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Soft Computing Agents for MPLS Networks

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Abstract: *The paper underlines the main advantages and drawbacks of IP routing. Some possibilities for resolving of routing problems are analyzed. A motivation for the use of Soft Computing Technologies (SCT) and Multiple Protocol Label Switching (MPLS) protocol for solving network routing problems is shown. The basic concept of the MPLS networks are described. Some definitions of Soft Computing Agents (SCAs) are briefly considered. It is demonstrated that the combination of the advantages of Soft Computing Technology with Software Agents paradigm is universal optimal resource allocation techniques. Optimal and Information SCA for MPLS network routing in accordance with users' preferences are developed. The ability of the Optimal SCA for processing and analysis of large amount of network information and generating of Label Switch Paths (LSP) is demonstrated. A special attention is paid to Information SCA that improve and support Optimal SCA in choosing the best path in respect to all available routing data.*

Keywords: *IP routing, MPLS protocol, soft computing agents*

1. Introduction

One of the key challenges for the Internet is how to evolve into a network that supports millions of users with their individual preferences and a host of wide ranging applications. The Internet has to evolve on many fronts including routing, QoS, addressing, efficiency and security.

In this hyper-growth environment, service providers must find a way to accommodate the dramatic growth in network traffic and the number of users. To do so in a cost-effective way, they must add management capabilities and higher predictability to their IP networks. Predictability is critical to the network routing and providing premium revenue-generating IP services. At the same time, both the capital costs of growing the network and operational costs of offering an ever-widening selection of services must be minimized. Further, the routing methods that service providers choose today must have a clearly articulated migration plan to incorporate future opportunities and technologies [13].

In just the last few years, the pace of the Internet's growth has seriously strained the capabilities of the traditional routed infrastructure.

Traditional routing technologies have its advantages and disadvantages. While being connectionless brings a number of well-known benefits to IP – for example, scalability and overall network resiliency – they have some drawbacks [3, 13]:

1. A tendency towards "hyper aggregation" of data on certain links, which leads to congestion;

2. A limited ability to alleviate hyper-aggregation by, for example, distributing traffic load over all available resources;

3. An inability to provide quality service levels across a network end-to-end;

4. An impossibility to make a routing decision according to the users' preferences.

All three limitations are due to IP's connectionless nature, whereby traffic is transported on a hop-by-hop basis, with routing decisions made at every node.

Conventional routing can create this kind of congestion in a network. Routers using the Open Shortest Path First (OSPF) routing protocol, for example, base routing decisions on the destination IP address of a packet's header, along with the least-cost path to that destination [1, 12]. All traffic then takes this least-cost path, congesting that path and leaving other paths through the network underutilized. OSPF gives routers no end-to-end, overall view of the network and, therefore, the routers are not aware of congestion in the network or of lightly loaded alternate routes and can not make the best use of all available network resources. Some of the larger ISPs claim that they lose up to forty percent of their network's capacity due to poor use of network resources by connectionless IP.

IP's hop-by-hop prioritization schema has another drawback: the inability to select paths through the network that guarantee the QoS requirements of latency – sensitive traffic flows. In an IP network, a real-time voice call or videoconference is routed by IP the same way as e-mail retrievals or bursty file transfers, so all three may experience congestion under conditions of hyper-aggregation [1, 2, 10].

While that may be fine for non-real-time data traffic like e-mail, a voice call or videoconference call has requirements for low-latency that must be met end-to-end across the network, from source to destination. IP routing protocols can not guarantee that these requirements will be met. Therefore, service providers running IP networks can not make these guarantees on a network that scales over time in bandwidth, users, sites, and applications. They are limited to offering a "best effort" service on user preferences [5, 8].

One emerging technology, Multi-Protocol Label Switching (MPLS), has been widely identified as a new tool to help service providers meet the often-conflicting challenges of increased predictability, growth in revenue, and cost reduction [1, 2, 3]. As will be discussed in this paper, it is MPLS's connection-oriented nature that provides an ability to increase IP service predictability, create differentiated IP services based on user choice, and potentially reduce operation costs in IP-centric and multi-service networks.

