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An Analytical Model of Web Server Load Distribution by Applying a Minimum Entropy Strategy

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***Abstract*—This paper presents an analytical model and the way of simulation for distributing workload on a distributed web server system. The increase in the Internet traffic has also necessitated the conventional Domain Naming Service (DNS) to operate at a much lower efficiency. Among a number of problems associated with the DNS, a key problem has to do with the authoritative DNS not being able to process complete knowledge of the proximity. This makes the authoritative DNS less effective in monitoring server availability and routing incoming requests around failed servers. The workload distribution strategy on the other hand, keeps track of the state and health of the web server. This avoids connection delay due to, for example, a failed server, which can be temporarily by passed by workload distribution. From a modeling standpoint, the conventional DNS assumes equal queue size for each web server in a round-robin setting. Under load balancing, the queue size for each web server differs based on the probability of accessing that server. This probability is based on such factors as the geography, server health, server response, server threshold, session capacities, and the round trip time. In this paper, both conventional and global workload distribution strategies are developed and compared based on a finite set of practical traffic scenarios.**

***Index Terms*—Domain name server, entropy, workload distribution strategy, round-robin setting.**

I. INTRODUCTION

Increasingly companies are turning to World-Wide-Web (WWW) as an option channel for software distribution, online customer service, and business transactions. In the modern day, the role performed of web server is vital to businesses. Successful companies need the capacity to cater to millions of transactions on its server. Initially, several companies reported that they who could not support the colossal volume of transactions specifically on days when stock markets experienced a crash [1].

The phenomenal growth in popularity of the Internet has necessitated internet traffic to be monitored and controlled. This growth has posed the need for research deliberated to decrease the volume of internet traffic originated web users and servers, by using Domain Name Server (DNS). This paper considers a global workload distribution strategy on a distributed web server system [1]-[3].

The most common convention distributed web server system is based on round-robin domain name resolution (RR-DNS), which assigns HTML document requests to web server [3]. The round-robin technique is useful specifically in the case that HTTP requests access HTML document of a standard size and the load and service rate of web servers are fairly comparable [4].

Nevertheless, the web servers are heterogeneous systems hence processing nodes are expected to have dissimilar processing speeds. They "can leave and joint the system resource pool at any time" [4]. Therefore dynamic strategies are desirable to balance workload among the web servers [5].

The drawback of the round-robin DNS is that address-caching mechanism permits DNS control on a relatively small portion of the requests. An uneven distribution of clients' requests from diverse number of domains causes imbalance so when many clients from one single domain are assigned to the same single server these results in overload of the web server [3].

II. SYSTEM MODEL

The system is modeled by open queuing network, which is made of numerous interconnected queued servers. An excessive number of requests are entered into the system independently. Therefore this research considers a distributed web server system architecture that uses DNS as a "typical centralized scheduler, applies some scheduling strategy in routing the requests to the most suitable web server" [1]. A well defined and transparent architecture is obtained from a "single virtual interface to the outside world, at the least at URL level" [4], as shown in Fig. 1.

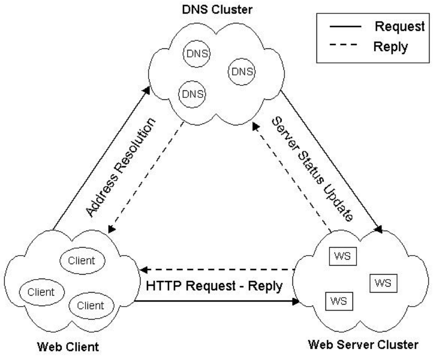

Fig. 1. System model and network flow.

Network is fault free and strongly connected. However, the traffic of the network is various. It depends on the request from web client. Also, web servers can leave and join the system resource pool at any time [8]. They are no communication between web servers.

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This research denotes the average page response time $E[R]$ by. This may write $E[R]$ as the sum of the average total waiting time, the average communication delay, and the average DNS synchronization; that is,

$$E[R]=E[W]+E[D]+E[S] \tag{1}$$

where $E[W]$ denotes the average waiting time, $E[D]$ denotes the average communication delay, and $E[S]$ denotes the average DNS synchronization.

