Wavenet Based Least Congested SPF by Congested Links Avoidance

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Abstract

Computer network routing and congestion control are two important tasks in computer networks. They are closely related in a manner such that routing protocol strategies can strongly affect network congestion. In this paper, a wavenet based least congested SPF by congested links avoidance (WLC-SPF/CLA) routing protocol is proposed taking into account the congestion state of each network link when it reconstructs paths for delivering packets from source to destination. During this process, congested links are avoided and the protocol tries to forward data through uncongested routes. The proposed routing protocol is a congestion adaptive routing protocol that has a facility to predict congestion states such that network congestion may be eliminated or at least minimized by the routing strategy. The congested state of each link is predicted using a wavenet based congestion predictor (WBCP).

Keywords: *Computer Network Routing, Congestion Control ,Wavelet-Neural Networks, Wavelet Analysis , Prediction, OSPF.*

1. Introduction

The widespread of computer networks, such as the well known Internet, and network related applications makes computer networks to be integral medium of information transfer. The basic function of computer network is that it delivers data from one node to other [1][2]. Many network components are needed to achieve this goal. These components include computers, links, network devices and protocols. One of the most important tasks in networking is the routing protocols. Routing is the process that logically connects network nodes by calculating paths between nodes so that data sent by one node traverses the calculated path to its destination [3]. Routing within network defines how the traffic flow is mapped in network topology [4]. Each network is composed of physical links that have finite bandwidth. Many links are shared among multiple independent users. As the case with any finite resources, network may be congested when the offered load exceeds network capacity [5].

The routing mechanism involved allows assigning network capacity, more or less efficiently, to demands or requests of traffic. The routing choice has direct impact on the existence of congestion [4]. High level congestion may decrease the grade of service, increasing time delay, increasing packet loss, making call blocking for voice traffic or real time applications, and so on. Congestion problem can be minimized by increasing the routing control and then optimizing network performance. Good routing mechanism can ensure high bandwidth utilization and avoid congestion [6]. Even if congestion occurred, it is necessary to minimize its duration and then minimizing the packets that may be lost.

In this paper, a proposed wavenet based least congested shortest path first routing protocol by congested links avoidance WLC-SPF/CLA is developed by modifying open shortest path first OSPF routing protocol in a way that makes the routing process sensitive to the congestion states that are commonly occurred in computer networks. Solving the problem of congestion occurrence is an essential task required to improve network performance. Nevertheless, some of congestion states may occurre even when efficient routing protocol is used [7]. However, good routing protocol can minimize congestion and reduce its effects on network service. The proposed WLC-SPF/CLA aims to eliminate congestion or at least minimize its occurrence. The proposed protocol can accomplish the routing task through computer networks using shortest path calculation after removing the congested links from the set of links in the computer network. Thus, shortest path remains the object function of router path calculation, but with a given constraint that is the shortest path must not contain any congested link.

Thus, the WLC-SPF/CLA routing protocol uses underutilized links to form path from source to destination and avoid overutilized links.

2. OSPF Routing Protocol

Open Shortest Path First (OSPF) routing protocol is one of routing protocols that is widely used in internet [3]. It is an intra domain routing protocol which is the dominant routing protocol in Internet today [8]. It is an interior routing protocol that is used in autonomous systems [9]. In OSPF networks, each node transfer data to other nodes through some intermediate nodes (routers) following the shortest path between edge nodes [10]. Each source destination pair transfers its data along that path between the source and destination. In OSPF networks, each router applies Dijkstra algorithm to its link state database to produce routing table. Dijkstra algorithm calculates the shortest path between any two nodes in graph made of nodes and edges of non negative weights [9]. In computer network case, nodes are routers, edges are network links, and the weights correspond to link costs.

Shortest paths of different source-destination pairs may share some links in the network. The shared links are likely to be congested. Even if there are several paths between each source- destination pair, only one path is used, the shortest one [11] [12]. That makes many packets are lost in congested links. The time delay will also be increased due to congestion [4].

3. Wavenet

Wavelet Neural Network (WNN), or wavenet, is a special type of neural networks that combines the wavelet transform theory together with the basic concepts of neural networks [13]. The use of wavenet neurons results in efficient networks that are optimal approximator for non linear and non stationary functions [14]. WNN takes the advantages of high-resolution nature of wavelet functions and learning with feed forward capabilities of neural networks [15].

