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Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: http://qu.edu.iq/journaleng/index.php/JQES

Efficient load balancer for local internet service providers based on operation research

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ARTICLE INFO

Article history:
Received 12 January 2024
Received in revised form 25 March 2024
Accepted 05 June 2024

Keywords
Round Robin
Weighted Round Robin
Transportation problem
Least Cost
Northwest

ABSTRACT

Load balancing in internet services acts as a reverse proxy to distribute network bandwidth or application traffic across multiple servers. To decrease the internet route cost and to make the network intermediate devices more intelligent distance, number of hops, bandwidth capacity, equipment maintenance, power consumption ...etc must be considered. .. The aim is for the devices to have self-decision: acting upon data found in the network and transport layer protocols (Internet Protocol IP, Transmission Control Protocol TCP, File Transfer Protocol FTP, User Datagram Protocol UDP), and delivering the services to the secondary internet (wireless or optical fibers) ISPs. To achieve this target, the use of an operation research algorithm, such as linear programming, has been proposed to solve the problem of minimizing transport and distribution costs by developing and overcoming the transmission load cost of the path selection. The proposed EWRRLB (Efficient Weighted Round Robin Load Balancer) will assign different costs to each internet connection based not only on its capacity or priority but also on the cost of transmission paths. This allows load balancers to allocate the best economic path and the share of the bandwidth to certain connections.

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1. Introduction

The management of Internet bandwidth, at the level of local operators, has become an important issue in recent years due to the steady increase in the number of users and the high demand for Internet speeds, to ensure Internet capacity distribution among sources and demands [1]. Many local companies distribute and sell the Internet capacity from WAN (hole sale) obtained from several sources. These are divided into the need and the demand transferred to many consumers who are also representing Internet retail companies [2]. This distribution is done through a set of network intermediary devices, such as routers, modems, switches, LAN, ISP network backbones, and internet exchange ports IXPs that use different operating systems. Many techniques have been used to overcome the problems of load balancing (Internet Bandwidth Balancing). These techniques can optimize network performance and ensure a good distribution of traffic across a large number of internet connections [3]. The Internet capacity is often provided with more than the customer needs to ensure that the data flows properly. This leads to a much larger value of payments than the actual for the internet capacity in which they are effectively exploited [1].

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https://doi.org/10.30772/qjes.2024.146016.1084
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Nomenclature:

LCM	*Least Common Multiple*	*Greek symbols*	
RR	*Round Robin*	ω	Priority weight
S	*Server Bandwidth Supply*	*Subscripts*	
D	*Server Bandwidth Demand*	i	Server index
ISP	*Internet Service Provider*	j	Weight index
OTN	*Optical Transport Network*	m	Index of priority (columns)
ONU	*Optical Network Unit*	n	Index of priority (rows)
WDM	*Wavelength Division Multiplexing*	ro	Initial Round
Z	*Overall cost*		
X	*Cell cost*		
C	*The index of cell*		
LC	*Least cost method Transportation problem*		
NW	*Northwest method Transportation problem*		