To understand workload behavior on the distributed web server system (physical or logical connection), the research adds two fictitious stations to the network: request and receive. The request station generates all external arrival and the receive station receives all customers leaving the web server cluster. This is shown in Fig. 2.

This paper uses q_{ei} ($\sum_{i=1}^{M} q_{ei} = 1$) [5], [6], and [7] to denote the probability that an external arrival is directed to web server i. Similarly, this paper uses q_{io} to denote the probability of the task that finishes it services at web server i and leaves the web cluster. From [5], [8], [9], [10], [11], and [12], the traffic equation for the network is given by: $\lambda_i = \gamma_i + \sum_{j=1}^{M} \lambda_i q_{ji}$. Where λ_i denotes the average arrival rate at web server i, γ_i denotes the external arrival into web server i from a Poisson stream ($\gamma_i = \gamma q_{ei}$). Then $\gamma = \sum_{i=1}^{M} \gamma_i$.

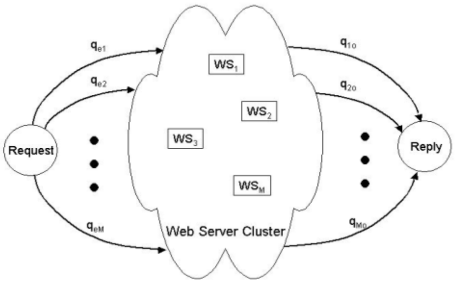

Fig. 2. Represent of an open web server queuing network.

This paper uses q_{ij} to denote the routing probability that on leaving web server i to web server j. However, this model, the web servers do not communicate to each other. Therefore, $q_{ij} = 0$ and $\lambda_i = \gamma_i$. It follows [7], [10], and [14] that the average waiting time in the network is given by:

$$W_i = \frac{1}{\mu_i(1-\rho_i)} \tag{2}$$

where μ_i is the service rate, and ρ_i is the traffic intensity. The utilization of web server i is given by $U_i = \rho_i$. In this model, the service rates of the web server are load-dependent [11] and [15]. Then $\mu_i = \mu_i^{\circ} C_i(n)$, where μ_i° is called the basic rate service rate. This research uses $C_i(n)$ to denote the capacity function where n denotes population vector, and by definition $C_i(1) = 1$. Using (2) therefore:

$$E[W] = \sum_{i=1}^{M} \frac{\lambda_i}{\gamma}\left[\frac{1}{\mu_i(1-\rho_i)}\right] \tag{3}$$

The average communication delay and the average DNS synchronization time are the average time that packet spent waiting for using channel. They are given by [8] and [11]:

$$E[T] = \sum_{i=1}^{M} \frac{\lambda_i}{\gamma}\left[\frac{1}{xK_i(1-\lambda_i)}\right] \tag{4}$$

where $E[T]$ is the average message delay, $1/x$ is the average length of a data packet, and K_i is the capacity channel at channel i. Using (4), then

$$E[D] = \sum_{i=1}^{M} \frac{\lambda_i}{\gamma}\left[\frac{1}{x_D K_{Di}(1-\lambda_i)}\right] \tag{5}$$

and

$$E[S] = \sum_{i=1}^{M+N} \frac{\lambda_i}{\gamma}\left[\frac{1}{x_S K_{Si}(1-\lambda_i)}\right] \tag{6}$$

where $1/x_D$ denotes the average length of a data packet that send and receive between web server and web client, K_{Di} denotes the capacity channel at channel i between web server and web client, $1/x_S$ denotes the average length of a data packet that send and receive between DNS and web server, K_{Si} denotes the capacity channel at channel i between DNS and web server, and N denotes number of DNS in DNS cluster. This research assumes the capacity channel between DNS to web server and web client to web server are equal, also the average length of a data packet from web server to web client and web server to DNS are equal. Using (1), (3), (5), and (6), therefore:

$$E[R] = \sum_{i=1}^{M} \frac{\lambda_i}{\gamma x_D}\left[\frac{x_D K_{Di}(1-\lambda_i) + 2\mu_i(1-\rho_i)}{\mu_i K_{Di}(1-\lambda_i)(1-\rho_i)}\right] + \sum_{j=1}^{N} \frac{\lambda_j}{\gamma}\left[\frac{1}{x_S K_{Sj}(1-\lambda_j)}\right] \tag{7}$$

Therefore (7) is “The average page response time corresponds to interval elapsed between the submission of the web client request for given page and the arrival at the client of all objects corresponding to the page request. It includes Transmission Control Protocol (TCP) establish connection time, delays at web server, network transmission time” [5].