The used WNN is a feed forward network that was developed as an alternative approach to the feed forward networks in 1992 [16]. In many applications, neural networks can not characterize local features likes jumps in time domain or frequency domain of the function [14]. Wavenet is a feed forward neural network that performs wavelet activation function in its hidden layer nodes rather than sigmoid function or radial basis functions used in traditional neural networks. A wavelet is an amplitude varying short waveform with a finite bandwidth [17]. It is also known as mother wavelet, analysis wavelet, or prototype wavelet. Because of wavelet function characteristics, wavelet neural network can deal with the problem of local features and discontinuities in time or frequency in an efficient manner [18]. Figure 1 shows the general structure of WNN. The output y of the WNN structure is calculated as

$$y = \sum_{j=1}^{P} w_j \psi_j(\tau) = \sum_{j=1}^{P} w_j \psi(\tau_j) \tag{1}$$

where P: number of nodes in the hidden layer,
y: the output of the output node,
w_j: the weight between j^{th}-hidden node and the output node,

$\psi_j(\tau) = \psi(\tau_j)$,

and $\tau_j = \dfrac{x - b_j}{a_j}$

a and b are the scale and translation parameters of wavelet, respectively.

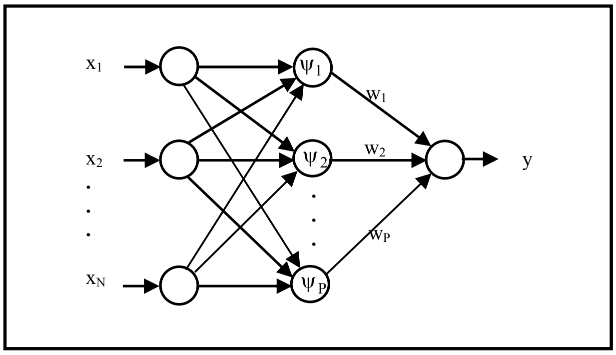

Figure 1. Wavenet structure.

4. The Procedure of WLC-SPF/CLA

WLC-SPF/CLA performs similar procedure to that performed by the traditional OSPF with few changes. The wavenet based congestion predictor (WBCP) [19] is used to generate the congestion vector that contains the predicted congestion states for all links in the computer network. The congestion vector generated by WBCP is used by the proposed protocol to get an indication about the predicted congestion state of each link. That means the routing protocol knows in advance which link will be congested in the near future. These links will be removed from the set of links in the network by setting the corresponding link cost to infinity in the adjacency matrix. Thus, congested links are treated as if they do physically not exist when the shortest path calculation is performed.

The structure of the proposed WLC-SPF/CLA includes the WBCP to generate the predicted congestion vector, modified OSPF, and the modified Dijkstra algorithm as shown in Figure 2.

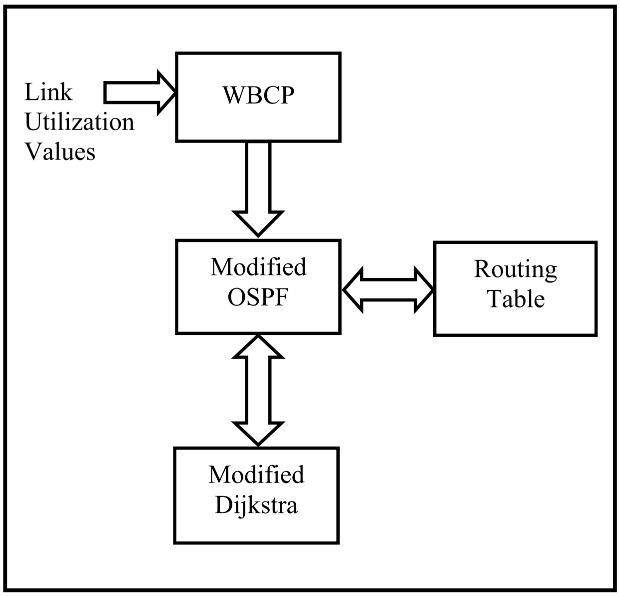

Figure 2. WLC-SPF/CLA Structure.

- ***Wavenet-Based Congestion Predictor WBCP***

Congestion is an important issue of packet switch networks that should be detected and minimized in its early stages[20][21]. Congestion minimization leads to reduce packet loss and then increase delivery reliability [22]. The WBCP is used to perform the congestion prediction task. It is implemented as a separate task that can run in parallel to other tasks of the routing protocol. WBCP consists of a number of WNNs equal to the number of links in the computer networks. Each WNN is responsible for congestion state of the corresponding link by generating a single output representing its state. Congestion vector represents total predicted congestion state. If the i^{th} congestion vector bit is set by its WNN to one, then the i^{th} link in the computer network is predicted to be congested in the next time interval. The number of inputs for each WNN are 5 each of them is the average link utilization for one minute in the past. Then link congestion state is predicted from its load in the previous five minutes. The congestion vector is passed to the Dijkstra algorithm. The new routes are computed by the modified Dijkstra given that the congestion vector is present.

