A Unified Approach to Survivability of Connection-Oriented Networks

Krzysztof Walkowiak

Chair of Systems and Computer Networks, Faculty of Electronics, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland
`Krzysztof.Walkowiak@pwr.wroc.pl`

Abstract. This paper deals with problems of computer networks survivability. We present and discuss survivability aspects of Content Delivery Networks (CDNs) and other services based on the anycast paradigm. After that, we propose a new unified approach to network survivability. This approach assumes using jointly survivability mechanisms for both kinds of traffic: anycast (one-to-one-of-many access to content servers) and unicast (one-to-one exchanging of data between individual users). We formulate a new optimization model for this scenario that can be used for development of algorithms. The optimization problem is NP-complete. The objective function is function of lost flow due to a failure of any single link. To our knowledge this problem have not received much attention in the literature. We provide also a numerical example to illustrate the proposed approach.

Keywords: survivability, MPLS, anycast, CDN

1 Introduction

Nowadays we watch an increasing role of computer networks, caused mainly by the growth of the Internet as well as introducing many new services. Telecommunication companies and operators focus on new ideas and concepts to enable radical transformation of networks and service infrastructures. One of the most vital attributes of current networks is provision of QoS guarantees with some survivability aspects. Service disruptions in networks are significant, since loss of services and traffic in high-speed fiber systems could cause a lot of damages including economic loses, political conflicts. Therefore, new self-healing restoration methods to provide network survivability are being deployed.

In general, current networks offer two kinds of services: access to content servers (anycast traffic) and exchanging of data between individual users (unicast traffic). Most of previous work in the field of network survivability focus on restoration and protection methods developed for unicast communication, for techniques like MPLS (Multiprotocol Label Switching).

Connection-oriented techniques use similar approach to enable network survivability. The main idea of this approach is as follows. Each connection, i.e. label switched path in MPLS, has a primary route and a backup route. The primary route is used for transmitting of data in normal, non-failure state of the network. After a failure of the primary route, the failed path is switched to the backup route [1], [8].

Less papers address survivability issues of anycast traffic and CDNs (Content Delivery Networks). There has not been any study, we are aware of, that gives specifics on how to apply jointly restoration methods of connection-oriented (c-o) networks and CDNs. Therefore, we propose a unified approach that improves survivability of networks carrying two types of traffic: unicast and anycast. We formulate a detailed optimization model that can be used for static assignment of network flows using a unified survivability approach. The optimization model can be applied for development of heuristic and exact algorithms. In order to illustrate theoretical analysis we provide a numerical example that shows robustness of the proposed approach. Results of this work can be easily modified in order to deploy a framework for dynamic optimization of network flows using the unified approach to survivability.

2 Survivability of Content Delivery Networks

Content Delivery Network (CDN) is defined as mechanism to deliver various content to end users on behalf of origin Web servers. The original information is offloaded from origin sites to other content servers located in different locations in the network. For each request, the CDN tries to find the closest server offering the requested Web page. CDN delivers the content from the origin server to the replicas that are much closer to end users. CDN techniques are based on caching of Web pages. Traffic of CDN is modeled as anycast flow. For more information on caching, replication, anycast communication refer to [2-6], [11].

Since modeling and optimization of CDN is a very complicated issue, in this work we consider a simplified model of CDN. We assume that CDN offers the same content replicated in a number of different locations called content servers or replicas. We can treat the origin server itself as simply one of the replicas. Obviously, we are not considering the case where there is a content server on every network node. A user is assigned to a number of these servers using the redirection mechanism. A variety of approaches exist for requests redirection [7]: client multiplexing, IP multiplexing, DNS indirection, HTTTP redirection and anycast.

One of CDN’s advantages is the survivability it offers. Since data is replicated in different locations in the network, CDN can cope with failures of the network or Web servers. Even if one of the content servers becomes unreachable, other servers can provide necessary data to. Additionally, CDN reduces network flow what also improves survivability of the network. If there are more resources of spare capacity in the network, the restoration process can be performed more effectively.

