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Multi Attribute Decision Making for Content Replacement Mechanism in Named Data Networking

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Abstract— *Named Data Network (NDN) is one of Information-Centric Networking (ICN) architectures which is gaining increasing attention, as an important direction of the Future Internet architecture research. This architecture is centered on content and it is worth noting that content caching plays a key role in NDN. Most researches concerning uniform caching base their replacement decision on just one parameter. This parameter does not do well because of the workload characteristics in NDN. Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as a decision analysis method is used to select the content name for eviction. To determine popularity and priority for a new Cache Replacement Mechanism (CRM) that would positively benefit both suppliers and users of the Internet. The results from the performance of CRM is evaluated through simulations and compared with the conventional First-In-First-Out (FIFO), Least Recently Used (LRU), Least Frequently Used (LFU), and Cache Content Popularity (CCP) strategies. As evident in the results documented, CRM performs better in comparison to FIFO, LRU, LFU, and CCP with respect to a cache hit ratio, server load, and throughput.*

Keywords— *Information-Centric Networking, Name Data Network, Future Internet, Fuzzy TOPSIS, Cache Replacement decision.*

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I. INTRODUCTION

The ICN thought was at first proposed in TRIAD [1],where a name-based information correspondence was proposed. From that period forward, researchers have proposed different structures as seen in Table 1.

Table 1
ICN Architecture

ICN Architecture Name	Project Name	Funding Source	Duration
DONA [2]	DONA	USA	2007
NetInf [3]	4WARD and SAIL	EU	2008 - 2013
COMET [4]	CONVERGENCE	EU	2010 - 2013
PURSUIT [5]	PSIRP and PURSUIT	EU	2010 - 2013
MobilityFirst [6]	MobilityFirst FIA	USA	2010 -2013
NDN [7, 8, 9, 10]	CCN, NDN and UCLA	USA	2010 - 2013

However, the most prominent one is known as Named Data Networking (NDN) (also referred to as CCN [11]). NDN means that every network router envisages the ubiquitous deployment of content caches [12, 13, 14]. In 1965, fuzzy sets Zadeh 1965; Bellman and Zadeh 1970) were proposed to confront the problems of linguistic or uncertain information and be a generalization of conventional set theory. With the successful applications in the field of automatic control, fuzzy sets have recently been incorporated into Multiple Attribute Decision Making (MADM) for dealing with MADM problems in situations of subjective uncertainty. Considering problems that involve selecting from a fixed number of alternatives, MADM rises to the challenge as an approach to be employed in solving the problems. In arriving at a choice from the alternatives, the method works by specifying the manner in which attribute information should be processed [15, 16, 17]. Both intraattribute and enter attribute comparisons are required by MADM methods. Appropriate explicit tradeoffs are also involved in the method. In the year 1981 Yoon and Hwang developed TOPSIS method that simultaneously considers the distance to the ideal solution. It chooses the alternative that has the maximum distance from the negative ideal solution and the minimum distance from the positive ideal solution. The Fuzzy TOPSIS technique was proposed by Chen [18], to solve multiple attributes decision-making problems under fuzzy environment and to deal efficiently with uncertainty in the evaluation matrices based on Alternative Leveuations and judgments.

The rest of the paper is then divided in the following manner: Section II presents the characteristics of the Operation of NDN Architecture III presents the characteristics of the problem statement, Section IV discusses the cache replacement strategies decision, Section V describes Fuzzy TOPSIS method, Section VI pseudo-code of the fuzzy TOPSIS method, Section VII content replacement mechanism, Section VIII simulation and evaluation, Section IX is the conclusion.

II. NDN ARCHITECTURE

All communications in NDN are performed using two distinct types of packets: Interest and Content. Both types of packets carry a name, which uniquely identifies a piece of content that can be carried in one Content packet. Content names in NDN are hierarchically structured and an example name for the first segment of a library video would like: "UUM/library/videos/0s79jts/0". NDN router maintains three major data structures: PIT, FIB and CS, as shown in Figure 1, which are indicated as follows:(1) PIT: It holds and keeps track of all "not yet satisfied" Interests that have been sent upstream towards potential data sources so that returned Content can be sent downstream to its requester(s). Each PIT entry contains one or multiple incoming and outgoing physical interfaces; multiple incoming interfaces indicate the same data is requested from multiple downstream users; multiple outgoing interfaces indicate the same Interest is forwarded along multiple paths. (2) FIB: It maps name prefixes to one or multiple physical network interfaces, specifying directions where Interests can be forwarded. (3) CS: It buffers Content packets that pass through this router, allowing efficient data retrieval by different consumers [19, 20].

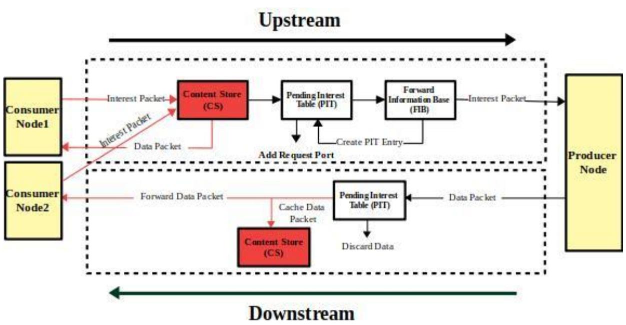

Figure 1: Forward Processing in NDN Node *[19]*

III. PROBLEM STATEMENT

It has been observed that media file streaming is growing largely in size daily and an inevitable aggravation of the congestion of the Internet is being experienced, with latency now being perceived by the user. For the NDN router, it caches every travelling data packet, and this data packet is fetched again from a physically close distance when a request to the identical data is made. A challenge with NDN is that the node of the intermediate nodes talks directly back to the consumer node and sends messages to the next node in line, therefore, many changes happen incrementally [21-29].

Specifically, the popular data packet gets the most requests, with a large portion of data packets, which are stored in the cache, being never requested again, and thus leading to an occupied cache [30, 31]. This occupied cache by the data packets not requested, may be stored in the cache forever, except there is an occurrence of some new contents that are of higher popularity and higher total hits. Therefore, cache occupancy may consist of previously popular data but recently used, even though its rarely used. Subsequently, the newly arriving content cannot be saved [13, 32, 33, 34]. The cached data can optionally have a long-freshness-period before its replacement, because the expiration of the freshness-period only means that the producer may have produced newer data [8]. This purpose is indispensable to the dissemination of information that is accessed by a large number of users, such as, disaster-related information or a viral video [33-39]. The main problem is about a lack of cache efficiency in the event of unavailability of content in the cache at the time the content is requested, as the content is still fetched and served as soon as possible to the user. The challenge arises in scenarios where routers attain full memory and there is no space to accommodate the contents that are newly arriving. Thus, in order to manage the routers' limited cache size, eviction of the stored contents is initiated [34-42]. To relate the aforementioned explanation to a certain scenario, we consider an empty network at initial time = 0.