There are seven wavenet neurons in the hidden layer; each uses Mexican Hat wavelet function and one output unit. WNN should be trained using wide variety training samples that include different states in order to make the wavenet network capable to interpolate any input and produce suitable predictions.

- ***The Modified OSPF***

The modified protocol performs much similar tasks as compared to OSPF to take the benefits of OSPF with additional benefits came from the enhancement or modification. The routing table of the proposed routing protocol has the same structure of the traditional OSPF routing table and the shortest paths are also calculated by Dijkstra algorithm, the modified one. The modification is that the routing protocol must be able to receive the congestion vector generated by the WBCP, check if there is any congestion state is signaled in any link (*i.e*., congestion vector contains at least a single bit set to 1), and call the modified Dijkstra algorithm (MDA). The routing table is updated with respect to four events that are periodic updates; each 30 minutes to refresh the routing table content, when link failure is detected, when there is a network topology change, or if there is any link being predicted as a congested one. The first three conditions are identical to that included in trditional OSPF, while the forth is added as a modification to the routing update states.

- ***The Modified Dijkstra Algorithm (MDA)***

Dijkstra algorithm generates the shortest path between any two nodes in computer network as it does with any directed graph with non-negative link weights. Network structure together with link costs are passed to Dijkstra algorithm through adjacency matrix. The adjacency matrix for an N-node network is a square matrix of N*N elements. The value of adjacency matrix element $\boldsymbol{m}$ (i,j) is infinity if there is no connection between node i and node j that is there is no physical link between router i and router j in the computer network. If there is a connection between the two nodes i and j, then the value $\boldsymbol{m}$ (i,j) is the cost of connecting link between two nodes or routers i and j. Thus, adjacency matrix reflects the full picture of the computer network nodes, links, and cost value of each link. Link cost values for networks operate in OSPF routing protocol are pre assigned and fixed by network operator and should not be changed during network run time.

The modified Dijkstra algorithm receives the graph structure and fixed link cost values through adjacency matrix. In addition to adjacency matrix, modified Dijkstra algorithm receives the predicted congestion vector C. A shortest path is generated between and source-distention pair (s,t) according to current adjacency matrix (Current_m). Current adjacency matrix is generated locally inside the modified algorithm from the original adjacency matrix by setting the cost value of the congested link to infinity. The current adjacency matrix is similar to the adjacency matrix but with logically removed congested links. The modified Dijkstra algorithm generates new shortest paths that contain no congested link because congested link costs are set to infinity, as they do not exist in the network. Thus, there is no need to reassign new values to link costs nor flooding these new values to all network routers. The pseudo code of the modified dijekstra algorithm is as follows:

```
procedure modified1_DA (G, m, C, s,t)
Current_m=m
for each link
if C (link) =1 then
corresponding current_m(i,j)=infinity
end if
end for
for all v ∈V do
l [v]←∞
π[v]←NIL
end for
Q ←V
l [s]←0
while Q≠Φ  do
u←MIN(Q); if u=t then terminate
Q ←Q \ {u}
for all node v ∈ N(u) do
if l [v]< l [u]+m(u, v) then
l [v]← l [u]+m(u, v)
π[v]←u
end if
end for
end while
end procedure
```

As a summary, the proposed WLC-SPF/CLA performs additional task in addition to all tasks included in the OSPF. This task is a time driven task runs each 3 minutes and includes the following steps:

1. Receive predicted congestion vector from WBCP.
2. If there is any bit in congestion state vector set to 1, perform steps 3-5, else perform step 6.
3. Pass adjacency matrix and congestion vector to modified Dijkstra algorithm to compute new set of routes. Route recalculation is performed for paths containing any congested link. If there is no path from source to destination, then the traditional Dijkstra algorithm is used to compute this path.
4. Receive new set of routes from modified Dijkstra algorithm.
5. update routing table of the router
6. Return