To achieve all of this, MPLS combines a variety of functions from both IP and ATM. Specifically, MPLS adds enhancements to IP routing protocols to make them connection-oriented. In short, MPLS aims to provide a Connection-Oriented Link Layer (COLL) for IP those results in reliable and predictable forwarding of IP traffic, and that enables traffic engineering, congestion management, optimized end-to-end transmission recovery, and differentiated IP services. Further, MPLS, when augmented with a QoS framework such as that specified in the IETF's Differentiated Services model, may enable deterministic QoS in IP networks [2, 3, 6, 8].

The other technology that can be used for resolving of the network routing problems is based on Soft Computing technologies. One of the first widespread and well-known intelligent routing methods is fuzzy based. Several attractive features, belonging to fuzzy model representation explain this phenomenon [7, 9, 10].

The main purpose of the paper is to realize a new fuzzy method for network routing based on users' preferences by a combination of Soft Computing Agents with MPLS network.

The paper is organized in the following way: In the second point the state of the MPLS network is briefly considered. The third part involves some definitions of Soft Computing Agents (SCA) and SCA classification is discussed. In the next part an application of CSA for users' preference optimal routing in MPLS network as well as one concrete realization is shown. Paper ends with concluding remarks.

2. What is MPLS

MPLS is a natural evolution required for networks to support predictable and optimized IP services, particularly in the next-generation IP networks. The connection-oriented nature of MPLS aims to help service providers to manage customer demands and their own revenue and profit goals [2, 3].

In order to designate different user preferences or service priorities depending on users, traffic must be marked with special labels, when it enters the network. Special routers called Label Edge Routers (LER) provide this labeling function (Fig. 1). The LER converts IP packets into MPLS packets, and MPLS packets into IP packets. The LER examines the incoming packet to determine whether the packet should be labeled. A special database in the LER matches the destination address to the label. An MPLS header (Fig. 2) is attached and the packet is sent on its way.

The Header consists of 32 bits in four parts – twenty bits are used for the label, three bits for experimental functions, one bit for stack function, and eight bits for time

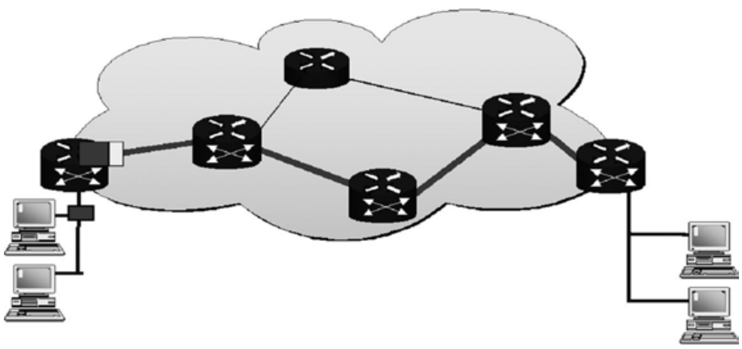

Fig.1. IP Network with LERs and an IP packet with header attached

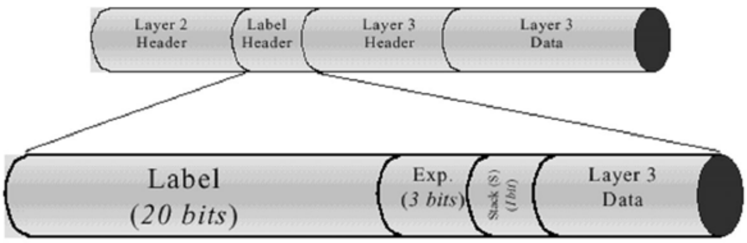

Fig. 2. MPLS header

to live (TTL). It allows compatibility with ATM (a layer-2 protocol) and IP (a layer-3 protocol) [1, 3].