At this time, all Consumer nodes will have no problem sending interest packets out as they are small and the network allows for a large number of interest packets. Then the intermediate nodes will use their forwarding strategies to forward the interest packets across the shared link towards the correct publishers in accordance with the sought out prefixes. As the network has no former traffic at this time, all data is at the publisher nodes and the network will have closer characteristics to the traditional IP-based networks. The problem encountered in the cache is as shown in Figure 2 below. For the interest packet traffic, the Consumer1, Consumer3 and Consumer4 packet streams do not share CS yet. Hence, the Publisher1 and Publisher2 starts to answer every interest packet with a data packet sent the same route back towards the respective consumer. Each node has CS and PIT to keep control of all data packets and interest packets received and sent out. For this reason, the rate of data packets arriving at the intermediate node will either equal the number of interest packets sent to the publisher node, or it will equal the available bandwidth from the publisher to the intermediate node. Where the maximum data packets received will be capped by the bandwidth and the minimum will be equal to the interest packet frequency. This will be the first shaping of the network capacity and may create congestion as the number of interest sent upstream can be greater than the capacity to send data back downstream. This means that that at the intermediate node, there will now be arrival of interest packets and data packets that both share a CS. This study will design a content replacement mechanism to obtain a new model depending on both popularity and priority in the cache.

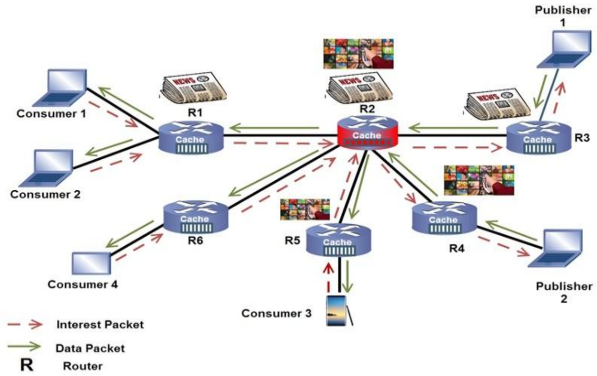

Figure 2: Research Problem

IV. THE CACHE REPLACEMENT STRATEGIES DECISION

The cache replacement have an important role in NDN. Replacement strategies are an important part of achieving the highly sophisticated mechanism of the cache. This replacement strategy helps evict the data packet from the cache and create a new space for the incoming data packet. However, a cache is not able to store the entire requested data packet because of its limited size. Therefore, room for new data packet is provided by the cache replacement strategies s [43, 44]. Thus, the cache replacement strategy a cache administrator chooses can significantly impact global network traffic as well as local resource utilization. The research into cache replacement strategies is very active.

A search in the literature reveals the existence of several cache replacement strategies that have been proposed for use in-network. Replacement strategies can be grouped into several broad categories depending on the key features of the workload and/or cached document used to make a replacement. The researchers [45, 46] are emphasized that the key features are :

(1) Recency: time of the last reference to the data packet,
(2) Frequency: number of requests to a data packet,
(3) Size: Size of the data packet,
(4) Cost of fetching the data packet: cost to fetch a data packet from its publisher, and
(5) Access latency of data packet.

Table 2 offers the replacement decision based on the key feature(s). This table is representing the existing state of affairs in this area.

Table 2
Rreplacement Decision Based on the Key Feature(s)

Replacement Decision	Feature				
	Size	Recency	Frequency	Cost	Latency
Least Frequent Recently Used (LFRU) [47]	-	X	X	-	-
Popularity Based content Eviction (PBCE) [28]	-	-	X		
Time Aware Least Recently Used (TLRU) [48]	-	X	-	-	X
Age-Based Cooperative Caching (ABC) [49]	-	X	-	-	-

Cache Replacement Policy Based On Content (CCP) [50]	-	X	-	-	-
Information-maximizing Caching (IC) [51]	-	X	-	-	-
Adaptive Replacement Cache (ARC) [52]	-	X	X	-	-
Least Frequently Used (LFU) [53, 54]	-	-	X	-	-
Least Recently Used (LRU) [54, 55]	-	X	-	-	-
First-In-First-Out (FIFO) [56]	-	-	-	-	-

V. FUZZY TOPSIS METHOD

The fuzzy TOPSIS technique is founded on two major features known as options and attributes. The options feature includes a list of alternatives that will be put into consideration when making a decision, while the attributes includes parameters that will be considered for selection when making the best or optimum decision [57, 58, 59].This technique transforms the user-benefit attributes and content store cost attributes into two categories which are benefit and cost, as shown in Figure 3. The chosen attributes of popularity (benefit) are content hit popularity and content size, while the attributes of priority (cost) are content miss popularity and cost time. The main input attribute considered in the content selection are broadly classified into user-related attributes and content-related attributes, as described below.

User-benefit attributes are the parameters which include cache hit and cache miss. When referring to a cache hit, this occurs in cases when the data requested by the consumer can be found in a cache, and is used for current hit rate (current popularity content). Whereas, a cache miss occurs when the data requested by the consumer cannot be found in a cache, and is used for previous miss rate (previous popularity for content. On the other hand, content store-cost attributes are the attributes related to the data content resources. They include cost time (the amount of time needed to fetch a content), freshness period of content (the period for content to stay in the content router), and content size (the size for each content which is saved in the content router).

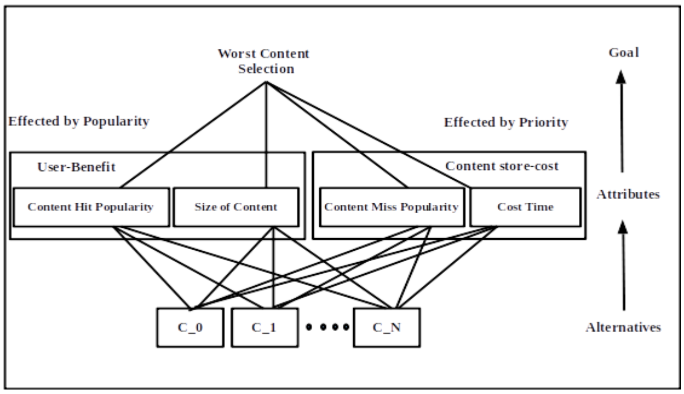

Figure 3: Content Replacement Mechanism Process Model

In a content replacement mechanism, each NDN router maintains a table called Popularity and Priority Table (PPT) as show in Table 3.
containing information concerning the popularity and priority of a content. This table contains the Content Name (CN), a counter called Content Miss Popularity (CMP), Request Time (RT), Arrival Time (AT), Cost Time (CT), content size (CZ) and a counter called Content Hit Popularity (CHP). When a request for a new content arrives, the information of request will store in the PPT. This PPT table saves CN, CMP and RT. When data content is received, the PPT stores AT, and CT by using this equation 1, The CHP is saved in this table after one cycle for router.

$$C_T = A_T - R_T \qquad 1$$

Table 3
The Popularity and Priority Table for Data Contents

CN	CMP	RT	AT	CT	CHP	CZ
/uum/new	6	10:20:40	10:21:00	00:00:60	10	5
/youtube/media	5	09:40:00	09:40:50	00:00:50	12	2

The main aims to apply the ability of multiple rule bases in decision processes and to improve the level of transparency for each attribute. In this app roach, the attributes are divided into two categories; benefit rule and cost rule, as shown in Figure 4. Therefore, by using the division at the beginning of the TOPSIS analysis, a researcher can track the performance of both attributes.