There are some hardware and software solutions to achieve this, such as Least Connection Load Balancing (LCLB) [4], Multi-WAN routers, firewalls, and Cloud Based Load Balancers [5]. Effective management of Internet distribution networks uses the Weighted Round Robin Load Balancer WRRLB [6]. This algorithm can ensure Internet bandwidth rations, which are distributed indiscriminately or unintentionally costing millions of dollars annually although it is not used. This tends to reduce network redundancy effectively [7]. Network redundancy presumes a process through which additional or alternate instances of network devices, equipment, and communication mediums are installed within the network infrastructure. It is a method used to ensure network availability in case of a network device or path failure providing a means of network failover. Network redundancy is primarily implemented in enterprise network infrastructure to provide a redundant source of network communications [2]. The weighted Round Robin Load Balancer (WRRLB) algorithm works by assigning different weights to each internet connection based on its CAPACITY OR PRIORITY only. This allows a larger share of bandwidth to certain connections [8]. All the mentioned algorithms including the last modified version of (WRRLB) do not take into account the path cost while distributing the rations of selected targets. Path cost, if added, will improve (WRRLB) algorithm by preventing the selection of an overpriced (uneconomical) path while ensuring that the capacity or priority are not LOST simultaneously. Figure (1) shows the scheme of WRRLB [9]. The WRRLB serves as a backup mechanism for quickly swapping network operations onto redundant infrastructure in the event of unplanned network outages [1]. Typically, network redundancy is achieved through the addition of alternate network paths, which are implemented through redundant standby routers and switches [2]. When the primary path is unavailable, the alternate path can be instantly deployed to ensure minimal downtime and continuity of network services [10]. The best bandwidth management should provide more client subscriptions without buying more bandwidth. This can handle the seasonal load (for example, heavy in summer while light in winter) dynamically, it improves Quality Of Service (QoS) without torturing the client. In this paper, the operation research transportation problem is suggested as an analogy to solve a similar problem in network capacity delivery using Load Balancers [11, 12]. This proposed modification for WRRLB is suggested to give a new efficient way that merges WRRLB, which ensures capacity and priority, with the cost of the transmission path. This is named an Efficient Weighted Round Robin Load Balancer (EWRRLB), to be used in optical networks connecting the sources to customers [13]. Merging and splitting of internet capacities by optical fiber switches will be used. The tabular methods are adopted to solve the transportation problem with linear programming [8, 15].

2. Load balancer in optical network

Load balancing techniques are typically associated with data networks, such as IP-based networks, where data packets are routed and distributed among various servers, routers, or links to optimize traffic and resource utilization [14]. In optical networks, load balancing may not be a direct concept as it is in data networks because optical networks operate differently and focus on the transmission of optical signals through fiber-optic cables [15]. However, there are related concepts and technologies used in optical networks to ensure efficient operation and traffic management. It is possible to use Load Balancers in many parts of the Optical Network [16], depending on the design and services to optimize traffic and resource utilization [17]. Wavelength Division Multiplexer (WDM) is a technology used in optical networks to transmit several wavelengths (colors of light) over a single fiber. This permits multiple data streams to travel simultaneously on the same optical medium, causing an increase in the network's capacity. Optical switches are used to route optical signals within the network. These switches can dynamically route traffic from one optical path to another to optimize network resource usage and minimize congestion [18]. Traffic engineering techniques are often employed in optical networks to manage the flow of traffic efficiently. This can optimize the path for different wavelengths or set protection and restoration mechanisms to deal with network failures. Optical Transport Network (OTN) is a standard for optical network infrastructure that provides a framework for efficiently multiplexing and routing optical signals. It offers features like error correction and OAM (Operations, Administration, and Maintenance) for better network management [19]. Optical networks also manage resources such as transponders, repeaters, and amplifiers to ensure that light signals are transmitted efficiently over long distances. While load balancing, as it's commonly understood in IP-based networks, may not be applied directly to optical networks, the optimization of traffic and resource utilization is a fundamental concern in both types of networks. Optical networks use specific techniques and technologies to achieve this optimization [20]. The weighted Load Balancing technique has many requests in network engineering such as:

A) Weight Assignment: Each internet connection is given a weight value. Higher weights specify a greater capacity or priority, while lower weights denote less capacity or lower priority. For instance, a faster and more reliable connection is assigned a higher weight, while a slower or less reliable one obtains a lower weight [21].

B) Traffic Distribution: The load balancer at that moment uses these weight values to fix how much traffic each link should handle. Connections with higher weights accept a larger share of the received traffic, while those with lower weights get a smaller share [22].