The essential element in assigning a label is that the device that will be using the label to forward packets will be forwarding all packets with the same label in the same way. The two protocols defined for the purpose of distributing MPLS labels are Constraint-based Routing Label Distribution Protocol (CR-LDP) and extensions to the ReSource Reservation Protocol (RSVP).

Experimental functions are the experimental bits. Usually applied for class of service (CoS), they can affect the queuing and discard algorithms applied to the packet as it is transmitted through the network.

The Stack (S) is an ordered set of labels. A labeled packet may carry a number of labels, organized as a last-in, first-out (LIFO) stack. This bit is set to one for the last entry in the label stack (i.e., for the bottom of the stack), and zero for all other label stack entries.

TTL is the Time-to-Live field, similar to IP. When a packet travels along a Label Switched Path, it should emerge with the same TTL value that it would have had if it had traversed the same sequence of routers without having been label switched.

In order to route traffic across the network once labels have been attached, the non-edge routers serve as LSR (Label Switch Routers). Note that these devices are still routers. Packet analysis determines whether they serve as MPLS switches or routers. The function of LSR is to examine incoming packets. Providing that a label is present, the LSR will look up and follow the label instructions, and then forward the packet according to the instructions. In general, the LSR performs a label swapping function (Fig. 3).

Paths are established between the LER and the LSR. These paths are called Label Switch Paths (LSP). The paths are designed for their traffic characteristics based on users' preferences. These characteristics can include peak traffic load, cost, capacity, priority and queue length [3, 4].

MPLS provides two key functions that enable more predictable IP flows: minimizing congestion, and optimizing network capacity, or user-based routing and congestion-awareness. A device using user-based routing routes traffic based on traditional network topology information along with a number of other constraints, including the capacity and utilization of links, the requirements of the flow itself (i.e. bandwidth, delay, and priority) and other administrative constraints. It may be used to guarantee specific applications (like video-conferencing) a fixed amount of bandwidth end-to-end through the network. It may also be used to minimize latency and delay for voice traffic and to provide very specific, guaranteed and quantifiable customer service levels.

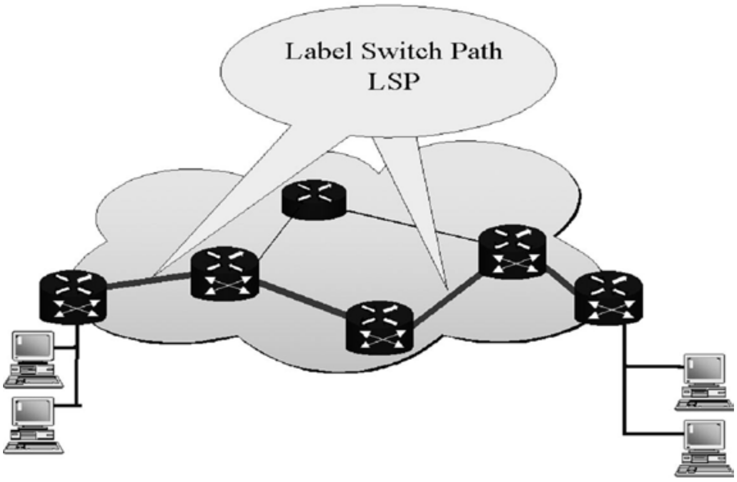

Fig. 3. Label switch paths

This ability to configure varying ranges of quality of service to different customers of the network is also an attractive method for service providers to offer their customers differentiated services.

User based routing and congestion awareness are critical to ATM's connection-oriented performance. When data is sent across an ATM network, MPLS routing (end-to-end connection) carries that data and takes into account:

1. The state of the network (available links, bandwidth available, etc.);
2. The latency and bandwidth requirements of the users (or applications);
3. Preferred routes that have been configured previously by the network manager.

The new requirements need new routing strategies to consider variety of parameters like topological and load specific parameters. The combination of SCA with MPLS network can be used to solve this complex network routing task.