The main procedure for implementing Fuzzy TOPSIS method by selecting the best alternative which is described in the following:

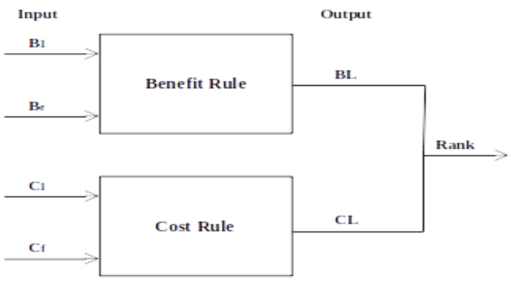

Figure 4: Content Replacement Mechanism Process Model

Definition 1: Let $\tilde{X}, \tilde{Y}$ be a fuzzy triangular number defined as [57-59]:

$$\tilde{X} = \left(a^{x}, b^{x}, c^{x}\right) \quad 1$$

$$\tilde{Y} = \left(a^{y}, b^{y}, c^{y}\right) \quad 2$$

Where $a < b < c$, *a* and *c* stand for the lower and upper values of the support of the fuzzy number, respectively.

The procedure for the fuzzy TOPSIS MADM approach is as the following steps:

Step 1: Construct a decision matrices are based on Alternative Level whereas it depends on two attributes categories as benefit attributes and cost attributes. The decision matrices are denoted by D^{B} , D^{C} as shown in:

$$\tilde{D}^{Benefit} = \begin{array}{c} \\ B1 \\ B2 \\ B3 \\ B4 \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \dots & A_m \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1m} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2m} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{e1} & \tilde{x}_{e2} & \dots & \tilde{x}_{em} \end{bmatrix} \end{array} \quad 3$$

And,

$$\tilde{D}^{Cost} = \begin{array}{c} \\ C1 \\ C2 \\ C3 \\ C4 \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \dots & A_n \end{array} \\ \begin{bmatrix} \tilde{y}_{11} & \tilde{y}_{12} & \dots & \tilde{y}_{1n} \\ \tilde{y}_{21} & \tilde{y}_{22} & \dots & \tilde{y}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{y}_{f1} & \tilde{y}_{f2} & \dots & \tilde{y}_{fn} \end{bmatrix} \end{array} \quad 4$$

The variables mij and nij in the decision matrices represent the rating of alternatives Aj(j=1,...,m) and Aj(j=1,...,m) with respect to benefit attributes Bi(i=1,...,e) and cost attributes Ci(i=1,...,f), respectively.

Step 2: Calculate the normalized decision matrices where each normalized value r_{ij}^{B} and r_{ij}^{C} are calculated as follows:

$$r_{ij}^{B} = \frac{\tilde{x}_{ij}}{\sqrt{\sum_{i=1}^{m} \tilde{x}_{ij}^{2}}} \quad 5$$

i=1,2,..m ,and j=1,2,..,n

$$\tilde{r}_{ij}^{B} = \left(\frac{a_{ij}^{\tilde{x}}}{c_i^{*}}, \frac{b_{ij}^{\tilde{x}}}{c_i^{*}}, \frac{c_{ij}^{\tilde{x}}}{c_i^{*}} \right) \quad 6$$

, for $B_i \in B$

Whereas, $c_i^{\tilde{x}} = \max_j c_{ij}^{\tilde{x}}$, (i=1,..,e), (j=1..f)

$$\tilde{r}_{ij}^{C} = \left(\frac{a_i^{\tilde{y}}}{c_{ij}^{*}}, \frac{a_i^{\tilde{y}}}{b_{ij}^{*}}, \frac{a_i^{\tilde{y}}}{a_{ij}^{*}} \right) \quad 7$$

, for $C_i \in C$

Whereas, $a_i^{\tilde{y}} = \min_j a_{ij}^{\tilde{y}}$, (i=1..f) , (j=1,..,e)

Therefore, $\tilde{r}_{ij}^{B} = \left(a_{ij}^{r^b}, b_{ij}^{r^b}, c_{ij}^{r^b} \right)$,and $\tilde{r}_{ij}^{C} = \left(a_{ij}^{r^c}, b_{ij}^{r^c}, c_{ij}^{r^c} \right)$

Assign weights importance to each attributes with respect to the objective. The variables $\tilde{w}_e^B$ and $\tilde{w}_f^C$ in the weight matrices represent the weights of benefit attributes Bi(i=1,...,e) and the weights of cost attributes Ci(i=1,...,f), which are calculated as follows.

$$\tilde{G} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2} \quad 8$$

, i=1,2,…,m ,and j=1,2,…,n

$$\tilde{W}_e^B = \frac{\sum_{j=1}^{n} \tilde{g}_{ij}}{n} \quad 9$$

And,

$$\tilde{H} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2} \quad 10$$

, i=1,2,…,m ,and j=1,2,…,n

$$\tilde{W}_e^C = \frac{\sum_{j=1}^{n} \tilde{g}_{ij}}{n} \quad 11$$

Where n is the number of comparable attributes.

$$\tilde{W}^B = \begin{matrix} B_1 & B_2 & \dots & B_e \\ [g_1 & g_2 & \dots & g_e] \end{matrix} \text{ ,and } \tilde{W}^C = \begin{matrix} C_1 & C_2 & \dots & C_f \\ [h_1 & h_2 & \dots & h_f] \end{matrix}$$

Step 4: Construct the weighted normalized decision matrix. A set of weights for each criterion such that $\tilde{W}_e^B$,and (e=1,2,…,n) and $\tilde{W}_f^C$,and (f=1,2,…,n). Multiply each column of $\tilde{r}_{ij}^B$, and $\tilde{r}_{ij}^C$ by its associated weight. An element of the new matrix is:

$$\tilde{V}_{ij} = \left(\tilde{r}_{ij}^{Benefit} \times \tilde{w}_i^{Benefit} \right) * \left(\tilde{r}_{ij}^{Cost} \times \tilde{w}_i^{Cost} \right) \quad 12$$

$\tilde{V}_{ij} = \left(a_{ij}^v, b_{ij}^v, c_{ij}^v \right)$, are fuzzy sets.