In c-o networks an anycast demand consists of two connections: one from the client to the server (upstream) and the second one in the opposite direction (downstream). Upstream connection is used to send user’s requests. Downstream connection carries requested data.

To improve the survivability of an existing CDN we suggest two approaches [9]. The first one uses a backup content server. Each client is assigned to two content servers: the primary one, used in non-failure state of the network, and the backup one, that is applied when the primary server is unavailable due to network failure. In c-o networks it is arranged in the following way. Each client has four routes assigned: two primary (downstream and upstream) between client and primary content server and two backup (downstream and upstream) between client and backup server. Both backup routes are activated after a failure of one of primary connections, because the client can be assigned to another content server and two routes (downstream and upstream) must be provisioned to the new server. This scenario can protect the network against network element (e.g. link, node) failure or replica failure.

In the secondary approach, a client is assigned to the same replica. All four routes: primary downstream, primary upstream, backup downstream and backup upstream connect the same pair of nodes. If any of two primary routes is broken, it is switched to the backup route. There is no need to change the route of the second primary route if it is not failed. This scheme protects only against a failure of network element.

3 Unified Approach to Network Survivability

It has become increasingly evident that existing computer networks offer users two main kinds of services:

- Access to popular content providing various types of information and data. Content servers can be organized in a Content Delivery Network, i.e. the same information is replicated in many locations. Users can be connected to any of available servers. Flow of these kinds of services is referred to as anycast flow.
- One-to-one communication between individual users in the network modeled as unicast flow.

Examples of the former type of services are: popular WWW sites, archives of electronic entertainment (MP3 files, movies), FTP, peer-to-peer applications, electronic libraries, software distribution. The latter kind of services is: Voice over IP, teleconferences, exchanging of files, VPN, less popular WWW servers.

The central idea of this work is to provide survivability to the consider network using jointly restoration mechanisms developed for c-o networks (ATM, MPLS) and special capabilities offered by CDNs. We propose to combine using the backup routes for protection or restoration of unicast traffic and backup content servers for protection or restoration of anycast traffic. In many existing network there is no need to protect all services. Some clients don't require any network survivability, while others are willingly to pay extra for guarantees of data delivery in spite of failures. Therefore, we introduce four classes of traffic:

- Protected unicast (PU) – flow associated with communication between two individual users protected by a backup route.
- Unprotected unicast (UU) – flow associated with communication between two individual users not protected by a backup route.
- Protected anycast (PA) – flow associated with communication between an individual user and a content server protected by a connection to a backup server.
- Unprotected anycast (UA) – flow associated with communication between an individual user and a content server without any protection.

4 Optimization Model of Survivable Unified Network

According to our knowledge, the combinatorial optimization problems presented below have not received much attention in the literature. A unicast demand is defined by a following triple: origin node, destination node and bandwidth requirement. An anycast demand is defined by a following triple: client node, upstream bandwidth requirement and downstream bandwidth requirement. An anycast demand must select one of many content servers. Therefore, the destination node hosting a replica is not defined and must be found.

We assume that estimated bandwidth requirements for all classes of demands are given. In order to solve the problem three kinds of variables must be determined: selection of content servers, primary routes and backup routes. Primary routes are selected to satisfy all demands. Sets containing proposals of primary and backup routes that conform selected rerouting strategy are given.

We consider an existing facility network, i.e. location of content servers; link capacity and network topology are given. We assume that each anycast demand is divided into two connections: upstream and downstream. Both connections associated with one anycast demand must be considered jointly, i.e. the destination node of downstream connection must be the same as the origin node of associated upstream connection and vice versa. Furthermore, both associated connections either must be restored using the same backup replica, or both connections are lost.