III. A MINIMUM ENTROPY STRATEGY FOR WEB SERVER LOAD DISTRIBUTION

The uncertainty equation is derived for this group of objects which is an equation from Shannon. The information theoretic heuristic is analyzed at each decision level thus, decreasing the lower bound for the sub problem. In 1948, a measure of uncertainty of a discrete stochastic system known as entropy was introduced [8], [9], and [14]. For a probability distribution p define on a finite set $[n] = \{1,\ldots,n\}$ the Shannon entropy of p is defined by with the convention that $0 \log 0 = 0$.

$$H_s(p) = -\sum_{k=1}^{m} P(i)\log P(i) \tag{8}$$

Entropy is now an essential concept in decision making.

Additionally, entropy is a constructive information theory which is generally adopted in the information theory is used as a measure for the uncertainty of a discrete probability density function. Since this definition is similar to the one used in statistical mechanics, this measure of uncertainty is labeled entropy. When all probabilities are equal, the entropy reaches its maximum or minimum.

Entropy is adopted in the case that the decision matrix for a set of options contains a certain amount of information. Therefore, entropy is adopted as a tool in certainty level evaluation. Entropy is most practical in investigate the differences among data sets. Although entropy has increasingly adopted in these past years for a variety of cases in information theory, it has great potential as a decision-making tool until now this has not been fully exploited. This study underlines the functional capability of entropy which includes the derivation of probability distributions.

This research proposes a strategy that aims at improving the performance of distributed load to web servers that is likely to perform poorly scheduling algorithm RR-DNS. The proposed scheduling strategy uses information from each web server to make the decision in the mapping of URL names to IP-address of web servers, as illustrated in Fig. 3. This decision problem is solved with a greedy technique, which is used the entropy function as weighted linear function to decide the best web server. The entropy function is an uncertainty measure at the web server for the decision in each request.

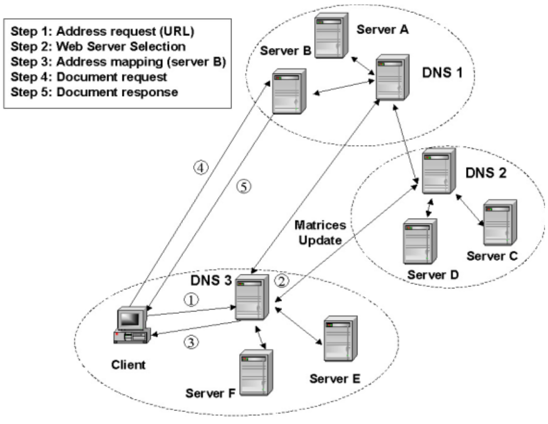

Fig. 3. DNS-Based web server load balancing with minimum entropy policy.

Let H_{ij} be entropy of a web server i with server matrices j, and let x_{ijk} be a set of mutually exclusive m events of web server i with server matrices j. The entropy function of web server i with server matrices j, $H_{ij}(X_k)$, is defined as

$$H_{ij}(X_k) = -\sum_{k=1}^{m} P_{ijk}(x_{ijk})\log P(x_{ijk}) \qquad (9)$$

In this paper, the server matrices (e.g., TTL, health condition, session capacity threshold, round-trip time, and geographical region) are mutually exclusive events, then [8] and [14]

$$H_{ij}(X_1,\ldots,X_k) = H_{ij}(X_1) + H_{ij}(X_2) + \ldots + H_{ij}(X_k) \qquad (10)$$

$$H_{ij}(X_1,\ldots,X_k) = -\sum_{j=1}^{n}\sum_{k=1}^{m} P(x_{ijk})\log P(x_{ijk}) \qquad (11)$$

