network and, accordingly, calculates the values of OSPF link weight. To achieve adaptability, the fuzzy logic is used. Adaptive model is tested on the network simulator, and the simulation results indicate significant enhancements while using adaptive routing, comparing to simple OSPF routing based on pre-defined link weights. The network stability and enhancements increasing the model stability are especially analyzed.

*Key-Words*: traffic engineering, OSPF, fuzzy, adaptive routing, stability, simulation

## 1. Introduction

Traffic engineering is concerned with performance optimization and speaking about the methods to achieve the goals of IP traffic engineering, there are the two approaches [1]: focusing on IP traffic and focusing on the network resources. The first approach refers to increasing of QoS of traffic streams, i.e. solving the problem of minimization of IP packet loss, minimization of delays and maximization of throughput. Within the second approach, focusing on the network resources, the mail goal is to efficiently manage bandwith resources.

The subject of this paper includes researches within a specific problem of IP traffic engineering related to finding a method for an efficient IP traffic distribution in the networks using OSPF routing. Within OSPF routing protocol, a complete traffic between two network nodes is forwarded through the shortest path between those nodes. This principle is implemented simply by means of a distributed management with IP traffic in the network, however, it also imposes certain limitations in the possibility for an efficient utilization of link capacity, i.e. some network links are overloaded while the others are unloaded. The purpose of this paper is to form an adaptive model for achieving a better network distribution of IP traffic with OSPF and to analyze the model stability. Except for definition of OSPF routing problem, this paper will also present the structure of the proposed adaptive routing model, the fuzzy system meant for achieving adaptibility, as well as the results of the adaptive model implementation on on-line simulator. Especially treated will be the model stability and modifications to be made in order to reduce traffic oscillations in the network.

## 2. OSPF routing problem definition

The problem of optimal routing can be defined in the following way. A network represented with directed graph is described with: $G = (V, E, c), \quad E \subseteq V \times V, \quad c : E \rightarrow N$ , where V is a set of nodes (vertices) representing routers in IP network, E is a set of links (edges) between the nodes, while c is a set of link capacities from E. Matrix of demands D for each node pair $(s,t) \in VxV$ defines the requirement for IP traffic between s and t nodes. Matrix elements are indicated as $d_{st}$. With $f_i^{(s,t)}$ we indicate the traffic flow from node $s$ to node $t$ running through link $e_i$. For arbitrary node $m$ in the network, it will be:

$$\sum_{p:(p,m)\in E} f_{(p,m)}^{(s,t)} - \sum_{n:(m,n)\in E} f_{(m,n)}^{(s,t)} = \begin{cases} -d_{st} & if \quad m = s \\ d_{st} & if \quad m = t \\ 0 & if \quad m \neq s,t \end{cases} \qquad (1)$$

The cost function $\Phi_i(f_i)$ depending on the link load is specified for each link $e_i \in E$. Formal objective of the problem of optimal routing is to distribute the demanded flow so as to minimize the sum:

$$\Phi = \sum_{e_i \in E} \Phi_i(f_i) \qquad (2)$$

In relation to a general routing problem, OSPF brings additional limitations. For each link, weight (w) is defined, and a total traffic flow from s to t runs over the shortest route calculated according to the Dijkstra algorithm on the basis of links weight. If there is one shortest route for traffic distribution in OSPF network, then it will be:

$$f_i^{(s,t)} = \begin{cases} d_{st} & \text{if } e_i \in E \text{ is on a shorthest path from s to t} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Additionally, if there is more than one shortest path, the traffic will be equally shared between them. More exactly, if the traffic in m node is shared to two best routes over $n_1$ and $n_2$ nodes, then it will be:

$$f_{(m,n1)}^{(s,t)} = f_{(m,n2)}^{(s,t)} \quad (4)$$

OSPF routing problem can be now formulated as finding the settings for link weights which are discrete variables (integer values) in order to minimize the function of total cost. So formulated problem presents a problem of combinatorial optimization and it has been shown in [2] that it is a NP hard problem when the cost function is defined in a following way:

$$\Phi_i = \begin{cases} f_i & \text{if} \quad 0 \le f_i/c_i \le 1/3 \\ 3 \cdot f_i - \frac{2}{3} \cdot c_i & \text{if} \quad 1/3 < f_i/c_i \le 2/3 \\ 10 \cdot f_i - \frac{16}{3} \cdot c_i & \text{if} \quad 2/3 < f_i/c_i \le 9/10 \\ 70 \cdot f_i - \frac{178}{3} \cdot c_i & \text{if} \quad 9/10 < f_i/c_i \le 1 \\ 500 \cdot f_i - \frac{1468}{3} \cdot c_i & \text{if} \quad 1 < f_i/c_i \le 11/10 \\ 5000 \cdot f_i - \frac{16318}{3} \cdot c_i & \text{if} \quad 11/10 < f_i/c_i \end{cases} \quad (5)$$

So, there is no efficient algorithm that can guarantee the solution of OSPF routing problem can be found in a resonable time limit.

## 3. Adaptive routing

In the literature considering combinatorial optimization [2], the above presented problem is analyzed and solved starting from the assumptions that the traffic requirements matrix is defined and that each change in the network topology is taken as a new problem to be solved separately, i.e. the results obtained for one topology cannot be taken into consideration for another topology.

In practical use, these assumptions are unacceptable for the following reasons. Firstly, it is impossible to define precisely all traffic requirements between each two nodes in the network. Even if there are analyses of the previous traffic behaviour, some unforeseen events can cause a change in the requirements in a very short time period. The traffic requirements during a day or week are not constant. If the traffic requirements are somehow identified at one moment, in two hours they need not be the same even without any drastic changes in the network. Outages of certain links or nodes completely change the network conditions. The solution for OSPF problem which is acceptable for one topology does not have to be acceptable upon outage of only one network link even with the same traffic requirements. Accordingly, adaptive routing is considered as an acceptable solution for traffic engineering in the stated conditions.

Adaptive routing is extension of dynamic routing, when the changes in routing tables are made in accordance with the system parameters depending on the system load. The model of adaptive routing as analyzed in this paper is based on extension of OSPF routing protocol and consists of the following modules (Figure 1.):

1. collecting parameters of link,
2. calculation of new link weight on the basis of read out parameters,
3. activation of changes and forming of new OSPF routing tables
4. measuring of parameters and repeating of above 1-3 steps after expiration of pre-defined time period.

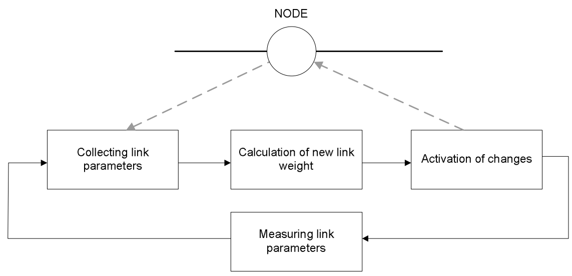


Figure 1. Adaptive model structure

Step 2 is implemented by means of the fuzzy logic, and step 3 is applied completely with a standard OSPF application on the node. The parameters to be measured are link load in the previous period and the number of droped packets in the previous period.

The key problem with such models is stability [3], i.e. a possibility for reaching an equilibrium of traffic distribution for fixed traffic requirements in the network. So, in the results analysis, a special attention will be paid to the model stability.

## 4. Fuzzy system

The main idea for using the fuzzy logic in adaptive routing based on OSPF lies in the fact that fuzzy logic was successfully applied in different systems where human expertise and insufficiently precisely defined conditions for the system operation present the basis for a decision making on operation i.e. set up of the system parameters [4]. The process of calculation of new weights is performed in three steps as follows:

- fuzzification – process in which input variables transform to fuzzy sets by means of membership function,
- fuzzy reasoning – process for calculation of the value of output fuzzy set by means of a rule-base,
- defuzzification – process in which output fuzzy set turns into a numerical value.

Figure 2. shows the membership functions of fuzzy sets associated to term set Link Load, and Figure 3. shows the ones associated to term set Droped Packets. The scope, on which a variable of link load is defined, is a relative amount of link load.