3. Soft Computing Agents (SCA) for routing network applications

3.1. Some definitions

Definition 1. Soft Computing Technologies (SCT) is defined as Intelligent Technologies (IT), using methods tolerant towards uncertainty and complexity of real world phenomena [6, 9].

SCT representatives are: fuzzy logic, neural networks, and genetic algorithms, which can be enriched with another group of probabilistic reasoning, evidence theory, rough sets theory, taboo search etc. Summing some advantages of such approach we state:

1. Modeling and developing of accessible solutions of complex ill-defined objects without existence of precise mathematical models,

2. Obtaining of low cost robust, decisions of already proven difficult cases,

3. Using human being intuition and the best expert assessments instead of tedious and frequently impossible mathematical models,

4. A great variability of approaches and hence opportunity of solutions using the best sides of every one of SCT methods.

Definition 2. Soft Computing Agents (SCA) are such agents that combine benefits of soft computing technologies with software agent's paradigms [8, 11].

Since human SCA interaction is a basic feature of these agents the above definition diverse slightly from classical one for automatic action of agents' entities. In fact an interaction, at least in primary tuning of SCA, is mandatory. On the other hand once tuned and feature selected SCA acts as habitual SA. A motivation of SCA creation can be expressed in the following three points:

1. To benefit from obviously proven in practice advantages of SCT;
2. To gain of endorsing SA with new frequently subjective, but very important;
3. features depending on human being and personal preferences;
4. To improve Quality of Services – a primordial goal of agent technology.

Since SCA has no interference to the basic strategies and definitions of SA every one is free to chose, combine, and hence to create new classes of SA within every one of above described categories.

The main goals of SCAs' are to act as optimal resource allocation, so that they have to resolve the following problems:

1. Interactions with other agents in such a way that to minimize inter-communication;
2. Agents' granularity: one per node, one per physical link, one to represent each connection;
3. Mobile or stationery strategy of agents creation;
4. Awareness of agent in respect to other indirectly related events occurring in the agents proximity;
5. Agent dependability or system robustness in agent's dying conditions.

3.2. SCA for routing network

Three type of SCA are defined: information, optimal routing, and transport [7, 8].

Definition 3. Information MSCA is called such agent that is responsible for recent topology collection. They are spread in broadcasting mode to all nodes for collection of the net topology.

Definition 4. Optimal Routing MSCA is agent, which finds the best decision in accordance with customers' preferences.

Definition 5. Inter-node Interactive MSCA is agent that realizes information exchange between remote nodes.

4. SCA in MPLS realization

The goal is to implement an agent routing strategy in MPLS network that takes into consideration individual and professional customers' preferences. The sense of this is that the best path has not always associated with the shortest path to given destination. If we consider broad number of factors such as price, priority, security they may "colour" the best path giving it other dimensions. The same is when we consider different professions. Different professionals have different attitude and value system for the best decision. For example, businessman may claim for highest priority and security by highest price, when scientist will be content of lower priority and security by affordable price. Besides changing basic profession settings one can choose his own, different from initial model preferences. The mean of the above considerations is that the different users' preferences can be marked with different labels by LER in MPLS networks.

4.1. Optimal routing soft computing agents

4.1.1. Basic concepts – definition, purpose, principles

The main purpose of the Optimal Routing SCA (ORSCA) is to find the best path between two nodes based on information provided by Information SCA and defined by the labels in MPLS network. The ORSCA are oriented to improve Quality of Services (QoS) and endorse Intelligent Agents with ability to perceive, be aware and perform sensitive to customers' claims optimal actions [8]. By embedding functionality in ORSCA and distributed these agents across the MPLS network it is pushed intelligence in every LER node. The LER mark incoming packets with labels depending on user preferences. ORSCA paradigm has two constituents:

1. SCT that endorses more intelligence;
2. Ordinary SA features.

Concerning first it is possible to apply one of the most wide spread SCT, namely fuzzy logic. As a working shell it is combined fuzzy toolbox of MATLAB covering the first constituent with Java language – responsible for the second [8, 10].