Therefore

$$OPT(H_{ij}) = \min_{i}\left(\sum_{j=1}^{n} H_{ij}(X_1,\ldots,X_k)\right) \qquad (12)$$

where $OPT(H_{ij})$ is the web server that has minimum entropy. It follows [16], the entropy function is minimum, in fact equal to zero, when its values is certain, an observation can yield a good condition on the web server. Similarly, the entropy function maximum when the random variable is uniformly distributed; the outcome of the web server has maximum uncertainty. This research measures entropy level by server matrices from each web server to calculate the desired relative workload distribution workload between the distributed web servers. Fig. 4 shows an example of certainty level in each web server. The workload will be assigned to the web servers are depended on the entropy. The web server with smaller entropy will be assigned workload more than the web server with higher entropy.

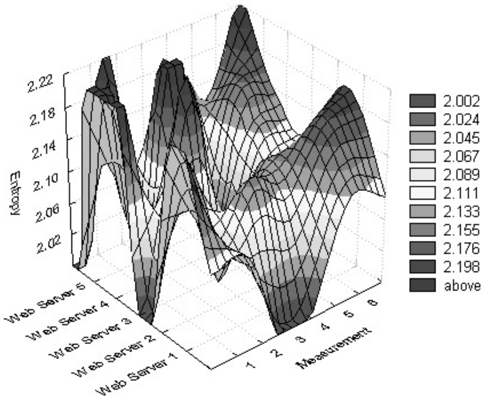

Fig. 4. Web server entropy measurement.

IV. PARAMETER AND EXPERIMENTS DESIGN

This section presents the experiment with their base value and distributions that characterize the entire system and the DNS with minimum entropy policy. Table I summarizes the system and workload parameters that compare the performance of the minimum entropy load balancing strategy with the traditional RR-DNS, the RR- DNS [3] and [10]. HTML document response time is a major index to measure the performance of the load balancing strategy. In particular, looking at the minimum average page response time, this can deduce whether the load balance or not. Hence, the performance of several scheduling policies is evaluated by focusing on the minimum page response time observed during the simulation runs.

This experiment divides global DNS cluster into small regions. When a client requests the HTML document from web server, it sends the query to intermediate name server. Both Intermediate name server and client is the same region, and assume that the number of hop to reach web server from DNS and client are similar. Entire system operates with no cache. Each DNS, the minimum entropy load balancing policy, sends the queries to each web server and other DNS for updating their information. Server metrics on each DNS contains with web server round trip time, TTL to reach the web server, and response time.

TABLE I: PARAMETERS OF THE SYSTEM

Category	Parameter	Value(default)
DNS	Number of DNS	3
Web Server	Number of Web Server	5
	Basic Service Rate	400 – 450 packet/second
Workload	Number of HTTP Requests	1000
	Documents Size	10 –100 packets
Server Matrices	Round Trip Time	32 – 500 ms.
	Response Time	1 – 10 ms.
	TTL	64 – 254

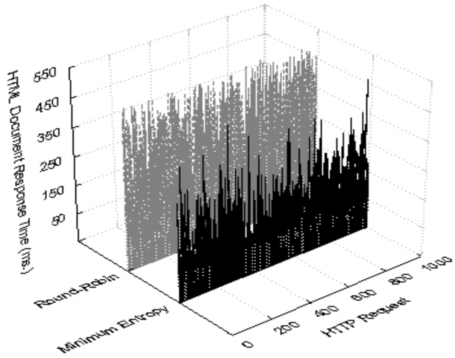

Fig. 5. 1000 HTML documents average response time.

This research uses load distribution and cumulative distribution of the HTML document response time as the performance criterion, because in a highly variable system it is more significant than average values [4] and [15]. For the performance evaluation of proposed policy, this research carried out a large number of experiments. The gold is to measure how effectively the minimum entropy load balancing that controls only a very small percentage of address resolution requests can minimize the workload of the distributed web server. Fig. 5 shows the HTML document average response time of each strategy in 1000 HTTP document requests. The average of the HTML document response time of the minimum entropy strategy is less than the RR-DNS.

