Reverse Auction-Based Dynamic Caching and Pricing Scheme in Producer-Driven ICN

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***Abstract*—Dynamic cache allocation and pricing in Information-Centric Networks (ICNs) is a challenging problem, especially when multiple content producers and competing ICN cache service providers are involved. Many existing ICN caching schemes generalize their frameworks as producer-agnostic architectures while considering a single ICN cache service provider. Realistically, as ICNs grow, multiple cache providers will compete for valuable content that would generate higher cache hits, and the ecosystem will inevitably become market-driven. In this paper, we investigate the dynamic cache allocation and price determination problem considering a caching system consisting of multiple content producers who act as the buyers and multiple competing ICN cache providers who act as the sellers of the caching resources. We propose a novel reverse auction-based caching and pricing scheme named *SEMRA* that aims to maximize the caching benefits of content producers. Simulation results demonstrate how the proposed scheme improved ICN caching over several caching metrics across varying cache sizes and popularity skewness values. Future work in this domain is highlighted in the conclusion.**

***Index Terms*—Information-Centric Networks (ICNs), ICN caching, Producer-driven caching, Reverse auction-based caching, Vickrey auction.**

I. Introduction

Cache nodes in ICN are ubiquitous, and network routers along the content delivery path can cache named content and respond to content requests [1]. However, due to the fundamental differences between caching in ICN and the current Internet, the relationships among the network players, including content producers, cache service providers, and consumers in the ICN caching system have changed. Consequently, the current pricing policies cannot incentivize ICN cache service providers to provide caching services [2]. Hence, it is important to investigate new economic models and pricing policies to incentivize the ICN cache providers while addressing the dynamic cache allocation and pricing problem.

A significant body of literature addresses the economic aspects of ICN caching [2]–[9]. These works consider cache allocation from the point of view of either the consumer or the caching nodes, maximizing the Quality of Experience (QoE) for the former and utilizing the caching resources from the latter. However, in these dynamics, the content producer plays an important role. They often aim to disseminate their content to maximize their revenue, and seek to place it as close as possible to interested users to improve their QoE. To the best of our knowledge, no previous research has proposed economic incentive model for cache allocation with the aim of maximizing caching utilities of content producers while considering multiple content producers and competing ICN cache service providers.

Our contributions in this paper are summarized as follows:

1) We present a reverse auction-based caching system model comprising a dynamic cache allocation and pricing scheme called Second-price Sealed-bid Multi-attribute Reverse Auction *(SEMRA)*.
2) We propose a bid value generation mechanism for bidding ICN providers to regulate a reverse auction scheme while considering multiple attributes of the requested contents and competing cache nodes.
3) Finally, we analyze and evaluate the performances of our proposed *SEMRA* scheme contrasting with a cost-based cache allocation and pricing scheme named *CCAP* in terms of several performance metrics.

The remainder of this paper is organized as follows. Section II provides an overview of research on the economic aspects of ICN caching. Section III elaborates on the system model and Section IV describes the system variables of the proposed scheme. Section V details the proposed reverse auction-based caching and pricing scheme. Section VI consists of the details of the performance evaluation results of the auction-based and cost-based schemes and Section VII consists of the final discussions, and plans for future work.

II. Literature Review

The economic aspects of ICN caching can be divided into three different research areas. Some research proposes economic models or business models for particular types of services or applications involving the main network players or stakeholders to deploy in-network caching [5], [9], other research addresses the issue of cache partitioning among the content providers (CPs) using game theory models or utility-based optimization [3], [7], and lastly, some proposes caching and pricing models for the cache service providers and the CPs using game-theoretic and auction-based approaches [2], [4], [6], [8].

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Although auction mechanism-based economic models have been investigated as effective mechanisms for resource management [10], [11], the investigation of an auction mechanism to incentivize caching nodes in ICN is nascent. Among the few existing works, the *BidCache* method [6] allows cache nodes along the content delivery path to compete for selection based on an auction mechanism but does not provide any payment determination mechanism. Ndikumana et al. [8] have proposed a reverse auction-based economic incentive mechanism where the auctioneer collects and evaluates bid values submitted by competing CPs, and finally selects the winning CP with the lowest bid value so that the total payment of the Internet Service Provider (ISP) for purchasing content can be minimized. Though the proposed reverse auction mechanism is more comprehensive than the *BidCache* scheme [6], the auction mechanism does not consider any actual bid value generation mechanism and the bid values are generated as random numbers. Moreover, this mechanism considers only one ISP providing caching services which limits the applicability of the proposed mechanism.