It suggests a user-friendly dialogue in definition of customers' choice as compromise between their preferences and temporary Internet abilities. The interaction with an operator is defined via user-friendly interface as is shown in Fig. 4, Fig. 5, and Fig. 6, which have been built in VJAVA^{++}6.0 shell. Fuzzy experts, responsible for system core of ORSCA creation, define the first two windows in LER in MPLS network. They firstly tune inference machine as is shown in Figure 6. The expert module determines the approach that matches users' preferences with appropriate labels.

After setting fuzzy engine parameters, the profession experts define parameters of the following professions: lawyer, scientist, economist, businessman, financier, broker, physician, and journalist in accordance with their professional preferences in respect to the five factors shown on Fig. 5. In Fig. 6 a customer interaction is shown. It is

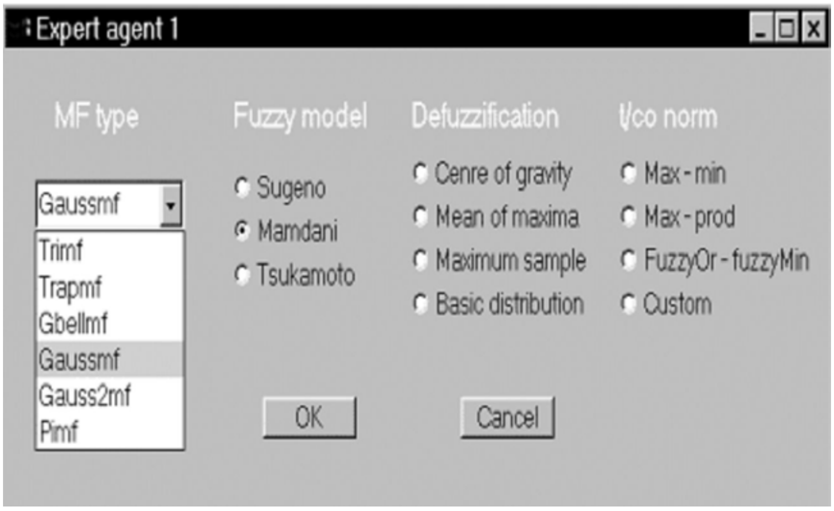

Fig. 4. Fuzzy inference system generation

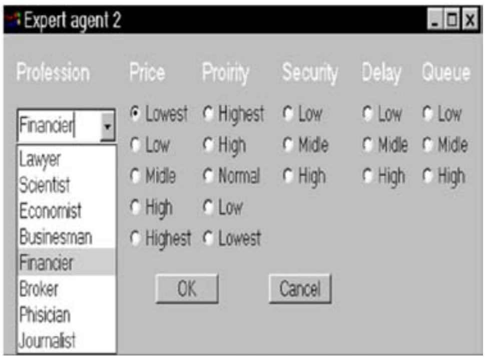

Fig. 5. Expert professions' defining

Fig. 6. Customer's interactive window

realized on user's computer. This dialog may have two forms: short when user assigns his own profession and start automatic procedure of SCA creation, or using multiple choice, when he selects several professions with different percentage participation in preference definition. It depends on label generation in LER. A claiming user can also change his subjective assessments in accordance with his own preferences. Once done, a system automatically tunes a SCA routing optimizer.

4.1.2. Perspective routing paths generation

By definition the ORSCA have to find the best Connection-Oriented Paths (COP) among all the perspective paths according to the assigned labels. The MPLS agent routing strategy enhancements IP routing protocols to make them connection-oriented. The ORSCA algorithm consists of the following steps [7, 11]:

1. Choice of optimal connection-oriented path topology;
2. Assessment of input string parameters;
3. Optimal path selection.

The problem that has to be resolved is how to generate the set of these perspective COP. The perspective paths correspond to label switch paths. The proposed technique is similar to dynamic programming. The experimental network is shown in Fig. 7.