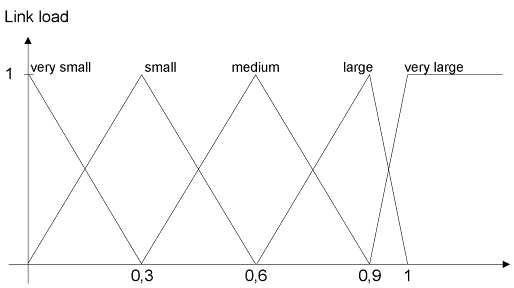


Figure 2. The membership functions of fuzzy fets for link load

The variable Droped Packets from Figure 3., is defined on the scope showing the relation of the number of droped packets and total number of packets which can be forwarded per link in the measured period.

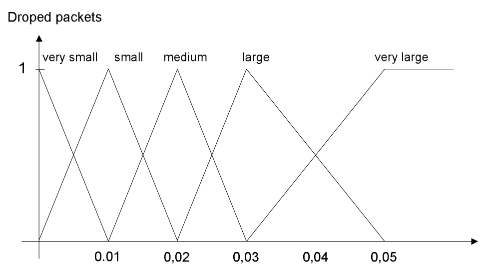


Figure 3. The membership functions of fuzzy sets for droped packets

The membership functions of fuzzy sets for weight changes coefficient are shown in Figure 4. An even discretization of fuzzy system output value was used.

The new value for link weight is calculated on the basis of the previous one, calculating firstly the weight change coefficient on the basis of fuzzy membership functions of as shown in Figure 4. With so defined functions, that coefficient can have values in 0,9 – 1,1 interval. After calculation, the coefficient is multiplied with the previous weight value, rounded to integer number and that result is the new link weight. Per this principle, minimum weight value can be 5.

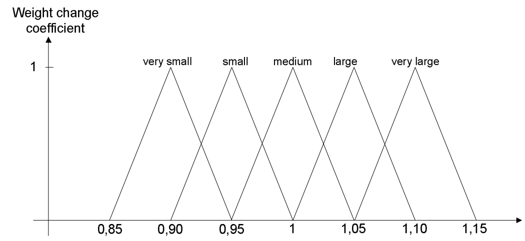


Figure 4. The membership functions of fuzzy sets for weight change coefficient

In the adaptive model, the absolute amount of new weight is limited to 1,5 times higher value from the nominal link weight. The nominal link weight is the one as defined in [5]. This restriction was introduced to avoid network oscillations caused by a drastic increase of weight per certain link, resulting in a full unload of that link and overload of some other link. It further leads to unlimited increase in weight of loaded link and decrease in weight of the first link etc., which most often brings to oscillations in IP traffic.
Specification of the rule-base (Table 1.) is the key aspect of the fuzzy system implementation.

| | | Link load | | | | |
|---|---|---|---|---|---|---|
| | | VS | S | M | L | VL |
| Droped packet | VS | VS | S | M | L | L |
| | S | M | M | M | L | VL |
| | M | M | M | L | L | VL |
| | L | L | L | L | VL | VL |
| | VL | VL | VL | VL | VL | VL |

Table 1. Rule-base for adaptive model

Table 1. shows that both variables have the same influence on the weight change. More significant quantity of droped packages regardless of previous link load gives a signal that the link is overloaded and the weight needs to be increased. As the defuzzification method, the Center of Area [4] is applied.

## 5. Application of adaptive routing and results analysis

The adaptive routing model is tested on ns2 network simulator [6]. Two networks are used having 8 nodes and 11 links, i.e. 20 nodes and 26 links.

Behaviour of the adaptive model was examined with different load levels in the network, in the way that the traffic requirements in the range of 0% to the average of 35% from the total network capacity were generated. The upper limit was taken as a case of big losses of IP packets in the network, i.e. when the network topology and foreseen capacities are not correctly designed in relation to requirements. Accordingly, neither regular OSPF protocol nor adaptive model can provide traffic distribution in the network in order to drastically reduce the losses. This is the most often situation when some links reach overload higher than 25%.
Diagram in Figure 5. shows the load cost for 8 node network topology depending on the network load. The cost function is given in (5).