None of the above-mentioned economic schemes has proposed an economic incentive model to maximize the utility of the content producer while considering multiple content producers and competing ICN cache providers. As a remedy, we propose a novel economic incentive model aiming to maximize the content producer's utilities while considering multiple competing ICN cache service providers as sellers who compete to win to cache the requested contents, and multiple content producers as buyers who purchase caching resources and pay accordingly.

The novelties of our contributions are the following. First, our economic incentive model is a producer-driven mechanism that handles the joint caching and pricing problem aiming to maximize the utilities of content producers. Second, our system model considers a more realistic environment with a caching system consisting of multiple content producers and multiple ICN cache service providers. Lastly, we propose a bid value generation mechanism considering multiple attributes of contents and cache nodes.

III. System Model

Our proposed model has four system components depicted in Fig. 1 and described as follows:

1) Content producers are the network nodes that originate, publish, and store content. Content producer purchases cache resources for caching content and acts as the buyer of the model.
2) We consider an auctioneer who acts as an intermediate agent to conduct the auction mechanism and determine the winning ICN cache provider and the payment.
3) ICN cache service providers consist of access and intermediate cache routers and a network manager (NM). The ICN providers act as the bidders or sellers who offer to sell their caching resources to the content producers by submitting bids through the auctioneer. Because of the reverse auction mechanism, we consider multiple competing sellers, i.e., bidders ICN providers who compete with each other by submitting bid values to sell their caching resources to win the auction.
4) Consumers are the network nodes that subscribe to or request content. In our model, any consumer can send a request to and retrieve content from any ICN provider.

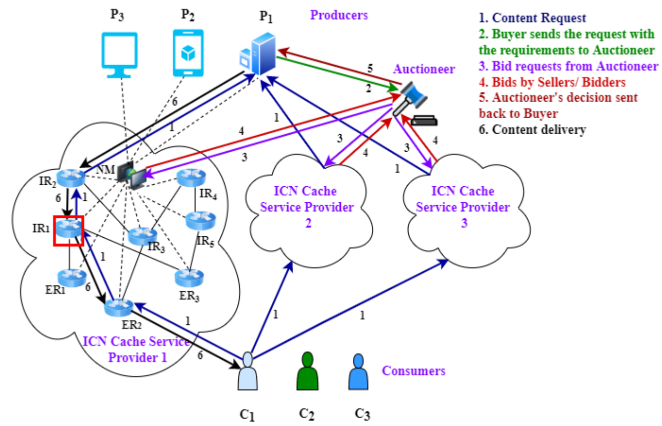


Fig. 1: System components and operation of proposed reverse auction-based cache allocation and pricing scheme: The 6-step process of selection of winning ICN cache service provider and its corresponding cache nodes is highlighted with numbered arrows

IV. System Variables

Our reverse auction-based scheme considers two variables for cache allocation and payment determination, caching cost and visibility score.

A. Caching Cost of Content

Caching cost is the money that the content producers pay the ICN cache service providers for caching their contents. Equation (1) determines the caching cost $CC_{k,i,j}$ that the producer of content k has to pay the ICN cache service provider i if its content k is cached by the ICN cache service provider i at cache node j.

$$CC_{k,i,j} = \frac{1}{CV_{k,i,j}} \tag{1}$$

In equation (1), $CV_{k,i,j}$ is the value of content k at cache node j belonging to ICN cache service provider i.

To determine caching costs, ICN providers consider the requested contents differently in terms of their value as every requested content has different dynamic caching and pricing parameters. The more valuable a content is, the ICN providers charge lower caching cost to the content producer to cache the content so that the possibility of content caching is increased and their profits can be maximized. Hence, the caching cost $CC_{k,i,j}$ of content k at cache node j belonging to ICN provider i is defined as inversely proportional to the value of content k, $CV_{k,i,j}$, at cache node j belonging to ICN i.