The solicited service node is point N and destination is point 1. A strategy based on dynamic programming would start with optimization in backward direction from point 1. Once the best hop has been found it is proceed with searching such optimal in the next level. Next step finds all paths directly inputting point 1, i.e. 21, 22, 23. They form second level of the hierarchy. Next repeating the same procedure for 21, 22, and 23 as starting points the next, third level, i.e.: 31, 32, 33, 34, 35, 36, 37, and 38 is derived. Following this technique for every node in every level the purpose is to go to the soliciting node. In order to minimize these obviously great quantities of paths it is applied two rules:

1. Never use more than two transitions on one level;
2. No back transitions from higher to lower level.

The first prunes excessive transitions in one particular level, whilst the second escapes the system from dead loops in the best path searching procedure. The perspective paths routing table (Table 1) is generated as set of strings connecting adjacent level in sequels to the solicited node.

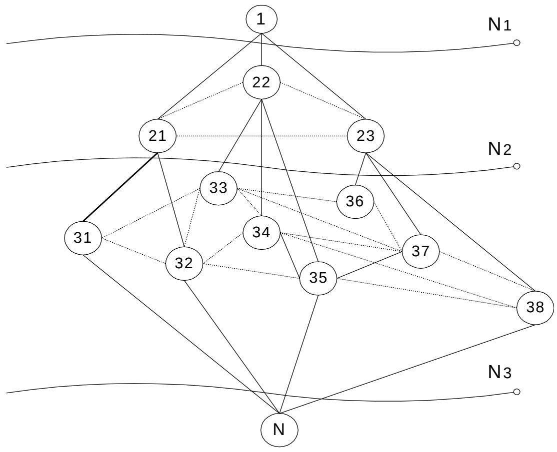

Fig. 7. Experimental network

Table 1

……………..(22–1)
…..(22-21) – (21–1)
…..(22-23) – (23–1)
……………...(23–1)
…..(23-21) – (21–1)
…..(23-22) – (22–1)

The data for each level are provided by routing tables of experiment data that are available in all nodes under consideration. Having a table of perspective string sequences it is ready to assess input string parameters. Every string consists of limit number of hops. The input parameters of every string are defined as follows:

(1) $$\text{del.} = \sum_{i=1}^{I}\sum_{j=1}^{J} del_{ij} \text{ – total delay,}$$

(2) $$\text{cost} = \sum_{i=1}^{I}\sum_{j=1}^{J} cost_{ij} \text{ – path cost,}$$

(3) $$\text{que} = \sum_{i=1}^{I}\sum_{j=1}^{J} que_{ij} \text{ – queue length,}$$

(4) $$\text{pri.} = \min{}_{ij} \text{ – path priority,}$$

(5) $$\text{cap.} = \min{}_{ij} \text{ – bond capacity,}$$

where *i* denotes hierarchy level, *j* – the number of bonds at each hierarchy level. Here for simplicity *j* is accepted to vary from 1 to *J* for all levels.

4.1.3. Simulation in SIMULINK environment

The MPLS fuzzy routing model is embedded and simulated in SIMULINK environment. A fuzzy routing system is generated according to above described rules and reflects fuzzy decision process, but simulation inputs are crisp values. These values are read from updated MPLS routing table of Perspective LSP. This updated routing table consists of data structures that contain the whole information about network topology and routing parameters supplied by Information SCA according to the labels. In the case these are generalized parameters of all Perspective LSP, namely: time delay of transmission, waiting queue, cost of proposed routing, link capacity, and priority of transmitted messages [10].

Table 2

Path	Cost	Capacity	Delay	Queue length	Priority
1	0.32	0.67	0.4	0.78	1
2	0.75	0.45	0.9	0.28	0.56
3	0.23	0.87	0.34	0.59	0.86
4	0.43	0.12	0.54	0.65	0.4

For each path system produce crisp value of link quality in [0, 1]: the bigger value means the better counterpart between link quality and generated label (user preferences). The simulation results of our experiment are: Path1 = 0.687, Path2 = 0.378, Path3 = 0.769, Path4 = 0.337. The optimal order of the best routing path based on fuzzy routing system computing is: Path3, Path1, Path2 and Path4.