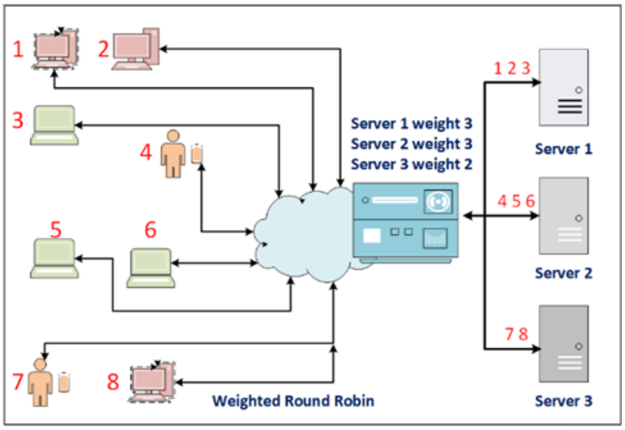

Figure. 1 Weighted Round Robin Load Balancer Algorithm [9]

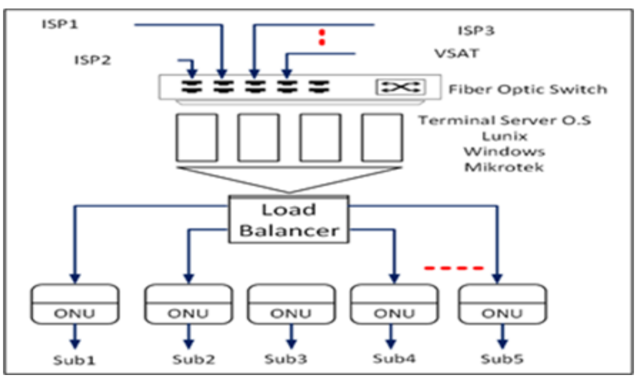

Figure. 2 (OTN) with Load Balancer hardware [19]

Load balancer hardware in an OTN environment helps evenly distribute traffic across multiple optical links or paths. It ensures that the network resources are utilized efficiently preventing any single link from being overloaded. This helps in achieving better network performance, increased reliability, and improved fault tolerance [23]. Fig.2 shows an Optical Transport Network (OTN) with Load Balancer hardware.

3. Weighted round robin algorithm

The Weighted Round Robin (WRR) algorithm is a load-balancing algorithm that assigns a weight to each server in a pool, and it distributes incoming requests to the servers based on their weights. The higher the weight, the more requests a server will receive. The mathematical model for Weighted Round Robin can be described as follows [24]:
To implement the Weighted round-robin procedure mathematically, the next steps will be used:

1. Determine the weights for each server/resource. Assume that there are n servers/resources with priority weights $= \omega_1, \omega_2, \omega_3, \dots, \omega_n$.
2. Calculate the least common multiple (LCM) of the weights. It signifies the maximum number of rounds required to cycle over all the servers/resources.

$$Maximum\ rounds = LCM(\omega_1, \omega_2, \dots, \omega_n) \quad (1)$$

3. Define a variable current Round to keep track of the current round.
4. For each round from 1 to maximum rounds, the weights assigned to servers $S_1, S_2, S_3 \dots, S_n$, are given.

The Weighted round-robin algorithm cycles through the servers circularly and selects the next server based on the weights. Let i be the index of the current server, and n be the total number of servers. The index of the next server S_{NEXT} is selected using the following formula:

$$i = (i + 1) mod\ n \quad (2)$$

The algorithm ensures that the index i wraps around to 1 when it reaches n, creating a circular cycle.

The selection is based on the weight of the server. If the weight of S_i is ω_i, the server S_{NEXT} is selected such that: $S_{NEXT} = S_i$, with the probability of $\frac{\omega_i}{\sum_{j=1}^{n} \omega_j}$.

This formula confirms that server with higher weight receives a larger share proportion of requests. The probability of selecting each server is proportional to its weight (the weight represents the capacity or priority only). Server with higher weights receives more requests compared to servers with lower weights, attaining a form of load balancing based on the specified weights. As seen above, the algorithm did not take into account the path cost, it just got its weight from the capacity or priority.