TABLE II: THE EXPERIMENT STATISTICAL VALUES

Policy	Average	Minimum	Maximum	Variance	Std.Dev
Minimum Entropy	112.6942	33.0024	487.002	5997.33	77.4424
Round-Robin	262.6742	38.0023	510.002	18758.15	136.9604

Fig. 6 shows load distribution of 1000 HTML document request on minimum entropy and round-robin strategy. In the minimum entropy policy, 40-percent of the requests are between 100 – 150 ms., 14-percent of the request are between 50 – 100 ms., and 46-percent are greater than 150 ms. In the other hand, round-robin policy, 12-percent are between 100 – 150 ms. and 450 – 500 ms., 4-percent of the requests are between 50 – 100 ms., 11-percent are greater than 500 ms. and the rest are spread from 150 ms. to 450 ms.

Fig. 7 compares the cumulative distribution for the DNS proximity using minimum entropy strategy and traditional DNS with round-robin strategy. This figure shows that both policies guarantee that the maximum HTML document response time is below 550 ms. The 90-percentile of the minimum entropy policy is less than 225 ms and the 50-percentile is below 125 ms. The RR policy has slightly worse performance with the 90- percentile is less than 450 ms., and the 50-percentile is less than 275 ms. The propose method can improve the average response time much further by tuning the web server matrices to the workload level. To archive this goal, the experiment needs to monitor the server matrices, choosing minimum entropy web server to assign the heavily load and choosing maximum entropy web server to assign light load.

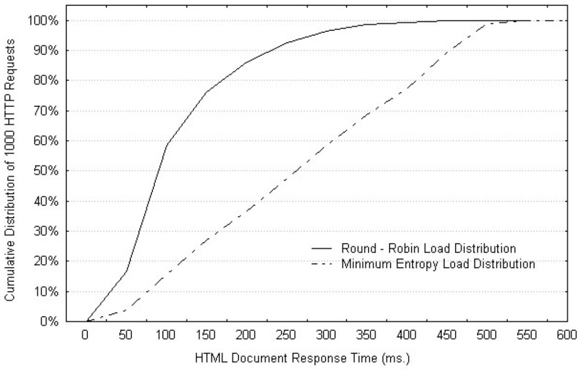

Fig. 6. A minimum entropy load distribution strategy and Round-Robin strategy.

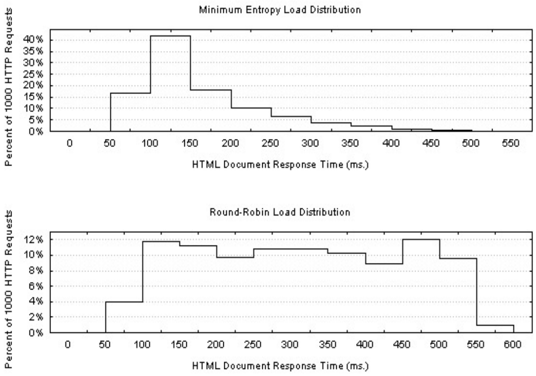

Fig. 7. Cumulative distribution of HTML document average response time.

V. CONCLUSION

In this paper, the experiment modified the traditional scheduling strategy to the Domain Name Server (DNS), proposed new policy, and studied the impact for a diverse range of scenarios. The new approach proposed is based on the entropy function of the web server matrices (e.g., health condition, session capacity threshold, round-trip time, and geographical region). The tradition round-robin DNS (RR-DNS) policy is not applicable to network with dynamic traffic scenarios. The experiments of new policy showed that they are able to providing suitable web server in each request to the web client. The entropy strategy can be useful for analyzing and modifying an existing system, and assessing other newly proposed strategies. In the near future, the experiment will improved the technique to distributing workload on the distributed web server system whether local or global connection. The research is also going on building a simulation environment to have more validation for the obtained results.

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