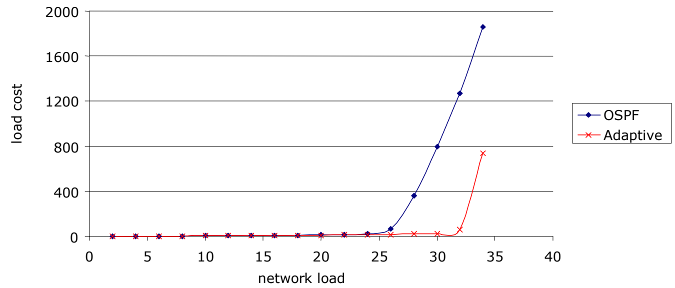


Figure 5. Load cost for 8 node network topology

Diagram shows that the adaptive model makes significantly better results than OSPF routing for network loads over 25%. It is the limit under which all links are loaded with less than 2/3 capacity when OSPF routing is used.
Another parameter which is important for the quality evaluation of the adaptive model is loss of IP packets in certain time period. Graph in Figure 6. shows the total data for the entire network for both OSPF routing and applying the adaptive model.

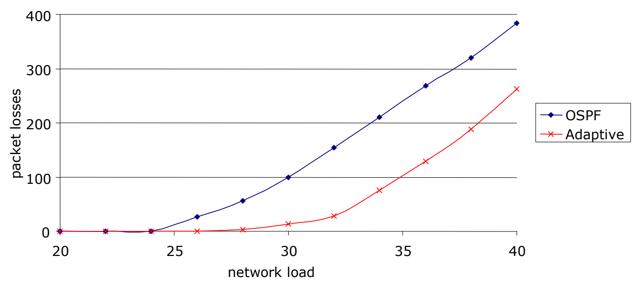


Figure 6. Packet losses in 8 node network topology

In this Figure we can see that, unlike OSPF routing when losses become significant with 25% network load, with the adaptive model the losses become significant only over 30% network load. This way 20% enhancement was achieved, i.e. it is the percentage for which the limit of IP network losses manifestation is changed in relation to network load.
The similar results are achieved in 20 node network as well.

## 5.1. Stability

The simulation results of adaptive model show that equilibrium of IP traffic distribution is reached in most cases. Figure 7. shows the graph indicating the number of steps to reach the equilibrium for simulated 20 node network for adaptive model. The equilibrium is achieved between 11th and 23rd step.
To examine the efects of link weight limitations, a simulation was made without limitations to maximum link weight value for adaptive model. The results and comparison with adaptive model having limited weight value are also shown in Figure 7. It is visible that, for network loads between 15% and 20%, the oscillations occur if there are no limitations in weight values.

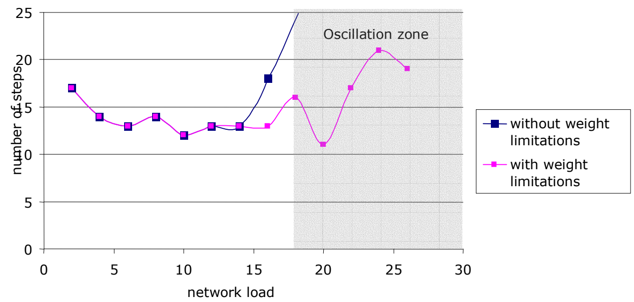


Figure 7. Comparison of number of steps to reach equilibrium for adaptive model with and without weight limitations

Although with the adaptive model as presented in this paper, in most cases the equilibrium is achieved, using the model in real conditions could cause problems with time necessary for that equilibrium to be reached. E.g. if the time between changing two weights is 5 minutes, one hour or more is necessary to reach the stability. In that period, the traffic requirements can be significantly changed.
Accordingly, it is necessary to consider implementation of presented adaptive model so to fully use the positive effects of this model, without significant oscillations in IP traffic. In that respect, we continue with presenting the results of adaptive model utilization in two ways: modified adaptive model focusing on elimination or reduction of IP packet drops and adaptive model within on-line IP network simulator.