Step 5: Find the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) for each alternative. The FPIS and FNIS solutions are correspondingly $A^+ = \left(v_1^+, v_2^+, \dots, v_{(e+f)}^+ \right)$,and $A^- = \left(v_1^-, v_2^-, \dots, v_{(e+f)}^- \right)$, whereas $v_i^+ = (1,1,1)$,and $v_i^- = (0,0,0)$ are fuzzy sets.

Step 6: Find the distance between each alternative to FPIS and FNIS. The distance for benefit attributes of each alternative A_j from A^+ is p_j^+, calculated as shown in

$$p_j^+ = \sum_{i=1}^{e} \left(v_{ij}, v_i^+\right) \quad 13$$

Whereas,

$$p(v_{ij}, v_i^+) = \sqrt{\frac{1}{3}\left[\left(a_{ij} - 1\right)^2 + \left(b_{ij} - 1\right)^2 + \left(c_{ij} - 1\right)^2\right]} \quad 14$$

for j=1,…,m.

The distance for benefit attributes of each alternative A_j from A^- is p_j^-, calculated as shown in

$$p_j^- = \sum_{i=1}^{e} \left(v_{ij}, v_i^-\right) \quad 15$$

Whereas,

$$p(v_{ij}, v_i^-) = \sqrt{\frac{1}{3}\left[\left(a_{ij} - 0\right)^2 + \left(b_{ij} - 0\right)^2 + \left(c_{ij} - 0\right)^2\right]} \quad 16$$

for j=1,…,m.

Step 7: Find the Closeness Coefficients (CC) for the benefit and cost. The closeness coefficients denoted by CC_j^B ,and CC_j^C for the benefit and the cost, respectively, are calculated in $CC_j = \frac{\Delta_j^-}{\Delta_j^+ + \Delta_j^-}$

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, $0 < CC_j < 1$, for j=1,…,m.

Whereas $CC_j = 1$, in case of best condition, and $CC_j = 0$, in case of worst condition.

Step 8: Finally, rank alternative base on final score value, the lowest final value the better the alternative performance. Thus, the ranking order of all alternatives can be determined such that the lowest values of r_j mean better alternatives of j.

According to our Fuzzy TOPSIS method, the goal is to evict the worst content at a router having less popular and low priority content is replaced. The pseudo-code of the fuzzy TOPSIS method for content replacement is summarized in Algorithm

VI. THE PSEUDO-CODE OF THE FUZZY TOPSIS METHOD

According to our Fuzzy TOPSIS method, the goal is to evict the worst content at a router having less popular and low priority content is replaced. The pseudo-code of the fuzzy TOPSIS method for content replacement is summarized in

Algorithm 1:

1 : $Input : i : alternatives^{Benefit}, j : attributes^{Benefit}, e : attributes^{Cost}, X_{i,j}^{Benefit}, Y_{i,e}^{Cost}$

2 : $Output$:

3 : $TOPSIS(attributes^{Benefit}, alternatives^{Benefit}, attributes^{Cost}, alternatives^{Cost})$;

4 : $Data\_packet - Selection.\_remove\_Range$ ();

The pseudo-code of the TOPSIS decision-making strategy is summarized in Algorithm 2. After defining the main criteria and alternatives related to Content Replacement, TOPSIS formulates the decision making matrices.

$$Algorithm\_2$$

$$Input : A \ Decision \ Making \ Matrices \ X^{Benefit} = (x_{ij})_{m*n}, Y^{Cost} = (y_{ij})_{m*n}$$

$$Output : A \ List \ L = (L_1, j); \ j \in \{1, m\}$$

$$Let \ x, y \ be \ a \ fuzzy\_tringular\_number$$

$$X_{ij}^{Benefit} = (a_{ij}^{x}, b_{ij}^{x}, c_{ij}^{x})$$

$$Y_{ij}^{Cost} = (a_{ij}^{y}, b_{ij}^{y}, c_{ij}^{y})$$

$$Q = \{m\}$$

$$while \ Q \neq 0 \ do$$

$$if \ Categories = Benefit \ then$$

$$\forall s \in \{1, n\}; \ c_i^{x^{Benefit}} \leftarrow \max_s c_{i,s}^{Benefit}$$

$$\forall s \in \{1, n\}; \ c_{i,s}^{x^{Benefit}} \leftarrow \left(\frac{a_{ij}^{B}}{c_i^{x^*}}, \frac{b_{ij}^{B}}{c_i^{x^*}}, \frac{c_{ij}^{B}}{c_i^{x^*}} \right)$$

$$\forall s \in \{1, n\}; \ w_s^{Benefit} \leftarrow x_{is} / sum \ (x_{is}^2)$$

$$endif$$

$$if \ Categories = Cost \ then$$

$$\forall s \in \{1, n\}; \ c_i^{y^{Cost}} \leftarrow \min_s a_{i,s}^{Cost}$$

$$\forall s \in \{1, n\}; \ c_{i,s}^{x^{Benefit}} \leftarrow \left(\frac{a_i^{y^*}}{c_{ij}^{*}}, \frac{a_i^{y^*}}{b_{ij}^{*}}, \frac{a_i^{y^*}}{a_{ij}^{*}} \right)$$

$$\forall s \in \{1, n\}; \ w_s^{Cost} \leftarrow y_{is} / sum \ (y_{is}^2)$$

$$endif$$

$$\forall s \in \{1, n\}; \ v_{is} \leftarrow \left(\tilde{r}_{is}^{Benefit} \times \tilde{w}_s^{Benefit}\right) * \left(\tilde{r}_{is}^{Cost} \times \tilde{w}_s^{Cost}\right)$$

$$\forall j \in \{1, m\}; \ (v_{ij}, v_j^{*^+}) \leftarrow sqrt \ (1/3 \left[sum \ ((a_{ij}^{v} - 1)^2 + (b_{ij}^{v} - 1)^2 + (c_{ij}^{v} - 1)^2 \right]$$

$$\forall j \in \{1, m\}; \ p_j^{+} \leftarrow dist \ (v_{ij}, v_j^{*^+}) \ // \text{ the Euclidean distance}$$

$$\forall j \in \{1, m\}; \ (v_{ij}, v_j^{*^-}) \leftarrow sqrt \ (1/3 \left[sum \ ((a_{ij}^{v} - 0)^2 + (b_{ij}^{v} - 0)^2 + (c_{ij}^{v} - 0)^2 \right]$$