To mathematically represent the problem, we introduce the following notations:

V	Set of $\lvert V\rvert$ vertices representing the network nodes.
A	set of $\lvert A\rvert$ arcs representing network directed links.
R	set of $\lvert R\rvert$ CDN's servers (replicas). Each server must be located in a network node.
P	set of $\lvert P\rvert$ connections in the network. A connection can be of three types: unicast, downstream anycast and upstream anycast.
P_{CL}	set of $\lvert P_{CL}\rvert$ connections included in a particular class, CL={PU,UU,PA,UA}.
Π_i	set of routes proposals for connection i; $\Pi_i = \left\{\pi_i^k : k = 1,...,l(i)\right\}$. For unicast connection set includes routes between origin and destination nodes of considered demand. Anycast connection set consists of routes between the client's node and nodes that host a content server.
X_r	set of primary route selection variables x_i^k, which are equal to one. X_r determines the unique set of currently selected primary routes
Π_{im}^k	set of backup routes of connection i using primary route π_i^k after failure of arc m; $\Pi_{im}^k = \left\{\pi_{im}^{kh} : h = 0,1,...,l(i,k,m)\right\}$. Route π_{im}^{k0} is an "null" route. If π_{im}^{k0} is selected it means that connection i using the primary route π_i^k is not restored after failure of arc m.
Y_r	set of backup route selection variables y_{im}^{kh}, which are equal to one. Y_r determines the unique set of currently used backup routes.
c_j	capacity of arc j.

Q_i	bandwidth requirement of connection *i*.
$\delta(i)$	index of the connection associated with anycast connection *i*. If *i* is a downstream connection $\delta(i)$ must be an upstream connection and vice versa.
a_{ij}^{k}	binary variable, which is 1 if arc *j* belongs the route π_i^k and is 0 otherwise.
b_{imj}^{kh}	binary variable, which is 1 if arc *j* belongs the route π_{im}^{kh} and is 0 otherwise.
$o(\pi)$	origin node of route π.
$d(\pi)$	destination node of route π.

A function that represents the flow lost due to failure of link *m* is a follows

$$LF_m(X_r,Y_r) = \sum_{i\in P_{\mathrm{PU}}} \sum_{\pi_i^k \in \Pi_i} a_{im}^k x_i^k y_{im}^{k0} Q_i + \sum_{i\in P_{\mathrm{PA}}} \sum_{\pi_i^k \in \Pi_i} a_{im}^k x_i^k y_{im}^{k0} (Q_i + Q_{\delta(i)}) \tag{1}$$

Function $LF_m(X_r,Y_r)$ is a sum over all connections using arc *m* ($a_{im}^k=1$) and are not restored after a failure of this arc ($y_{im}^{k0}=1$). If anycast connection $i\in P_{\mathrm{PA}}$ is not restored we must also add bandwidth requirement of connection $\delta(i)$ associated with *i*, because if one of two anycast connections is broken and not restored, the second one is also removed from the network and lost.

The objective function $LF(X_r,Y_r)$ is formulated as follows

$$LF(X_r,Y_r) = \sum_{m\in A} LF_m(X_r,Y_r) \tag{2}$$

We consider a single failure of any arc $m \in A$. Therefore, the function $LF(X_r,Y_r)$ is a sum of functions $LF_m(X_r,Y_r)$ over all arcs. However, the objective function can include also other failure scenarios, e.g. multiple links failures.

The optimization problem is formulated as follows

$$\min_{X_r,Y_r} \quad LF(X_r,Y_r) \tag{3}$$

subject to

$$f_{jr} = \sum_{i\in P} \sum_{\pi_i^k \in \Pi_i} a_{ij}^k x_i^k Q_i \qquad \forall j \in A \tag{4}$$