5. Compute the index of the server/resource for the current round utilizing the formula:

$$c_r = c_{ro} - \omega_n \quad (3)$$

Where c_r is the current index and c_{ro} is the current round. Assuming 0-based indexing. Use the calculated current index to select the server/resource for that round [25].
The transportation packet model can be represented as shown in Figure (3) with a's representing the sources and b's representing the destinations. The a's represent the main ISPs, while the b's represent the sub-ISPs. Here, one can easily observe the similarity between these operations and the transportation problem. Depending on that analogy, the transportation procedure is used.
The weights assigned to servers can be dynamically adjusted to put up changes in server capacity, performance, or traffic patterns. This allows the load balancer to adapt to variations in demand and ensure optimal resource utilization continuously. Round Robin algorithm with weights provides a straightforward yet current approach to load balancing by allocating incoming requests to servers in a manner that reflects their capacities, guaranteeing optimal performance and resource consumption in a server group or network location.[26].

4. Enhanced weighted round-robin algorithm (EWRRLB)

The proposed algorithm named EWRRLB, uses two operation research transportation problem solving techniques, the Northwest (NW) and Least Cost (LC) techniques. In operation research, the least cost and northwest methods are two popular techniques used to solve transportation problems. These methods are essential in logistics and supply chain management, where the efficient movement of goods from one location to another is critical [26]. The least cost method is an optimization technique that aims to minimize the total transportation cost while meeting the demand for goods at each destination. The method involves creating a transportation table, which shows the distance and cost of moving goods between each origin and destination. The least cost path is then determined by finding the shortest path with the lowest total cost [27]. The northwest method, also known as the northeast corner rule, is a heuristic technique used to approximate the optimal solution for the transportation problem. The method involves filling the transportation table from the top left corner and moving diagonally towards the bottom right corner. The northwest method is useful when the transportation table is large and complex, as it provides a quick and approximate solution [26]. Both methods are essential in solving transportation problems because they help to minimize transportation costs, optimize resource utilization, and improve overall efficiency. They are also useful in identifying potential bottlenecks and inefficiencies in the transportation network, which can be addressed through process improvements or infrastructure [28].

In this paper, these techniques were employed due to the similarity in goal, whereas the purpose is to transfer Internet capacities and improve the performance of load balancer devices, as it takes into account the capacity of sources and the priority of destinations only, without considering the path cost. This algorithm adds the calculation of the path cost by using minimum computing resources (tabular method), without using AI complexities, to allocate adequate bandwidth size from the source to the target according to the precedence as well as the cheapest path cost. To take into account the path cost, the amount of supply available at source i, is a_i, and the demand required at destination j is b_j [27]. The cost of transporting one unit between source i and destination j is c_{ij}. Let x_{ij} denote the bandwidth transported from Primary ISP i to secondary ISP j. The cost associated with this subdivision is the cost quantity which is equal to $c_{ij}\, x_{ij}$. The proposed modification is to add the weights $\omega_1, \omega_2, \omega_3, \dots, \omega_n$ to the cost equation mentioned in equation (4), The cost of transporting the commodity from source i to all destinations will be [28]:

$$\sum_{j=1}^{n} |c_{ij} - \omega_{ij}| x_{ij} = |c_{i1} - \omega_{i1}| x_{i1} + |c_{i2} - \omega_{i2}| x_{i2} + \cdots + |c_{in} - \omega_{in}| x_{in} \quad (4)$$

Thus, the overall packet transmitting cost representing the product from all ISPs (sources) to all sub ISPs (destinations) will be:

$$\text{Total Transmission cost} = \sum_{i=1}^{m} \sum_{j=1}^{n} |c_{ij} - \omega_{ij}| x_{ij} \quad (5)$$

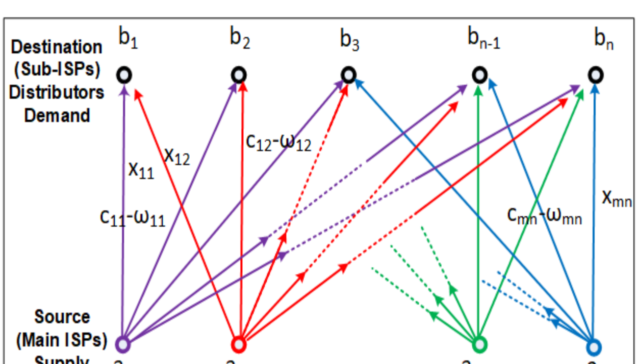

Figure. 3 Load Balancer with minimum transportation cost calculations

To minimize bandwidth transportation cost, by taking into account the work of the load balancer calculated as the ω_{mn} (the priority), equation (5) is rewritten as:

$$z = \sum_{i=1}^{m} \sum_{j=1}^{n} |c_{ij} - \omega_{ij}| x_{ij} \quad (6)$$

Subject to $\sum_{j=1}^{n} x_{ij} \le a_i$ for all i=1,…,m (7)

and $\sum_{i=1}^{m} x_{ij} \ge b_i$ for all j=1,…,n (8)

where, $x_{ij} \ge 0$ for all i and j.

5. Bandwidth distribution using operation research

In this paper, traditional methods of solving transportation problems used in operational research will be adopted by analogy to solve the bandwidth distribution problems of Internet packets received from various Internet service providers. These methods have been used due to the similarity between the transportation in operation research and the bandwidth transportation in networking [24]. By mentioning the current algorithm (Weighted Round Robin) used in the load balancer, a proposed modification (Enhancement) was added to improve its work by using tabular methods in operations research and giving the name EWRRLB.

The target of simplification algorithms is to achieve the minimum cost of supplying the internet packets from multi-sources to multi-destinations, without any loss and with minimum cost. Thus, transportation methods (Least Cost, North West, and Voggel's Method) will be used based on the demands D: D1, D2, D3, and D4 in Gigabit/second (bandwidth) and the supplier ability S: S1, S2, and S3 to supply these amounts in Gigabit/second (bandwidth). The same values shown in Table (1) for the demands and supplier ability are used in the North-West Corner and Least Cost methods to make a fair comparison of the resultant cost values. These two methods will be tested then, and the minimum expense resultant path will be assigned which of them will be chosen. This is applied to the transportation problem, which ensures that there is an initial basic feasible solution [25].

Table 1. Supply and Demand Table

	D1	D2	D3	D4	Supply
S1	4	6	2	4	5
S2	3	0	5	6	25
S3	7	8	9	10	20
Demand	10	5	15	20	50

The minimum values for *S*1=5 and *D*1=10 are compared. The smaller of the two i.e. min(5,10) = **5** is assigned to *S*1 *D*1, this exhausts the capacity of *S*1 and leaves 10 - 5 = 5 units with *D*1.

5.1 Transportation problem using the north-west corner method

The North-West Corner method is a technique in operations research used to solve transportation problems. It starts allocating shipments from the top-left corner, proceeding to the right and down. In the following test, it is assumed that the Number of supply constraints: is 3, the Number of demand constraints, A numerical test for the North-West Corner method is illustrated in tables (2-6) that show the steps of the solution of Transportation Problem using North-West Corner method. It is assumed that there are three sources (ISPs) of S1, S2, and S3 with 5, 20 and 25 Gbps respectively and the demands (Sub ISPs) of D1, D2, D3, and D4 are 10, 5, 15 and 20 Gbps respectively.

Table 2. The first iteration NW corner method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	~~4**(5)**~~	~~6~~	~~2~~	4	5-5=0
*S*2	3	0	5	6	25
*S*3	7	8	9	10	20
Demand	5 5=10-5	5	15	20	

The minimum values for *S*2=25 and *D*1=5 are compared. The smaller of the two i.e. min(25,5) = **5** is assigned to *S*2 *D*1; This meets the complete demand of *D*1 and leaves 25 - 5 = 20 units with *S*2

Table 3. The second iteration NW corner method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	~~4**(5)**~~	~~6~~	~~2~~	~~4~~	0
*S*2	3**(5)**	0	5	6	25-5=20
*S*3	7	8	9	10	20
Demand	5-5=0	5	15	20	

The minimum values for *S*2=20 and *D*2=5 are compared. The smaller of the two i.e. min(20,5) = **5** is assigned to *S*2 *D*2, This meets the complete demand of *D*2 and leaves 20 - 5 = 15 units with *S*2