The ICN provider i determines the value of content k at node j by the Weighted Sum Value (WSV) of the content popularity, the number of cached replicas of that content contained by the ICN provider, and the reputation of the content producer and is defined by equation (2). Here, the content popularity, replica, and reputation value are normalized. The weight parameters ζ, θ and ω sum up to 1 and are adjusted according to the designed system.

$$CV_{k,i,j} = \zeta.Pop_{k,i,j} + \theta.RP_k + \omega.(1 - \frac{\sum_{j \in \mathcal{J}} Replica_{k,i,j}}{|\mathcal{J}_i|}) \quad (2)$$

Content popularity $Pop_{k,i,j}$ of content k at cache node j belonging to ICN provider i is determined by equation (3), where $Rq_{k,i,j}$ is the total number of requests that the cache node j receives for the content k and $\mathcal{K}$ is the candidate set of contents to be cached.

$$Pop_{k,i,j} = \frac{Rq_{k,i,j}}{\sum_{k \in \mathcal{K}} Rq_{k,i,j}} \quad (3)$$

The replica value of content k at cache node j, denoted as $\sum_{j \in \mathcal{J}} Replica_{k,i,j}$, is defined in a collaborative way with respect to the whole ICN cache service provider i consisting of the set of cache nodes $\mathcal{J}$. In equation (2), $\sum_{j \in \mathcal{J}} Replica_{k,i,j}$ means the total number of instances or replicas of the content k cached across the set of cache nodes $\mathcal{J}$ inside ICN cache service provider i and $|\mathcal{J}_i|$ means the total number of cache nodes inside the ICN cache service provider i.

Regarding the reputation value, we assume reputation values of the content producers are already computed and known to us. Reputation value of a content producer P_k is denoted as RP_k and assigned a value in the interval [0, 1].

In the reverse auction model, cache nodes along content delivery paths, that have available cache capacities, compete to win (cache) the requested content. They compete based on their caching costs and visibility scores. The caching cost charged by an ICN provider i for caching content k, $CC_{k,i}$ is determined by equation (4) as the maximum caching cost among all caching costs charged by the on-path cache nodes $j \in \mathcal{J}$ of ICN i which receive the requests for the content k, where the caching cost of content k at an on-path cache node j is determined by equation (1). In equation (4), the set $\mathcal{CC}_{k,i,j}$ consists of all the caching costs charged by the on-path cache nodes that receive request for content k.

$$CC_{k,i} = \max_{j \in \mathcal{J}} \{\mathcal{CC}_{k,i,j}\} \quad (4)$$

B. Visibility Score of Content

The visibility score reflects how much exposure to consumers a content producer can get for its content when cached by a given ICN cache service provider. The higher visibility score a cache node has, the higher exposure a content producer gets if its content is cached at that node.

The visibility score of content k at cache node j contained by ICN cache service provider i is defined by equation (5) where the visibility score $VS_{k,i,j}$ is a Weighted Sum Value (WSV) of the topological and dynamic attributes of cache node j. The weight parameters ϕ and ψ sum up to 1 and are adjusted according to the designed system.

$$VS_{k,i,j} = \phi(Top_{i,j}) + \psi(Dyn_{i,j}) \quad (5)$$

The topological value of cache node j belonging to ICN provider i, $Top_{i,j}$, is determined by its Betweenness Centrality (BC) and Degree Centrality (DC) values [12] shown in equation (6).

$$Top_{i,j} = (BC_{i,j})(DC_{i,j}) \quad (6)$$

Betweenness Centrality (BC) is defined by equation (7), where $\sigma_{s,t}$ is the total number of content delivery paths between cache nodes s and $t (s \neq j \neq t)$ and $\sigma_{s,t}(i,j)$ is the number of content delivery paths between s and t that pass through cache node j inside ICN provider i.

$$BC_{i,j} = \sum_{s \neq j \neq t \epsilon \mathcal{J}} \frac{\sigma_{s,t}(i,j)}{\sigma_{s,t}} \quad (7)$$

Degree Centrality (DC) value of cache node j can be determined by equation (8), where $degree(i,j)$ is the number of edges incident upon the cache node j and $|\mathcal{J}_i|$ is the total number of cache nodes inside ICN cache service provider i.

$$DC_{i,j} = \frac{degree(i,j)}{(|\mathcal{J}_i| - 1)} \quad (8)$$

The dynamic attribute value $Dyn_{i,j}$ of cache node j is determined using equation (9), where the distance of cache node j from the producer of content k is proportional, and the replacement ratio of node j is inversely proportional to the dynamic attribute value of node j.

$$Dyn_{i,j} = (Dist_{i,j}(k))(1 - CRR_{i,j}) \quad (9)$$

We define the distance of cache node j as

$$Dist_{i,j}(k) = \frac{Hops_{P_k,i,j}}{Hops_{P_k,C_k}} \quad (10)$$

where $Hops_{P_k,i,j}$ defines the number of hops between content producer of content k, P_k and the cache node j inside ICN provider i and $Hops_{P_k,C_k}$ defines the number of hops between the content producer P_k and the requesting consumer of content k, C_k.