$$\hat{f}_{jr}^{m} = \sum_{i\in P_{\mathrm{PU}}} \sum_{\pi_i^k \in \Pi_i} a_{im}^k x_i^k a_{ij}^k Q_i + \sum_{i\in P_{\mathrm{PA}}} \sum_{\pi_i^k \in \Pi_i} a_{im}^k x_i^k \left(a_{ij}^k Q_i + \sum_{\pi_d^k \in \Pi_{\delta(i)}} x_d^k a_{dj}^k Q_d \right) \tag{5}$$

$$f_{jr}^{m} = f_{jr} - \hat{f}_{jr}^{m} + \sum_{i\in P} \sum_{\pi_i^k \in \Pi_i} \sum_{\pi_i^{kh} \in \Pi_{im}^k} x_i^k y_{im}^{kh} b_{imj}^{kh} Q_i \tag{6}$$

$$\sum_{\pi_i^k \in \Pi_i} x_i^k = 1 \qquad \forall i \in P \tag{7}$$

$$\sum_{\pi_{im}^{kh} \in \Pi_{im}^{k}} y_{im}^{kh} = x_i^k \qquad \forall m \in A; i \in (P_{\mathrm{PU}} \cup P_{\mathrm{PA}}) \tag{8}$$

$$y_{im}^{k0} = y_{\delta(i)m}^{k0} \qquad \forall m \in A; i \in P_{\mathrm{PA}} \tag{9}$$

$$f_{jr} \le c_j \qquad \forall j \in A \tag{10}$$

$$f_{jr}^{m} \le c_j \qquad \forall j, m \in A; j \ne m \tag{11}$$

$$\sum_{\pi_i^k \in \Pi_i} x_i^k d(\pi_i^k) = \sum_{\pi_j^k \in \Pi_{\delta(i)}} x_j^k o(\pi_j^k) \qquad \forall i \in (P_{\mathrm{PA}} \cup P_{\mathrm{NA}}) \tag{12}$$

$$\sum_{\pi_i^k \in \Pi_i} \sum_{\pi_{im}^{kh} \in \Pi_{im}^{k}} x_i^k y_{im}^{kh} o(\pi_{mi}^{kh}) = \sum_{\pi_j^k \in \Pi_{\delta(i)}} \sum_{\pi_{jm}^{kh} \in \Pi_{\delta(i)m}^{k}} x_j^k y_{jm}^{kh} d(\pi_{jm}^{kh}) \qquad \forall m \in A; i \in P_{\mathrm{PA}} \tag{13}$$

$$x_i^k \in \{0,1\} \qquad \forall i \in P; \pi \in \Pi_i \tag{14}$$

$$y_{im}^{kh} \in \{0,1\} \qquad \forall m \in A; i \in (P_{\mathrm{PU}} \cup P_{\mathrm{PA}}); \pi_i^k \in \Pi_i; \pi_{im}^{kh} \in \Pi_{im}^{k} \tag{15}$$

Variable r denotes the index of sets X_r and Y_r that include information on current primary routes (variables x) and backup routes (variables y). (4) is a definition of arc flow. Formula (5) defines flow of arc j released from the network after failure of m. This approach is called stub release [1]. We sum bandwidth requirements over connections, which primary routes include: the failed arc ($x_i^k a_{im}^k = 1$) and the considered arc j ($a_{ij}^k = 1$). Additionally, for each anycast connection i which is broken due to failure of m, we also remove from the network flow of connection $\delta(i)$ if primary route of $\delta(i)$ includes j. (6) shows the flow of arc j after a failure of m and network restoration. The last term denotes the new flow on j allocated on backup routes. Condition (7) states that each connection can use only one primary route. Consequently, (8) denotes that for selected primary route of connection i we either can decide not to restore this connection or select only one backup route. Equation (9) guarantees that both connections associated with anycast demand are altogether either restored or lost. Condition (10) is a capacity constraint in non-failure network and (11) is a capacity constraint after failure of link m and network restoration. Constraint (12) guarantees that two primary routes associated with the same anycast demand connect the same pair of nodes. Analogously, (13) ensures that backup routes associated with the same anycast demand connect the same pair of nodes. Constraints (14-15) guarantees that decision variables are binary ones.