5. The Results

The proposed WLC-SPF/CLA routing protocol is tested for two network topologies that are shown in Figure 3. For each topology, four load demands are defined each of seven hour time duration as in Table 1. These load scenarios cover different types of loading environments including several congested paths but not at the same time, many congested link that are congested in non-simultaneous manner, several simultaneously congested links and many simultaneously congested links. For each test load scenario, four factors are measured to evaluate the performance of the proposed protocol they are maximum link utilization, average link utilization, average queuing delay (QD), and average packet loss ratio (PLR). Before testing the WLC-SPF/CLA in both topologies, the WNN is trained for the data gathered from the simulation of senario3 in topology 1 for (7 hours). The training samples are generated as the link utilization is used for each 5 minutes to generate single WNN input vector. The target output for that input vector is 1 if there is any congestion state in the next time interval. Only one WNN is trained and other WNNs are just copies of that WNN. WBCP is constructed from number of WNN equals to the number of links in the given network topology (22 for Topology 1 and 18 for Topology 2). The prediction accuracy for WBCP after its test on the four scenarios of both topologies is shown in Table 2. Congestion accuracy is given by

$$P_{acc} = \frac{\text{Number of correct prediction states}}{\text{Total number of prediction samples}} \tag{2}$$

Incorrect prediction states is due to two types of congestion states. They are missed congestion (there is a congestion state in the link in the next interval while the corresponding predictor output is 0) and false signaling (link WNN generates 1 at its output while the link is not congested).

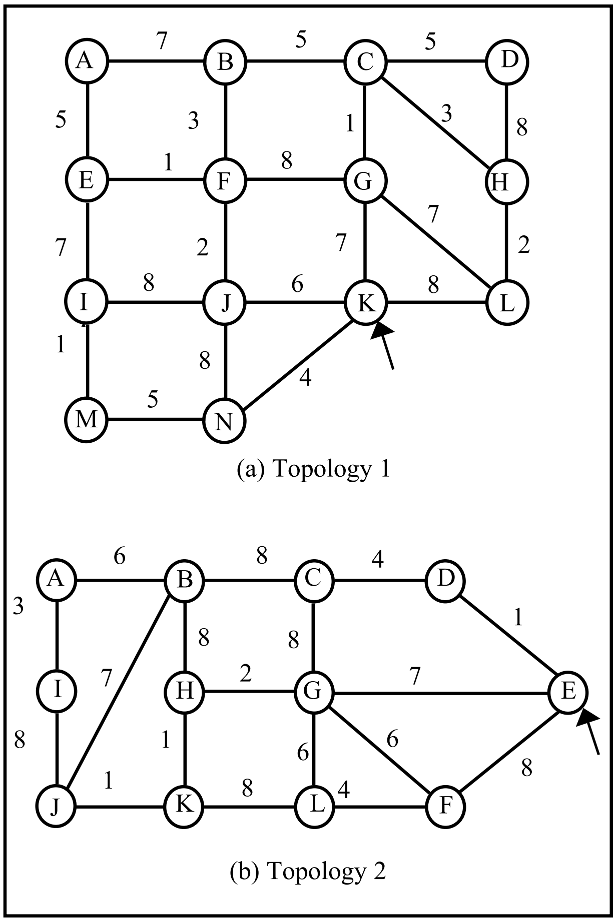

Figure 3. Two tested network topologies.

Table 1. Network Load Scenarios.

Load Style	Description
Scenario1	Load is applied throw several edge routers while others are unloaded (only light loads are applied on each of the other edge routers).
Scenario2	All edge routers have load that is fluctuated in a manner so that not all links connected to the server are congested simultaneously
Scenario3	All edge routers have load that is fluctuated in a manner so that some links connected to the server may be congested simultaneously
Scenario4	All edge routers have load that is fluctuated in a manner so that all links connected to the server are congested simultaneously

5.1 Topology 1 Results

After applying each load scenario, measurements are performed that include maximum link utilization, average link utilization, average queuing delay (QD) in seconds, and average packet loss ratio (PLR). Table 3 shows these results after applying demand load defined by scenario 1 using first the traditional OSPF protocol and then by the proposed WLC-SPF/CLA protocol. The last row summarizes the results for all links. It contains the maximum values of all measurements. Table 4 shows the summarized results for the four load scenarios related to Topology 1.

5.2 Topology 2 Results

The proposed protocol is used to perform the routing process for the previously defined four traffic demands on Topology 2. After applying each load scenario, the same measurements of Topology 1 are also performed. Table 5 shows the summarized results for the same four load scenarios related to Topology 2 using the traditional OSPF protocol and then the proposed WLC-SPF/CLA protocol..