### 5.2. Modified Adaptive Model for Reduction in IP Traffic Oscillations

The main idea of modified adaptive model is based on the following consideration. Diagram in Figure 8. shows IP traffic losses in adaptive model within 20 node network as measured between each two changes in weight parameters. Graphs below are given for various percentages of network load.

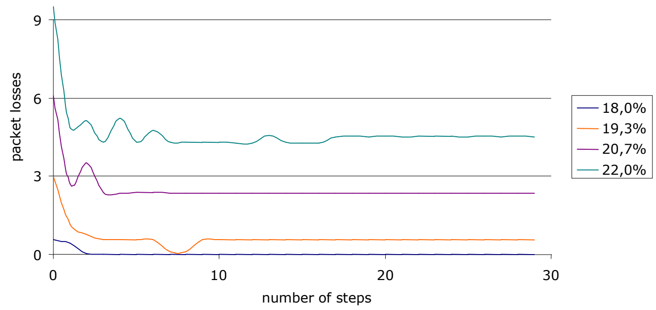


Figure 8. Review of losses in certain intervals before reaching equilibrium

As for network loads below 18% there are no IP packets losses, the data shows load of 18% - 22%. Although the stationary status is reached in 10-20 steps, graph indicates that the level of IP packet losses is stabilized already after 6 or 7 steps approximately. It is also noticeable that immediately upon activation of adaptive mechanism the losses level is significantly reduced in relation to the first interval where distribution is performed on the basis of the initial OSPF settings of link weight. So it can be concluded that utilization of adaptive model results in improvement in terms of losses reduction, but further weight changes after sixth or seventh step have no practical significant effect.
If the goal of the adaptive model utilization is elimination or reduction of IP packet losses, then on the basis of results shown in Figure 8. a modified adaptive model can be formed for implementation of that goal, and IP traffic oscillations will be significantly reduced in the network. The pseudo-code in Figure 9. describes modifications.

```
begin
  allowed_drops = 0 ;
  while (not termination_criteria) do
    if drops > allowed_drops then
      call fuzzy_weights ;
      if allowed_drops ≠ 0  then
        allowed_drops = allowed_drops * 2 ;
      else d allowed_drops = allowed_drops_INIT ;
    end if
    else allowed_drops = allowed_drops /2 ;
  end while
end
```

Figure 9.Pseudo-code of modifications

The aim of these corrections is to avoid frequent changes of weights still taking advantages of selective application of adaptive mechanism in order to reduce losses of IP packets. At the beginning, allowed losses are set to 0. In the first step in which IP traffic losses appear, the parameter allowed losses is set to 0,01% of the total traffic running through a link in one interval. Figure 10. shows losses using adaptive model with and without modification, as well as for OSPF routing.

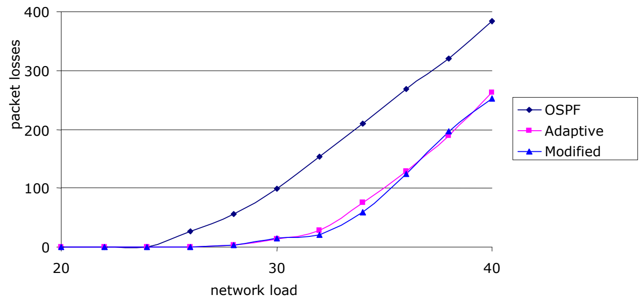


Figure 10. Losses of using modified model

The losses with implementation of modified adaptive model are much smaller than with implementation of OSPF routing, the same as with the adaptive model without modification. However, the main advantage of modified model can be seen on diagram in Figure 11.

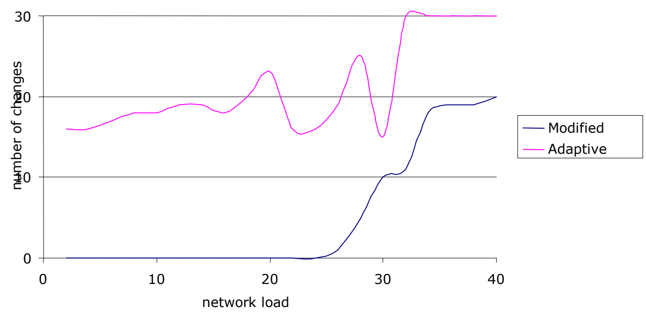


Figure 11. Effects of using modified model

Diagram shows the number of steps in which changes in link weights were made, observing the time period of totally 30 steps. The number of changes in modified model is rather lower, i.e. oscillations in IP network traffic are also rather lower.