Optimization model (3-15) can be applied to both restoration methods discussed in previous sections. The only difference is in sets of routes proposals for anycast connection. If we use backup server method, sets of primary and backup routes should include paths to (upstream) and from (downstream) various nodes hosting replica servers. In the second restoration method, all backup routes of the same anycast demand should be between the same pair of nodes as the primary route.

The presented optimization model could be modified to embrace some other constraints. For instance we can optimize also location of replica servers by introducing for each network node a binary variable indicating whether or not the considered node hosts a server. In another possible extension we propose to assign to each demand a priority as discussed in Section 4. Priorities could be included in the objective function of lost flow as a multiplication factor of bandwidth requirement to impose better restoration of high-valued demands.

5 Simulation Study

We now describe our simulation setup and scenarios. We run the experiments for 2, 3 and 4 replica servers located in various nodes in the network. In total, 18 different servers' locations are tested. For each anycast demand we select content server closest (in terms of the hop number) to the client's node. If two or more servers are located in the same distance, we select a server with the highest capacity node calculated as a sum of capacity all arcs leaving the node in which the server is located. For assignment of primary routes (two routes for each anycast demand and one route for each unicast demand) we use an algorithm for non-bifurcated flows proposed in [10].

Next we simulate network failures. We assume a single failure of each arc, according to [1] it is the most probable failure scenario. Upon each arc cut, all of the affected connections are identified. Next, all broken connections are sequentially processed using a greedy method in the following way. For each connection it is checked if a feasible backup route can be found. If such a route exists, the available capacity is updated and the next connection in the sequence gets its chance, and so on until all affected connections have had a chance to find a backup route. If there is not a feasible route, flow of the considered connection is lost. For unicast connections we simply sum all un-restored connections' bandwidth requirements to obtain the lost flow. If one route of anycast connection is affected by the failure and the backup route cannot be established we add to the lost flow bandwidth requirements of both: downstream and upstream connections associated with the same anycast demand.

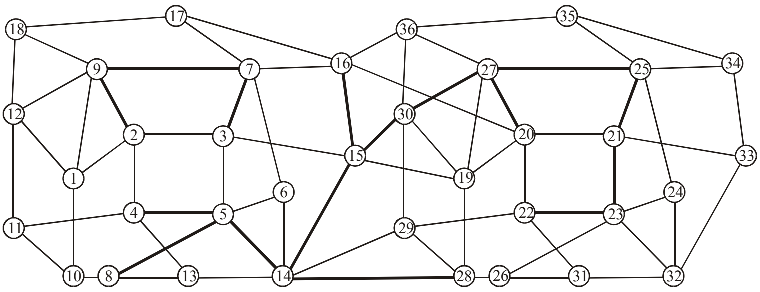

Fig. 1. Topology of sample network

The goal of the simulation study is to compare the performance of various survivability approaches for an example network topology and to study the impact of the unified approach on network restoration process in terms of the lost flow function. The network consists of 36 nodes and 144 directed links (Fig. 1). The bold lines represent links of size 96 units while other lines are links of size 48 units. The link capacities were chosen to model capacity ratio of OC-48 circuits. During simulations, the link capacities were scaled by a factor 10 to enable establishing of many connections. In the experiment it is assumed that there is a full mesh of unicast demands. Thus, the total number of unicast demands is $|V|(|V|-1)=1260$ between each node pair. In one particular experiment the unicast bandwidth requirement (U_BR) for each demand is the same. We run simulation for the following values of U_BR={6, 7, 8, 9, 10}. Additionally, there are 5 anycast demands for each node in the network. Therefore, the total number of anycast demands is $5|V|=180$. As above, anycast demands tested in one experiment have the same bandwidth requirement. Since, more data is received by clients then is sent to replicas, we make an assumption, that traffic between clients and replicas is asymmetric. Consequently, volume of downstream anycast connection is usually much higher than volume of upstream anycast connection. Therefore, we assume that upstream bandwidth is always set to 1. The following values of downstream anycast bandwidth requirement (A_BR) are tested A_BR={5,10,15,20,25,30,35,40}. We assume that all demands in the network are protected and have the same priority. Overall, for each tested location of replicas we simulate 5x8=40 various demands patterns.