$$\forall j \in \{1, m\}; \ p_j^{-} \leftarrow dist \ (v_{ij}, v_j^{*^-}) \ //$$

$$\forall j \in \{1, m\}; \ sim \ 1, j \leftarrow p_j^{-} / (p_j^{+} + p_j^{-})$$

$$\forall j \in \{1, m\}; \ L1, j \leftarrow sort \ (sim)$$

$$endwhile$$

VII. CONTENT REPLACEMENT MECHANISM (CRM)

The content replacement mechanism decides which documents stay and which documents replace, it affects which future requests will be cache hits. The CRM must decide which content to evict based only on information it has collected about previously used contents. In other words, CRM must use past information to predict the future. When a content router receives a data packet which hasn't been stored, it needs to calculate the difference between the threshold value of the cache size and the number of cached contents to get the remaining size of cache space. If a data packet is greater than the rest of the space, the replacement will happen. On the basis of CRM, the content with less popular (less benefit) and low priority (low cost) content will be replaced depending on TOPSIS procedure and its record in PPT will be deleted at the same time. Then the new arrival content will be cached in CS and set up its own record in PPT at the same time as shown in figure 5.

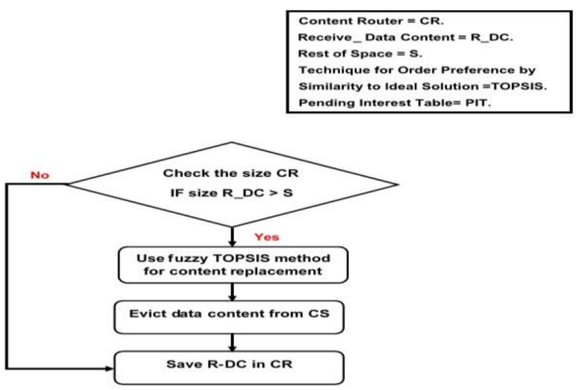

Figure 5: The Content Replacement Mechanism (CRM) Model

According to Al-Momani and Ghazali [60, 61], the selection of the performance evaluation metric is a key step and an important part of all performance evaluations. Performance metrics are adopted to evaluate the performance of the cache replacement strategies for NDN, and this evaluation is needed when researchers want to make comparison between some alternative designs in order to identify the best design [59]. Following the studies already existent in literature [36, 49], the selected metrics for performance measurement in this study depend on the Table 4 to choose the best performance metric and discussed as follows.

A- Cache Hit Ratio: Hit ratio means the portion of content requests satisfied by caches implemented within the network. Cache Hit ratio returns the amount in an average of available content hit (found) when requests are sent. Several studies in database and networking domain have emphasized on the performance of the network through better cache hit ratio.

B- Throughput: Throughput is defined as a measurement of the total quantity of information units being processed per a specific time by a system, measured in bytes per second (bps). However, when considering throughput in the area of storage systems, it refers to the quantity of incoming data, either read from media, or written to the storage medium, and then sent back to the system initiating the request. In terms of the applications of throughput, its areas of applications in organizations are vast, with its usage being adopted in different aspects of network and computer systems. Some criteria for measuring its system productivity include workload completion speed, response time to requests, and time duration from the initiation of a single interactive request by the user till when the user receives the corresponding response.

C- Server Load: Server Load is defined as the traffic quantity carried by the server. Its expression is in number format, representing the number of processes standing in chain for seeking processor.

Table 4
Comparison of Performance Metrics

Replacement Decision	Feature				
	Size	Recency	Frequency	Cost	Latency
Least Frequent Recently Used (LFRU)	-	X	X	-	-
Popularity Based Content Eviction (PBCE)	-	-	X		
Time Aware Least Recently Used (TLRU)	-	X	-	-	X
Age-Based Cooperative Caching (ABC)	-	X	-	-	-
Cache Replacement Policy Based On Content (CCP)	-	X	-	-	-
Information-maximizing Caching (IC)	-	X	-	-	-
Adaptive Replacement Cache *(ARC)*	-	X	X	-	-
Least Frequently Used (LFU)	-	-	X	-	-
Least Recently Used (LRU)	-	X	-	-	-
First-In-First-Out (FIFO)	-	-	-	-	-

VIII. SIMULATION AND EVALUATION

An in-depth evaluation study is presented, with the aim of quantifying how effective the other strategies by using the simulation scenario as shown in Table II. For surety, the CRM was run on a 4X4 grid topology with

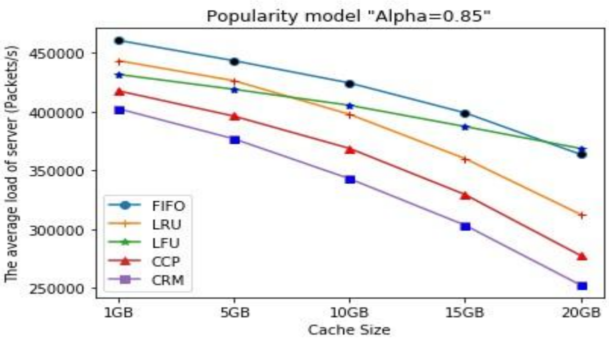

Figure 7: Average Server Load on Different Cache Sizes

33 consumers randomly distributed across the network and three origin. The obtained results were compared with four popular strategies, which include First-In-First-Out (FIFO), Least Frequently Used (LFU), Least Recently Used (LRU), and Cache Content Popularity (CCP). The validation was done using ndnSIM 2.7v and the value of the using Mandelbrot-Zipf (MZipf) distribution model parameter was set as q =65, α =0.85. The cache size (specifying each node's available space for the temporal storage of content objects) ranged from 100 to 2000 elements (1GB to 20GB); and the catalog (representing the total number of contents within the network) is 10^6 elements. The simulation was run for 10 times on topology and performances metrics of cache hit ratio, average network throughput, and server load was obtained for FIFO, LFU, LRU, CCP and CRM.

1- Cache Hit Ratio with Grid Topology

The ratio of cache hit with respect to the 4X4 topology is shown in Figure 6. In popularity scenario (when α = 0.85), the ratio of cache hit is low on cache sizes 100 to 100,000 (1GB to 20GB) elements as shown in Table 5 with an increase of the cache size, showed a higher hit ratio being achieved.