Equation (10) dynamically calculates the closeness of a cache node from the corresponding consumer requesting a specific content and the node closer to the consumer has a higher probability of being selected for caching.

Equation (11) defines the cache replacement ratio of a cache node j inside ICN cache service provider i, $CRR_{i,j}$, as the ratio between the total number of replaced contents, $TotalRpc_{i,j}$, and the total number of received content requests, $TotalInterest_{i,j}$, at that cache node j.

$$CRR_{i,j} = \frac{TotalRpc_{i,j}}{TotalInterest_{i,j}} \quad (11)$$

The cache replacement ratio of a cache node has an inversely proportional relationship with the selection probability of that node so that the excessive caching tendencies of the important central and near consumer nodes can be prevented.

Finally, the visibility score offered by ICN provider i for content k, $VS_{k,i}$, is defined by equation (12) as the maximum visibility score offered by all on-path cache nodes which receive the requests for content k inside ICN provider i. The set $\mathcal{VS}_{k,i,j}$ consists of all the visibility scores offered by the on-path cache nodes $j \in \mathcal{J}$ that receive requests for content k.

$$VS_{k,i} = \max_{j \in \mathcal{J}} \{\mathcal{VS}_{k,i,j}\} \tag{12}$$

V. Second-Price Sealed-Bid Reverse Auction-based Caching and Pricing Scheme

We propose a reverse auction (RA)-based scheme, referred to as Second-price Sealed-bid Multi-attribute Reverse Auction *(SEMRA)* to dynamically allocate cache resources and determine payments.

In our system, there are multiple ICN cache service providers acting as sellers (or bidders) who submit bids to sell their cache resources to content producers who are looking for ICN cache service providers to cache their contents. Our objective is to design a reverse auction-based model that aims to maximize the visibility scores of contents and minimize the producers' caching cost.

A. Bid Value Generation of SEMRA Scheme

SEMRA is a multi-attribute auction that allows negotiation between the buyer (content producer) and the seller (ICN cache service provider) regarding monetary attribute such as caching cost, and non-monetary attribute such as visibility score of the cache node where the content is going to be cached.

In *SEMRA*, the Bid value $Bid_{k,i}$ for any bidder ICN provider $i \in \mathcal{I}$, for any content $k \in \mathcal{K}$ is generated based on two attributes: caching cost ($CC_{k,i}$) and the visibility score ($VS_{k,i}$) and can be defined as $Bid_{k,i} = (VS_{k,i}, CC_{k,i})$.

Caching cost ($CC_{k,i}$) is the price that the ICN cache service provider i charges a content producer P_k for caching its content k (determined by equation (4)). Visibility score $VS_{k,i}$ is the value that an ICN cache service provider i provides the content producer P_k for its content k (determined using equation (12)) while cached by the provider.

B. Operation of SEMRA Scheme

SEMRA runs independently for every requested content and is depicted in Fig. 1 where the 6-step process is highlighted using numbered arrows and is described as follows.

In step 1, consumer C_1 forwards its request for content k to all ICN cache service providers that it is connected to, and the request(s) is then forwarded to the producer of content k, which is producer P_1 here.

In step 2, P_1 forwards the received requests to the auctioneer stating its required visibility score for its content k.

In step 3, the auctioneer requests the bid values from the participating ICN cache service providers.

In step 4, all participating ICN cache providers submit their bids to the auctioneer.

In step 5, the auctioneer eliminates bids from the ICN providers that do not meet the visibility score requirement. Then, the auctioneer evaluates all remaining bids to determine the winning ICN provider which charges the minimum caching cost, and informs P_1 with the auction result.

Finally in step 6, content k gets cached by the winning ICN provider as depicted in Fig. 1, while being forwarded from producer P_1 to the requesting consumer C_1, and P_1 pays the winning ICN based on the payment mechanism of *SEMRA*.