In the simulation we use two restoration approaches. In the approach A all demands of type PU and PA are protected using the backup route method. Therefore, anycast flow is restored using the same replica server that is used for primary route. In the second approach, referred to as B, we apply the backup server method.

In Table 1 we report the value of lost flow function for three servers locations: (5,9,23,30), (5,23,30) and (5,23). Both restoration approaches A and B are considered. Empty cells of the table indicate that for the particular demand pattern and servers' location the algorithm cannot find a feasible solution. The experiment confirms that the unified approach proposed in the paper is more efficient then the traditional approach. The lost flow obtained for approach B is lower than for approach A. In some cases the difference is substantial. Analysis of results suggests that increasing the number of replica servers improves the lost flow function drastically. Moreover, if the number of servers grows, more demands with higher bandwidth requirements can be satisfied. The above analysis shows that applying the unified approach is reasonable and provides considerable reduction of lost flow. Another important observation is that when the proportion of the anycast flow in the overall network flow increases, adding new replicas improves the network survivability more robustly. It is in harmony with our understanding of the unified approach. Using the backup content server approach can improve the network survivability proportionally to the ratio of the anycast traffic to the whole traffic in the network.

Applying caching influences the network survivability also indirectly. When users can access the data in caches located nearby, the overall network flow decreases. Hence, more spare capacity is left for restoration of failed connections. In Table 2 we present the network flow allocated by the algorithm for the same cases as in Table 1. It is obvious that locating new replicas reduces the network flow. However, the reduction is not substantial. Comparing Table 1 against Table 2 we see that relatively small decrease in network flow can yield significant reduction of the lost flow for both tested approaches. This follows from the backup content server method. The second observation is that, as above, when the proportion of the anycast flow in the overall network flow increases, adding new replicas reduces the network flow more significantly than for other cases.

Table 1. The lost flow function for various scenarios, demand patterns and servers' location

Server location		**A_BR (Anycast Bandwidth Requirement)**							
	U_BR	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
A(5,9,23,30)	6	0	0	0	0	0	0	72	492
B(5,9,23,30)	6	0	0	0	0	0	0	0	0
A(5,23,30)	6	0	0	0	0	104	1395	2760	7603
B(5,23,30)	6	0	0	0	0	0	279	1896	6250
A(5,23)	6	0	0	144	378	1908	7980		
B(5,23)	6	0	0	0	0	192	2338		
A(5,9,23,30)	7	0	22	96	189	260	324	438	1252
B(5,9,23,30)	7	0	0	0	0	0	14	42	63
A(5,23,30)	7	0	0	16	84	624	2522	6580	
B(5,23,30)	7	0	0	0	0	286	2181	6076	
A(5,23)	7	78	297	512	2079	5873			
B(5,23)	7	0	0	0	903	2493			
A(5,9,23,30)	8	472	587	696	805	1232	1831	2856	4347
B(5,9,23,30)	8	376	400	424	448	712	1056	1524	2010
A(5,23,30)	8	456	556	656	924	2694	6474		
B(5,23,30)	8	336	336	336	483	2174	5699		
A(5,23)	8	816	1800	3688	6867				
B(5,23)	8	336	744	1880	4410				
A(5,9,23,30)	9	2544	3227	3865	4575	5395	6868		
B(5,9,23,30)	9	2412	2952	3465	4050	4693	5814		
A(5,23,30)	9	2322	2927	3574	5481	9698			
B(5,23,30)	9	2178	2652	3174	4956	8944			
A(5,23)	9	3894	5880						
B(5,23)	9	3330	4736						