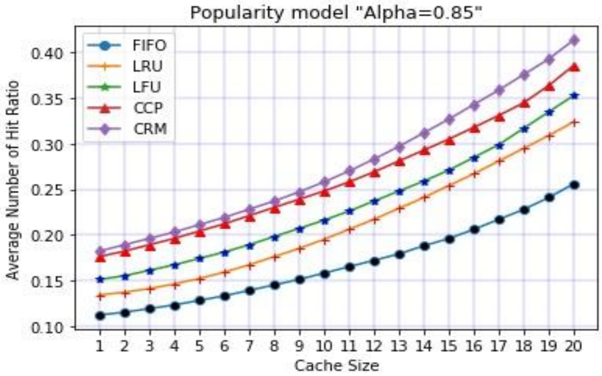

Figure 6: Cache Hit Ratio on Different Cache Sizes

Table 5

Cache Hit Ratio on Different Strategy and Cache Size

Cache Size	Cache Hit Ratio				
	FIFO	LRU	LFU	CCP	CRM
1 GB	0.112	0.137	0.151	0.172	0.187
5 GB	0.138	0.152	0.179	0.201	0.208
10 GB	0.154	0.197	0.211	0.249	0.258
15 GB	0.197	0.254	0.268	0.302	0.325
20 GB	0.253	0.321	0.352	0.388	0.412

In addition to the results in Figure 6, the productivity of the diverse cache strategies for defined scenarios having varying cache sizes with respect to the determined cache hit proportion is detailed in Table 5. The CRM, over

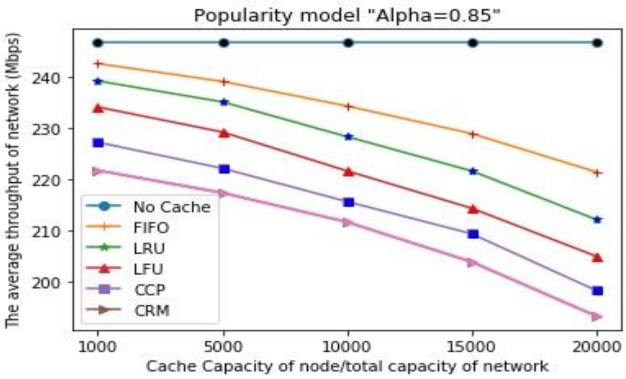

Figure 8: Average network throughput

the CCP, LFU, LRU, and FIFO for all various cache sizes obviously shows essentially the best outcomes. Bearing in mind that the cache hit proportion is generally adopted to give a decent understanding of the caching performance of the network when the data packets are distributed in a consistent way which is dependent on the dimensionality of the caches. Therefore, the small difference is a sign in the cache hit ratio.

2- Average Server Load with Grid Topology

The average server load in comparison to the cache capability is shown in Figure 7. In low popularity scenario (when α =0.85), the average server load decreases on cache sizes 100 to 100,000 (1GB to 1TB) elements as shown Table 6 with an increase of cache size, showed a decreased load being achieved. In addition to the results in Figure 7, the productivity of the diverse cache strategies for defined scenarios having varying cache sizes with respect to the determined average server load is detailed in Table 6. The ACS, over the CCP, LFU, LRU, and FIFO for all various cache sizes obviously shows the best outcomes essentially. Bearing in mind that the average server load is generally adopted to give a decent understanding of the caching performance of the network, when the data packets are distributed in a consistent way dependent on the dimensionality of the caches. Therefore, the small difference is a sign in the average server load.

Table 6
Average Server Load on Different Strategy and Cache Size

Cache Size	Average Server Load				
	FIFO	LRU	LFU	CCP	CRM
1 GB	460562	443282	431573	417583	402328
5 GB	443282	426229	418925	396074	376722
10 GB	424331	397643	405316	368634	342829
15 GB	398924	359962	387258	329349	303268
20 GB	363588	312477	368597	277516	252341

3- Average Throughput with Abilene Topology

The average throughput in comparison to the cache capability is shown in Figure 8. In low popularity scenario (when $\alpha = 0.85$), the average throughput decreases on cache sizes 100 to 100,000 (1GB to 1TB) elements as shown in Table 7 with an increase of cache size, showed a decreased average throughput being achieved.

In addition to the results in Figure 8, the productivity of the diverse cache strategies for defined scenarios having varying cache sizes with respect to the determined average throughput is detailed in Table 7. The ACS, over the CCP, LFU, LRU, FIFO and No Cache for all various cache sizes obviously shows the best outcomes essentially. Bearing in mind that the average throughput is generally adopted to give a decent understanding of the caching performance of the network, when the data packets are distributed in a consistent way dependent on the dimensionality of the caches. Therefore, the small difference is a sign in the average throughput.

Table 7
Average Throughput on Different Strategy and Cache Size

Cache Size	Average Throughput					
	No Cache	FIFO	LRU	LFU	CCP	CRM
1 GB	246.7	242.6	239.2	234.1	227.2	221.7
5 GB	246.7	239.1	235.1	229.2	222.1	217.3
10 GB	246.7	234.3	228.3	221.6	215.6	211.6
15 GB	246.7	228.9	221.6	214.3	209.3	203.8
20 GB	246.7	221.4	212.1	204.9	198.2	193.2

IX. CONCLUSION

Throughout this paper, various parameters which include the popularity model variation, metrics measurement, cache size, and topological impact, were used for the assessment of the performance of CRM. As discussed earlier, CRM gives a solution to the ‘what to cache’ problem with the relation of popularity, Therefore, CRM has shown to solve many problems in caching in current NDN architecture, which includes increasing request satisfaction, and reduction of content data item redundancy in different caches. This will translate to making an efficient and effective cache mechanism in NDN which will lead to a bright future of NDN in current internet access scenarios.

In consideration of CRM comparison with FIFO, LRU, LFU, and CCP strategy, the results showed that CRM is considered as the optimal technique for offering reliable cache, within the distribution of full caching by LCE strategy. Since each cache overflows its buffer opportunistic that is dependent on requests from users within its regional community, there is no collaborative work of data to just about every cache. Whereas with regards to a cache miss with the local cache, the area associated with data replacement is based on items’ association with the network path that results in a cache query similar to the one requested by clients. Meanwhile, it should be noted also that from almost requests, all peer is cached before forwarding the request towards the original resource.

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REFERENCES

[1]. D. R. Cheriton and M. Gritter, "TRIAD: A new next-generation Internet architecture," 2000.

[2]. T. Koponen, M. Chawla, B.-G. Chun, A. Ermolinskiy, K. H. Kim, S. Shenker, and I. Stoica, "A data-oriented (and beyond) network architecture," in ACM SIGCOMM Computer Communication Review, vol. 37, no. 4. ACM, 2007,pp. 181–192.

[3]. C. Dannewitz, D. Kutscher, B. Ohlman, S. Farrell, B. Ahlgren, and H. Karl, "Network of Information (NetInf)–an Information-Centric Networking architecture," Computer Communications, vol. 36, no. 7, pp. 721–735, 2013.

[4]. FP7 COMET project (Online), Available: http://www.comet-project.org/.

[5]. A. A. Barakabitze, T. Xiaoheng, and G. Tan, "A survey on naming, name resolution and data routing in Information Centric Networking (ICN)," Int. J. Adv. Res. Comput. Commun. Eng, vol. 3, no. 10, pp. 8322–8330, 2014.