C. Winner and Price Determination of SEMRA Scheme

The objective of *SEMRA* is defined by equation (13)

$$\min\{\mathcal{CC}_{k,i} | \; i \in \mathcal{I}_c\} \tag{13}$$

where the auctioneer aims to select the winning bidder i_w for caching content k from the competing bidders $\mathcal{I}_c$, which charges the content producer P_k the lowest caching cost. Here, the set $\mathcal{I}_c$ consists of the competing ICN providers whose visibility scores fulfill the visibility score requirement of P_k.

In *SEMRA*, for payment determination, we use the second-price sealed-bid (Vickrey) mechanism [11], [13]. We selected the Vickrey mechanism to enforce that the dominant strategy is to bid the true valuations [13]. According to the second-price payment mechanism, the winning bidder charges the lowest caching cost among all competing bidders, and in turn, receives a payment from the content producer equal to the second lowest caching cost among all the caching costs charged by the competing bidders. This motivates the bidders to submit their expected prices (charged caching costs) truthfully based on their actual valuations for their cache resources to increase their gains. The payment of our *SEMRA* scheme is defined by equation (14).

$$CC^*_{k,i_w} = \min\{\mathcal{CC}_{k,i'} | \; i' \in \mathcal{I}_{c \setminus i_w}\} \tag{14}$$

In equation (14), CC^*_{k,i_w} is the payment that the winning bidder i_w receives for caching content k which is the second lowest charged caching cost among all competing bidders $\mathcal{I}_c$.

D. SEMRA Algorithm

In Algorithm 1, lines 4 to 14 calculate the bids of all ICN providers for the content k. The required visibility score for bidding k is determined in line 16, where top $Per_i\%$ visibility score offering ICN providers, $\mathcal{I}_c$, are selected to compete. The minimum priced bidder i_w is selected in line 18. After i_w is selected, the top $Per_A i_w j\%$ on-path cache nodes of winning ICN provider i_w are selected based on their visibility scores for caching content k in line 20. The payment to the winning bidder i_w for caching content k is determined in line 21.

VI. Performance Assessment

In this section, we assess the performance of *SEMRA* under various experimental settings.

Algorithm 1: *SEMRA* Algorithm

Input : $\mathcal{K}$: Set of Contents, $\mathcal{J}$: Set of Cache Routers or Nodes, $\mathcal{I}$: Set of ICN Cache Service Providers, $\mathcal{P}_k$: Set of Content Producers, $\mathcal{RP}_k$: Set of reputation values, Per_i: Percentage of top ICN provider selection, $Per_A i_w j$: Percentage of top cache node selection

Output : Winning ICN provider i_w, $\mathcal{N}_A i_w$: Nodes of i_w that will cache k, CC^*_{k,i_w}: Price paid to winning ICN provider i_w

forall $k \in \mathcal{K}$ **do**
  forall $i \in \mathcal{I}$ **do**
    forall $j \in \mathcal{J}$ **do**
      if j *has cache space* **then**
        Calculate $VS_{k,i,j}$
        $\mathcal{VS}_{k,i,j} \leftarrow \mathcal{VS}_{k,i,j} \cup VS_{k,i,j}$
        Calculate $CC_{k,i,j}$
        $\mathcal{CC}_{k,i,j} \leftarrow \mathcal{CC}_{k,i,j} \cup CC_{k,i,j}$
      end
    end
    $VS_{k,i} \leftarrow \max_{j \in \mathcal{J}}(\mathcal{VS}_{k,i,j})$
    $CC_{k,i} \leftarrow \max_{j \in \mathcal{J}}(\mathcal{CC}_{k,i,j})$
    $\mathcal{VS}_{k,i} \leftarrow \mathcal{VS}_{k,i} \cup VS_{k,i}$
    $\mathcal{CC}_{k,i} \leftarrow \mathcal{CC}_{k,i} \cup CC_{k,i}$
  end
  $\mathcal{I}_c \leftarrow$ Select top $Per_i\%$ ICN i from $\mathcal{VS}_{k,i,i \in \mathcal{I}}$
  forall $i \in \mathcal{I}_c$ **do**
    $i_w \leftarrow \min_{i \in \mathcal{I}_c}\{\mathcal{CC}_{k,i}\}$
    $\mathcal{WVS}_{k,i,j} \leftarrow$ Sort$(\mathcal{VS}_{k,i,j,i=i_w,j \in \mathcal{J}})$
    $\mathcal{N}_A i_w \leftarrow$ Top $Per_A i_w j\%$ of $\mathcal{WVS}_{k,i,j}$
    $CC^*_{k,i_w} \leftarrow \min_{i' \in \mathcal{I}_c \setminus i_w}\{\mathcal{CC}_{k,i'}\}$
  end
end