6. Conclusions

WLC-SPF/CLA routing protocol has been proposed to perform load sensitive routing process based on congestion states prediction in each network link in order to reduce network congestion that are commonly occurred in computer networks. WBCP has been used to perform a simple high-accuracy topology-independent congestion prediction. When network congestion is predicted the proposed routing protocol update the routing tables in order not to include any congested link. This has been accomplished by virtually removing congested links from Dijkstra algorithm search space. The process do not alter link cost values so that there is no need for the undesired flooding of new link costs and congested links are avoided locally inside the modified Dijkstra algorithm. It has been shown that the proposed routing protocol gives better performance compared to the traditional OSPF for both topologies except in the case for which all paths are congested simultaneously.

Table 2. Congestion Prediction Accuracy.

Topology	Load Scenario	Prediction Accuracy %	False Signaling Ratio %	Missed congestion. Ratio %
Topology 1	Scenario 1	99.778	0.133	0.088
	Scenario 2	99.379	0.022	0.598
	Scenario 3	99.734	0.177	0.089
	Scenario 4	98.448	1.031	0.521
Topology 2	Scenario 1	98.604	0.786	0.610
	Scenario 2	98.550	0.840	0.611
	Scenario 3	98.198	0.999	0.800
	Scenario 4	98.347	0.908	0.745
Average		98.879	0.612	0.507

Table 3. WLC-SPF/CLA Results for Topology 1 – Scenario 1.

Link		OSPF				WLC-SPF/ CLA			
		Max. Util. %	**Aver. Util. %**	**Aver. QD Sec.**	**Aver. PLR %**	**Max. Util. %**	**Aver. Util. %**	**Aver. QD Sec.**	**Aver. PLR %**
1	AB	0	0	0	0	0	0	0	0
2	AE	69.928	39.298	0.0054	0	67.601	39.297	0.0039	0
3	BC	0	0	0	0	67.491	17.055	0.0018	0
4	BF	68.376	39.601	0.0054	0	67.485	22.577	0.0039	0
5	CD	4.783	1.895	0.0003	0	3.714	1.901	0.0002	0
6	CG	9.230	3.782	0.0011	0	72.551	20.848	0.0011	0
7	CH	0	0	0	0	0	0	0	0
8	DH	0	0	0	0	0	0	0	0
9	EF	73.807	41.602	0.0045	0	70.131	23.351	0.0016	0
10	EI	0	0	0	0	70.013	18.251	0.0029	0
11	FG	0	0	0	0	0	0	0	0
12	FJ	100	79.618	8.5953	1.6054	100	45.928	1.5898	0
13	GK	9.231	3.782	0.0032	0	72.551	20.848	0.0021	0
14	GL	0	0	0	0	0	0	0	0
15	HL	4.606	2.163	0.0031	0	3.696	2.166	0.0023	0
16	IJ	0	0	0	0	3.177	0.244	0.0005	0
17	IM	4.901	2.330	0.0071	0	72.543	20.552	0.0065	0
18	JK	100	79.618	8.5953	1.6054	98.668	45.976	1.6709	0
19	JN	0	0	0	0	5.059	0.044	0.0036	0
20	KL	8.227	3.310	0.0003	0	6.765	3.3105	0.0003	0
21	MN	8.381	4.519	0.0002	0	75.073	22.742	0.0013	0
22	NK	12.057	6.810	0.0027	0	77.603	24.990	0.0021	0
Maximum		**100**	**79.618**	**8.5953**	**1.6054**	**98.668**	**45.9768**	**1.6709**	**0**

Table 4. WLC-SPF/CLA Summarized Results for Topology 1.

Load Scenario	OSPF			WLC-SPF/ CLA		
	Aver. Utilization %	**Max. QD Sec.**	**Max. PLR %**	**Aver. Utilization %**	**Max. QD Sec.**	**Max. PLR %**
Scenario 1	79.619	8.5953	1.6054	45.9768	1.6709	0
Scenario 2	82.241	13.2267	6.9256	48.806	4.7577	0.7822
Scenario 3	83.532	14.5711	12.5652	50.054	6.1984	5.0768
Scenario 4	58.897	1.6824	1.6081	51.022	4.1239	5.3099

Table 5. WLC-SPF/CLA Summarized Results for Topology 2.

Load Scenario	OSPF			WLC-SPF/ CLA		
	Aver. Utilization %	**Max. QD Sec.**	**Max. PLR %**	**Aver. Utilization %**	**Max. QD Sec.**	**Max. PLR %**
Scenario 1	72.678	2.2080	0.3941	52.604	0.6939	0.0979
Scenario 2	76.986	13.1815	5.3162	59.611	5.4355	0.9207
Scenario 3	77.538	14.1247	10.7967	60.713	7.3797	4.0189
Scenario 4	57.211	4.6922	4.2616	53.367	5.3396	6.9555

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