[6]. Mobilityfirst future Internet architecture project (Online), Available: http://mobilityfirst.winlab.rutgers.edu/.

[7]. L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, P. Crowley, C. Papadopoulos, L. Wang, B. Zhang et al., "Named data networking," ACM SIGCOMM Computer Communication Review, vol. 44, no. 3, pp. 66–73, 2014.

[8]. Named Data Networking project (Online), Available: http://www. nameddata .net/.

[9]. M. Zhang, H. Luo, and H. Zhang, "A survey of caching mechanisms in Information-Centric Networking," IEEE Communications Surveys & Tutorials, vol. 17, no. 3, pp. 1473–1499, 2015.

[10]. S. J. Taher, O. Ghazali, and S. Hassan, "A review on cache replacement strategies in Named Data Network," J. Telecommun. Electron. Comput. Eng., vol. 10, no. 2–4, pp. 53–57, 2018.

[11]. I. U. Din, S. Hassan, M. K. Khan, M. Guizani, O. Ghazali, and A. Habbal, "Caching in Information-Centric Networking: Strategies, challenges, and future research directions," IEEE Communications Surveys & Tutorials, 2017.

[12]. V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, and R. L. Braynard, "Networking named content," in Proceedings of the 5th International Conference on Emerging Networking Experiments and Technologies. Rome, Italy: ACM, Dec. 2009, pp. 1–12.

[13]. A. Ghodsi, S. Shenker, T. Koponen, A. Singla, B. Raghavan, and J. Wilcox, "Information-Centric Networking: Seeing the forest for the trees," in Proceedings of the 10th ACM Workshop on Hot Topics in Networks. ACM,2011, p. 1.

[14]. G. Xylomenos, C. N. Ververidis, V. A. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, K. V. Katsaros, and G. C. Polyzos, "A survey of Information-Centric Networking research," IEEE Communications Surveys & Tutorials, vol. 16, no. 2, pp. 1024–1049, 2014.

[15]. M. Amadeo, C. Campolo, J. Quevedo, D. Corujo, A. Molinaro, A. Iera, R. L. Aguiar, and A. V. Vasilakos, "Information-Centric Networking for the Internet of things: Challenges and opportunities," IEEE Network, vol. 30, no. 2, pp. 92–100, 2016.

[16]. L. A. Zadeh, "Fuzzy sets," Information and control, vol. 8, no. 3, pp. 338–353, 1965.

[17]. K. P. Yoon and C.-L. Hwang, Multiple attribute decision making: An introduction. Sage publications, 1995, vol. 104.

[18]. S.-J. Chen and C.-L. Hwang, "Fuzzy multiple attribute decision making methods," in Fuzzy multiple attribute decision making. Springer, 1992, pp. 289–486.

[19]. C. Yi, A. Afanasyev, I. Moiseenko, L. Wang, B. Zhang, and L. Zhang, "A case for stateful forwarding plane," Computer Communications, vol. 36, no. 7, pp. 779–791, 2013.

[20]. R. N. K. Alubady, "An efficient pending interest table control management in named data network," Ph.D. dissertation, Universiti Utara Malaysia, 2017.

[21]. L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. Thornton, D. K. Smetters, B. Zhang, G. Tsudik, D. Massey, C. Papadopoulos et al., "Named Data Networking (NDN) project," Relatorio Tecnico NDN-0001, Xerox Palo Alto Research Center-PARC, 2010.

[22]. V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, and R. L. Braynard, "Networking named content," in Proceedings of the 5th International Conference on Emerging Networking Experiments and Technologies. Rome, Italy: ACM, Dec. 2009, pp. 1–12.

[23]. L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. Thornton, E. Uzun, B. Zhang, G. Tsudik, D. Krioukov, D. Massey et al., "Named Data Networking (NDN) project 2010-2011 progress summary," PARC, http://www. nameddata. net/ndnar2011. html, Tech. Rep, 2011.

[24]. Y. Sun, S. K. Fayaz, Y. Guo, V. Sekar, Y. Jin, M. A. Kaafar, and S. Uhlig, "Trace-driven analysis of ICN caching algorithms on video-ondemand workloads," in Proceedings of the 10th ACM International on Conference on emerging Networking Experiments and Technologies. Sydney, Australia: ACM, Dec. 2014, pp. 363–376.

[25]. R. S. Abbas, S. A. Nor, and A. Ahmad, "A review of cache placement algorithms for Video on Demand in Named Data Networking," J. Adv. Res. Dyn. Control Syst., vol. 10, no. 10–Special Issue, pp. 1322–1332, 2018.

[26]. G. Piro, L. A. Grieco, G. Boggia, and P. Chatzimisios, "Information-Centric Networking and Multimedia services: Present and future challenges," Transactions on Emerging Telecommunications Technologies, vol. 25, no. 4, pp. 392–406, 2014.

[27]. J. Li, S. Shi, Y. Ren, L. Li, and J. Zhi, "A content store-based module for congestion control algorithms of named data networking," in High PerformanceComputing and Communications; IEEE 14th International Conference on Smart City; IEEE 2nd International Conference on Data Science and Systems (HPCC/SmartCity/DSS), 2016 IEEE 18th International Conference on. Sydney, NSW, Australia: IEEE, Dec. 2016, pp. 253–259.

[28]. I. Hwang, D. Kim, and Y.-B. Ko, "Analysis of NDN repository architectures," in High Performance Computing & Simulation (HPCS), 2016 International Conference on. Innsbruck, Austria: IEEE, Jul. 2016, pp. 985–988.

[29]. K. N. Lal and A. Kumar, "A popularity based content eviction scheme via betweenness-centrality caching approach for content-centric networking (CCN)," Wireless Networks, pp. 1–12, 2017.

[30]. W. K. Chai, D. He, I. Psaras, and G. Pavlou, "Cache "less for more" in Information Centric Networks (extended version)," Computer Communications, vol. 36, no. 7, pp. 758–770, 2013.

[31]. D. Kim, J. Bi, A. V. Vasilakos, and I. Yeom, "Security of cached content in NDN," IEEE Transactions on Information Forensics and Security, vol. 12, no. 12, pp. 2933–2944, 2017.

[32]. H. Lee and A. Nakao, "User-assisted in-network caching in Information-Centric Networking," Computer Networks, vol. 57, no. 16, pp. 3142–3153, 2013.

[33]. Z. Feng, M. Xu, Y. Wang, and Q. Li, "An architecture for cache consistency support in Information Centric Networking," in Global Communications Conference (GLOBECOM), 2013 IEEE. Atlanta, GA, USA: IEEE, Dec. 2013, pp. 2126–2131.