Table 4. Third iteration NW corner method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	~~4**(5)**~~	~~6~~	~~2~~	~~4~~	0
*S*2	3**(5)**	0**(5)**	5	6	20-5=15
*S*3	7	8	9	10	20
Demand	0	5-5=0	15	20	

The minimum values for *S*2=15 and *D*3=15 are compared. The smaller of the two i.e. min(15,15) = **15** is assigned to *S*2 *D*3. This exhausts the capacity of *S*2 and leaves 15 - 15 = 0 units with *D*3

Table 5. Fourth iteration NW corner method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	~~4**(5)**~~	~~6~~	~~2~~	~~4~~	0
*S*2	~~3**(5)**~~	~~0**(5)**~~	~~5**(15)**~~	~~6~~	15-15=0
*S*3	7	8	9	10	20
Demand	0	0	15-15=0	20	

The minimum values for *S*3=20 and *D*3=0 are compared. The smaller of them i..e. min(20,0)= **0** is assigned to *S*3 *D*3, This meets the complete demand of *D*3 and leaves 20 - 0 = 20 units with *S*3

Table 6. Feasible solution of NW corner method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	4 **(5)**	6	2	4	5
*S*2	3 **(5)**	0 **(5)**	5 **(15)**	6	25
*S*3	7	8	9	10 **(20)**	20
Demand	10	5	15	20	

The minimum transportation is:
Cost(NW) =4×5+3×5+0×5+5×15+10×20=310

The number of allocated cells = 5, which is one less than (m + n – 1). Table 6 solution means that the total route cost of transmission among the supplies and destinations is 310 units, taking into account the cost of each cell and every single cell represents one connection.

5.2 Transportation problem using least Cost (LC) method

The same numbers used in sec.5.1, will be reused again in (LC) method, to facilitate a comparison of the results of total path cost between them: The minimum values for S1=5 and D1=10 are compared. The smaller of the two i.e. min(5,10) = 5 is assigned to S1 D1, this exhausts the capacity of S1 and leaves 10 - 5 = 5 units with D1. The smallest transportation cost is 0 in cell S2D2The allocation to this cell is min(25,5) = 5. This satisfies the entire demand of D2 and leaves 25 - 5 = 20 units with S2

Table 7. first iteration of LC method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	4	6	2	4	5
*S*2	3	0**(5)**	5	6	25-5=20
*S*3	7	8	9	10	20
Demand	10	5-5=0	15	20	

The smallest transportation cost is 2 in cell *S*1*D*3

Table 8. The second iteration of the LC method

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	~~4~~	~~6~~	~~2**(5)**~~	~~4~~	0
*S*2	~~3**(10)**~~	~~0**(5)**~~	~~5**(10)**~~	~~6~~	0
*S*3	~~7~~	~~8~~	~~9~~	~~10**(20)**~~	20-20=0
Demand	0	0	0	20-20=0	

Table 9. Third iteration LC method (feasible solution)

	*D*1	*D*2	*D*3	*D*4	Supply
*S*1	4	6	2 **(5)**	4	5
*S*2	3 **(10)**	0 **(5)**	5 **(10)**	6	25
*S*3	7	8	9	10 **(20)**	20
Demand	10	5	15	20	

The minimum transportation is:
Cost (LC)=2×5+3×10+0×5+5×10+10×20=290

Here, the number of allocated cells = 5, which is one less than m + n - 1 = 3 + 4 - 1 = 6. The alternate solution is available with unoccupied cell S3D1:d31 = [0], but with the same optimal value of LC method. It is clear from sec.5.1 and sec.5.2 that the Least Cost method (LC) outperforms the northwest corner giving lower path cost. Thus, LC method will be chosen for comparison and will be used with the load balancer algorithm.