7 Conclusion

In this paper, we have studied the performance improvements as the survivability mechanisms of c-o networks and restoration capabilities of CDNs are used in cooperation in one network. We have presented and discussed basic restoration methods used for unicast flow (ATM, MPLS) and anycast flow (CDNs). We have formulated a new optimization problem of providing survivability in a unified method. This problem is NP-complete. The objective condition is the function of lost flow due to a failure of a single link. Using this optimization model new algorithms can be developed. Although our goal in this paper is biased towards the c-o techniques, we believe that the results should be generally applicable to different network techniques and restoration methods. We have provided a numerical example to illustrate the proposed approach. Simulations have provided positive results to show that using the unified survivability approach is indeed useful. In future work we plan to develop new heuristics and also an exact algorithm solving the presented optimization problem. Next, we want to make extensive test in order to evaluate presented approach.

Acknowledgements. This work was supported by a research project of the Polish State Committee for Scientific Research carried out in years 2005-2007.

Table 2. The network flow various demand patterns and servers' location

Server location		**A_BR (Anycast Bandwidth Requirement)**							
	U_BR	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
(5,9,23,30)	6	27042	28191	29346	30033	31170	32319	33462	34581
(5,23,30)	6	27390	28840	29900	31362	32830	34364	35989	37974
(5,23)	6	27402	29244	31074	32916	34958	37428		
(5,9,23,30)	7	31058	32204	33322	34419	35558	36704	37878	39010
(5,23,30)	7	31427	32870	34327	35826	37290	38719	40442	
(5,23)	7	31861	33640	35538	37464	39619			
(5,9,23,30)	8	35470	36619	37720	38853	40026	41143	42356	43529
(5,23,30)	8	35828	37302	38728	40194	41652	43218		
(5,23)	8	36248	38088	40008	42072				
(5,9,23,30)	9	39996	41121	42156	43326	44517	45765		
(5,23,30)	9	40296	41746	43169	44619	46096			
(5,23)	9	40797	42660						

References

1. Grover, W.: Mesh-based Survivable Networks: Options and Strategies for Optical, MPLS, SONET and ATM Networking. Prentice Hall PTR, Upper Saddle River, New Jersey (2004)
2. Hao, F., Zegura, E., Ammar, M.: QoS routing for anycast communications: motivation and an architecture for DiffServ networks. IEEE Comm. Magazine, 6 (2002), 48-56
3. Krishnamurthy, B., Wills, C., Zhang, Y.: On the Use and Performance of Content Delivery Networks. in Proc. of ACM SigComm Internet Measurement Workshop, 2001
4. Markowski, M., Kasprzak, A.: An approximate algorithm for replica allocation problem in wide area networks. In Proc. of MMB & PGTS 2004, VDE Verlag: Berlin, 161-166
5. Markowski, M., Kasprzak, A.: The web replica allocation and topology assignment problem in wide area networks: algorithms and computational results. Lectures Notes in Computer Science, LNCS 3483 (2005), 772-781
6. Peng, G.: CDN: Content Distribution Networks. Technical Report, sunysb.edu/tr/rpe13.ps.gz, (2003)
7. Rabinovich, M.: Issues in Web Content Replication. Data Engineering Bulletin 4 (1998)
8. Sharma, V., Hellstrand, F. (ed.): Framework for MPLS-based Recovery. RFC 3469 (2003)
9. Walkowiak, K.: Designing of survivable web caching. in Proc. of 8th Polish Teletraffic Symposium (2001), 171-181
10. Walkowiak, K.: A New Method of Primary Routes Selection for Local Restoration. Lectures Notes in Computer Science, LNCS 3042 (2004), 1024-1035
11. Weber, S., Cheng, L.: A Survey of Anycast in IPV6 Networks. IEEE Comm. Magazine, 1 (2004), 127-132