[34]. S. H. Bouk, S. H. Ahmed, D. Kim, and H. Song, "Named-data-networkingbased ITS for smart cities," IEEE Communications Magazine, vol. 55, no. 1, pp. 105–111, 2017.

[35]. J. Quevedo, D. Corujo, and R. Aguiar, "Consumer driven information freshness approach for Content Centric Networking," in Computer Communications Workshops (INFOCOM WKSHPS), 2014 IEEE Conference on. Toronto, ON, Canada: IEEE, Apr. 2014, pp. 482–487.

[36]. A. M. J. GarciaLunaAceves, "Understanding optimal caching and opportunistic caching at the edge of information-centric networks," in Proceedings of the 1st ACM conference on information-centric networking, 2014, pp. 47–56.

[37]. B. Feng, H. Zhou, H. Zhang, J. Jiang, and S. Yu, "A popularity-based cache consistency mechanism for Information-Centric Networking," in Global Communications Conference (GLOBECOM), 2016 IEEE. Washington, DC, USA: IEEE, Dec. 2016, pp. 1–6.

[38]. M. Meddeb, A. Dhraief, A. Belghith, T. Monteil, K. Drira, and S. AlAhmadi, "Cache freshness in named data networking for the Internet of things," The Computer Journal, 2018.

[39]. Z. Ming, M. Xu, and D.Wang, "Age-based cooperative caching in Information- Centric Networking," in Computer Communication and Networks (ICCCN), 2014 23rd International Conference on. Shanghai, China: IEEE, Aug. 2014, pp. 1–8.

[40]. S. Tarnoi, K. Suksomboon, W. Kumwilaisak, and Y. Ji, "Performance of probabilistic caching and cache replacement policies for content-centric networks," in Local Computer Networks (LCN), 2014 IEEE 39th Conference on. Edmonton, AB, Canada: IEEE, Sep. 2014, pp. 99–106.

[41]. M. A. Hail, M. Amadeo, A. Molinaro, and S. Fischer, "Caching in named data networking for the wireless Internet of things," in Recent Advances in Internet of Things (RIoT), 2015 International Conference on. Singapore, Singapore: IEEE, Apr. 2015, pp. 1–6.

[42]. I. Ud Din, "Flexpop: A popularity-based caching strategy for multimedia applications in Information Centric Networking," Ph.D. dissertation, Universiti Utara Malaysia, 2016.

[43]. K. Arora and D. R. Ch, "Web cache page replacement by using LRU and LFU algorithms with hit ratio: A case unification," (IJCSIT) International Journal of Computer Science and Information Technologies, vol. 5, no. 3, pp. 3232–3235, 2014.

[44]. K. Shah, A. Mitra, and D. Matani, "An O (1) algorithm for implementing the LFU cache eviction scheme," Technical report, 2010.

[45]. S. Podlipnig and L. Boszormenyi, "A survey of web cache replacement strategies," ACM Computing Surveys (CSUR), vol. 35, no. 4, pp. 374– 398, 2003.

[46]. S. Romano and H. ElAarag, "A quantitative study of recency and frequency based web cache replacement strategies," in Proceedings of the 11th communications and networking simulation symposium. ACM, 2008, pp. 70–78.

[47]. M. Bilal and S.-G. Kang, "A cache management scheme for efficient content eviction and replication in cache networks," IEEE Access, vol. 5, pp. 1692– 1701, 2017.

[48]. Bilal, Muhammad, and Shin-Gak Kang. "Time aware least recent used (TLRU) cache management policy in ICN." In 16th International Conference on Advanced Communication Technology, pp. 528-532. IEEE, 2014.

[49]. Z. Ming, M. Xu, and D.Wang, "Age-based cooperative caching in Information-Centric Networking," in Computer Communication and Networks (ICCCN), 2014 23rd International Conference on. Shanghai, China: IEEE, Aug. 2014, pp. 1–8.

[50]. J. Ran, N. Lv, D. Zhang, Y. Ma, and Z. Xie, "On performance of cache policies in Named Data Networking," in International Conference on Advanced Computer Science and Electronics Information, China, Jul. 2013, pp. 668–671.

[51]. W. Dron, A. Leung, M. Uddin, S. Wang, T. Abdelzaher, R. Govindan, and J. Hancock, "Information-maximizing caching in Ad Hoc networks with Named Data Networking," in Network Science Workshop (NSW), 2013 IEEE 2nd. IEEE, 2013, pp. 90–93.

[52]. W. Lee, S. Park, B. Sung, and C. Park, "Improving Adaptive Replacement Cache (ARC) by reuse distance," in 9th USENIX Conference on File and Storage Technologies (FAST'11), 2011, pp. 1–2.

[53]. L. Saino, I. Psaras, and G. Pavlou, "Icarus: A caching simulator for Information Centric Networking (ICN)," in Proceedings of the 7th International ICST Conference on Simulation Tools and Techniques. Lisbon, Portugal: ICST (Institute for Computer Sciences, Social- Informatics and Telecommunications Engineering), Mar. 2014, pp. 66–75.

[54]. M. Garetto, E. Leonardi, and V. Martina, "A unified approach to the performance analysis of caching systems," ACM Transactions on Modeling and Performance Evaluation of Computing Systems, vol. 1, no. 3, p. 12, 2016.

[55]. K. Arora and D. R. Ch, "Web cache page replacement by using LRU and LFU algorithms with hit ratio: A case unification," (IJCSIT) International Journal of Computer Science and Information Technologies, vol. 5, no. 3, pp. 3232–3235, 2014.

[56]. B. Jeannet, T. Jeron, and T. Le Gall, "Abstract Interpretation of FIFO channels," Ph.D. dissertation, INRIA, 2005.

[57]. K. P. Yoon and C.-L. Hwang, Multiple attribute decision making: An introduction. Sage publications, 1995, vol. 104.

[58]. S.-J. Chen and C.-L. Hwang, "Fuzzy multiple attribute decision making methods," in Fuzzy multiple attribute decision making. Springer, 1992, pp. 289–486.

[59]. A. M. B. Yaakob, "Multi criteria decision making methodology for fuzzy rule based systems and networks using topsis." Ph.D. dissertation, University of Portsmouth, 2017.

[60]. G. Osman, "Scaleable and smooth TCP-friendly receiver-based layered multicast protocol," Ph.D. dissertation, Universiti Utara Malaysia, 2008.

[61]. O. M. D. Al-Momani, "Dynamic redundancy forward error correction mechanism for the enhancement of Internet-based video streaming," Ph.D. dissertation, Universiti Utara Malaysia, 2010.

Sadaq Jebur Taher, et. al. "Multi Attribute Decision Making for Content Replacement Mechanism in Named Data Networking." *IOSR Journal of Computer Engineering (IOSR-JCE)*, 24(2), 2022, pp. 01-13.