### 5.3. Adaptive Model Applied on On-Line Network Simulator

Another application of the adaptive model refers to network resources management system based on on-line simulation. This system is presented in [7], and for solving OSPF routing problem, it was used in [8]. The main idea is based on use of on-line simulator of the managed network, when simulator and network operate in parallel (Figure 12.).

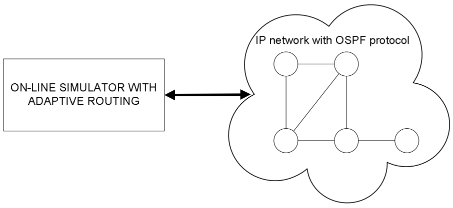


Figure 12. Adaptive model on On-line simulator

Current network status is modelled and adaptive routing model is applied on the simulator. Afterwards, the best settings for link weights are set in the network.
The following effects are the results of this application of the adaptive model:

- there are no frequent changes in link weights, i.e. network oscillations, because the best settings for current traffic requirements are calculated on simulator
- simulation results in weight settings, provide minimum losses or the most acceptable network traffic distribution immediately upon application of those settings in real network

Figures 13. and 14. show the effects of adaptive model application on on-line simulator.

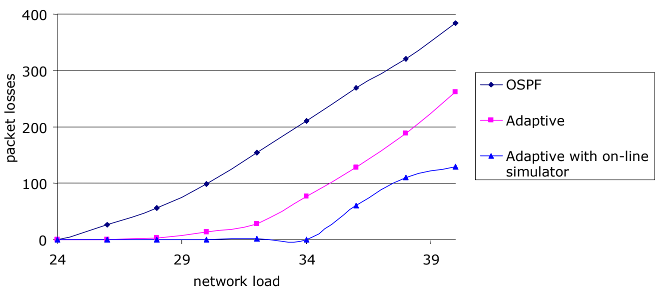


Figure 13.Effects of using adaptive model on On-Line simulator for 8 node network

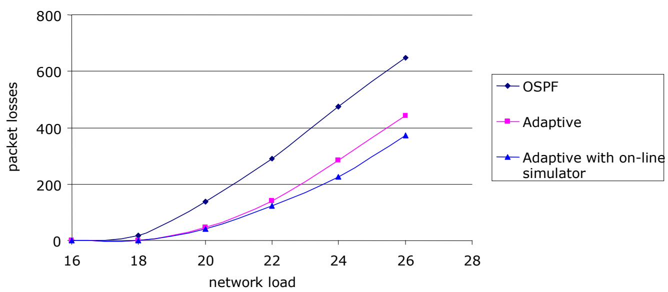


Figure 14.Effects of using adaptive model on On-Line simulator for 20 node network

Figure 13. shows the losses in 8 node network depending on the network load. Adaptive model on on-line simulator was compared with simple adaptive model and OSPF routing. It can be seen that IP traffic losses in adaptive model with simulator are negligible up to amount of 34% of the network load, as is an improvement of 21,4% in relation to adaptive model or 41,7% in relation to the results of OSPF routing.
Application of on-line simulator on 20 node network also brings some enhancements, but not so big as with 8 node network, as shown in Figure 14.

## 6. Conclusion

According to above presented, we can conclude as follows:

- OSPF routing problem is NP-hard
- it is possible to form the adaptive routing model based on OSPF,
- adaptive activity can be efficiently described with a linguistic model, so the fuzzy logic can be applied for reaching adaptibility,
- adaptive model shows a higher efficiency in terms of usage level of link capacity and reduction of IP packet losses,
- to achieve a stable network operation, it is possible to improve this model by means of reduction in the network oscillations.

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