4.2. Information soft computing agents

4.2.1. Basic concepts – definition, purpose, principles

By definition Information SCA is such an agent that provides information to some soliciting service active node. The main idea behind such an agent is to improve and support Optimal SCA in choosing the best routing search in respect to assigned labels. The Information Agent collects information about the following five parameters: cost or routing path, link capacity, delay of transmission, queue length and priority of transmitted messages. It is able to identify and use resources specific to any node on which it resides [5, 11].

4.2.2. Access to the network resources

The Information SCAs are SNMP based. This allows an Information SCA to access the MPLS network resources. The control window of ISCA and part of information table are shown in Fig.8 [11].

Fig. 8. Part of information table and Control Window of ISCA

It orients user to make solutions for active network management based on user preferences. There are three groups of parameters that he can actively influence: TCP, UPD, and IP. He can interact and involve its constraints using his proper choice. By means of ISCA control window the user can chose one of three groups of alternatives: TCP, UPD, or IP. The parameters, which are under consideration, have been selected preliminary in the fuzzy expert system. For example, in link congestion task using IP they can be: IP packets received, received packets discarded, received packets delivered, routing discards, etc.

An attractive feature of ISCA is that it uses information of the routing tables only instead of active interference or changing their parameters. This really prevents Internet organization from unauthorized access, interaction or misbalance of it as a whole.

5. Conclusions

In this paper a new fuzzy method for network routing based on users' preferences by a combination of Soft Computing Agents with MPLS network is realized. It is shown the realization of Optimal Routing SCA and Information SCA They provide ability to increase IP service predictability, create differentiated IP services based on user choice, and potentially reduce operation costs in IP and multi-service networks. The proposed agent strategy aims to provide a connection-oriented link for IP those results in reliable and predictable forwarding of IP traffic, and that enables traffic engineering, congestion management, optimized end-to-end transmission recovery, and differentiated IP services.

SCA add enhancements to MPLS routing to make one more sensitive to users' preferences. SCA technology improves the labeling function of the Label Edge Routers (LER). This can be explained with attractive features, belonging to Optimal Routing SCA and Information SCA:

1. Optimal Routing SCA

Able to find the best path between two nodes based on information provided by Information SCA in accordance with customers' preferences.

- Able to exploit significant amounts of domain knowledge.
- Able to use symbols and abstractions to mark incoming packets.
- Capable of adaptive, goal-oriented behavior.

2. Information SCA

- The Information Agent collects information about the following five parameters: cost or routing path, link capacity, delay of transmission, queue length and priority of transmitted messages.
- The main idea behind such agent is to improve and support Optimal SCA in choosing the best routing search in respect to all MPLS labels.

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Soft Computing агенти за MPLS мрежи

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Статията подчертава главните предимства и недостатъци на IP маршрутизацията. Анализирани са някои възможности за решаване на маршрутизиращи проблеми. Мотивирано е използването на Soft Computing технологии (SCT) и протокол с множествено превключване на етикетите (MPLS) за решаване на мрежов маршрутизиращ проблем. Коментират се накратко основни определения на Soft Computing агентите (SCA). Показано е, че комбинацията от предимствата на SCT и софтуерни агенти (SA) е универсална техника за оптимално разпределение на ресурсите. Създадени са опимални и информационни SCA в съответствие с потребителските предпочитания. Демонстрирана е способността на оптималния SCA за обработка и анализ на голямо количество мрежова информация и генериране на маршрути на базата на превключващи етикети. Отделено е специално внимание на информационните SCA, които подобряват и поддържат оптималните SCA в избора на най-добър маршрут по отношение на цялата налична маршрутизираща информация.