6. Results discussion

Four experiments were conducted, as shown in Figure (4), to examine the response of four methods in terms of the total path cost of Internet service providers via (optical cable). In the first method, the basic round-robin (RR) algorithm was used with a Load Balancer (RRLB). In the second method, different and scattered weights were used (from 1 to 3) representing (priority and capacity). In the third method, the Least Cost (LC) was used, and the (bandwidth) here was distributed using the Least cost Transportation Problem only. The fourth method is proposed in this paper by combining the WRRLB and LC methods. This is named Enhanced Weighted Round Robin Load Balancer (EWRRLB). From the experimental simulation results, in Figure (4), it is noticed that the EWRRLB gives the lowest cost in calculating the path, which means that the efficiency of bandwidth distribution is better than in the previous cases. EWRRLB maintained the lower cost even when the path cost was increased in a nonlinear manner for all cells as shown in Table 10. This means that the highest performance of the proposed method will maintain stability and consistency when the path cost calculation is increased while maintaining the bandwidth shares distributed between the source ISP and the destination. It should be noted, however, that the same values given in Table (1) were used to simulate the previous four methods to ensure a fair comparison between them.

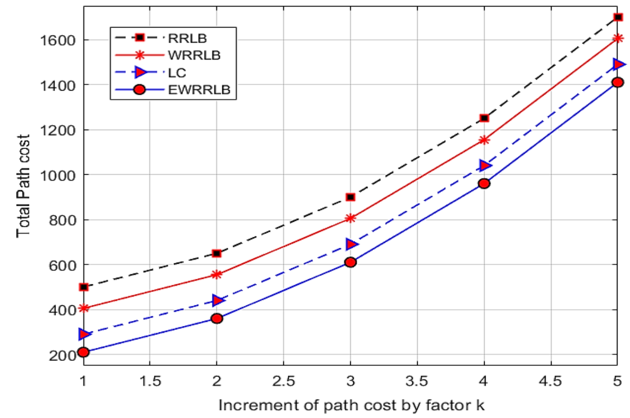

Figure 4. Comparison of the proposed method with other methods

It is noticed that the proposed EWRRLB method, as it is clear in Table 10, has the lowest path cost while maintaining the bandwidth requests from the load balancer at the demand side being the same.

Table 10. Comparison of the cost in terms of the highest and lowest path

Algorithm	Max path cost	Min path cost
RRLB	500	1700
WRRLB	405	1605
LC	290	1490
EWRRLB	210	1410

7. Conclusions

One of the basic factors that internet services take into account is the cost of communication paths coming from multiple sources. The cost of paths varies according to capacity, priority, and path, where the latter is not considered in load balancer structures. Load balancers use different algorithms, including Round Robin and Weighted Round Robin, to distribute the bandwidth according to priority and capacity. The proposed algorithm identified as EWRRLB (Efficient Weighted Round Robin Load Balancer) adds the path as another parameter. It has been showcased that it always finds the bandwidth distribution with the lowest cost, additionally, it takes into consideration the two essential factors capacity and priority which are always used in recent load balancer devices.

Declaration of competing interest

The authors declare that there is no conflict of interest related to this paper. They confirm that there are no personal, financial, or professional associations that could inspire the research, analysis, or explanation of the findings presented in this work.

Author's contributions

Conceptualization: All authors contributed to the conceptualization of the efficient load balancer for local internet service providers based on operations research. Methodology: [Author 1] and [Author 2], have developed the methodology, combining operation research algorithms, explicitly linear programming, to address the challenges in minimizing transport and distribution of internet bandwidth cost. Algorithm Design: [Author 1] designed the Efficient Weighted Round Robin Load Balancer (EWRRLB), introducing a novel approach by considering the cost of transmission paths along with capacity and priority. Data Analysis: [Author

3] conducted data analysis, confirming the proposed algorithm's ability to allocate bandwidth efficiently while minimizing cost. Writing - Original Draft: The initial draft of the paper was organized by [Tariq M. Salman], with input and revisions from both authors. Writing - Review & Editing: The authors reviewed and contributed to the editing and refinement of the paper.

Funding source

This study didn't receive any specific funds.

Acknowledgment

We would like to express our deep thankfulness to the University of Mustansiriyah, the College of Engineering, and the Belarusian State University of Informatics and Radio Electronics for their helpful support and resources in this research.

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