A. Simulation Environment

We use ndnSIM for our simulation and BRITE [14] for generating a realistic random network topology. To demonstrate the scale of our proposed scheme, without loss of generality, we consider 4 content producers where each producer produces 3000 contents. We consider 135 consumers and 5 ICN cache service providers, where each ICN provider consists of 20 cache nodes. Content requests are generated according to *Zipf* distribution and requests arrival follows a Poisson distribution process. We consider 2 seconds fixed caching time for all cached contents, 30% cache capacity as cache size, popularity skewness value = 1.2, percentage of selected top cache nodes inside winning ICN = 20% and percentage of ICN selection in *SEMRA* = 60% as default settings. We consider 95% confidence interval in our performance analysis.

B. Compared Schemes

We compare the performance of *SEMRA* with a cost-based cache allocation and pricing scheme named *CCAP*. In *CCAP*, the ICN provider that charges the producer the minimum caching cost is selected as the winning ICN provider, and the producers pay the winner equal to its charged caching cost. *CCAP* ignores visibility scores offered by ICN providers for winner selection. *CCAP* also considers the caching costs of the cache nodes to select the cache nodes inside the winning ICN cache service provider for content caching.

C. Performance Metrics

For performance assessment, we consider the following three performance metrics defined below.

1) Producer's Unit Cost: Producer's unit cost is the caching cost that the producer pays the winning ICN cache service provider to cache its content.
2) Total Cache Hits: Total cache hits are the total number of requested contents retrieved from the cache nodes inside the ICN cache service providers.
3) Required Hop Ratio: Required hop ratio is the ratio between the hop count from the consumer to the first cache node where a cache hit occurs and the hop count from the requesting consumer to the content producer.

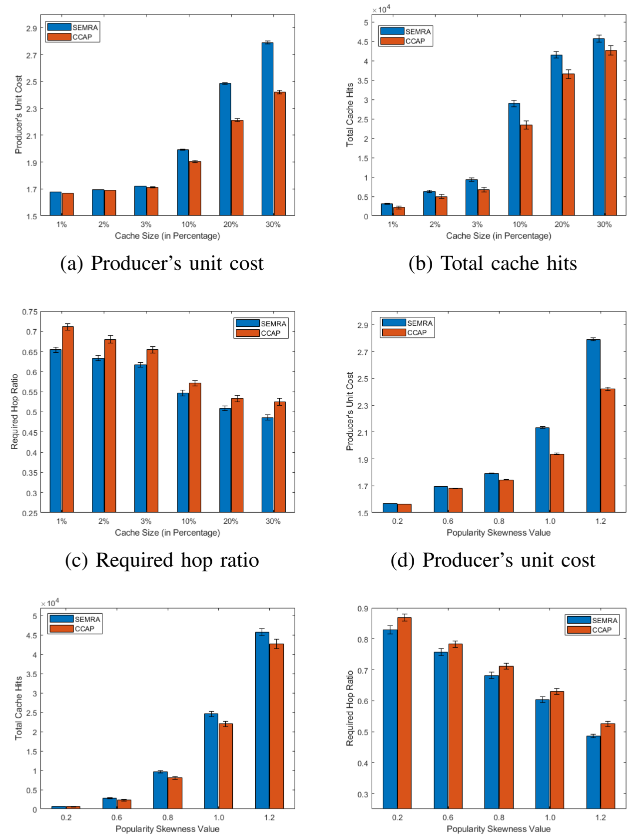
D. Performance Analysis

Fig. 2a depicts that *CCAP* incurs the lower caching cost than *SEMRA* because it selects the minimum-cost ICN provider as the winning provider. *SEMRA* incurs higher caching cost compared to *CCAP* for two reasons. First, *SEMRA* ensures the quality of attained cache services in terms of visibility scores of cache nodes before considering the caching cost paid by producers. So, even the minimum-cost ICN bidder can be restricted from participating in the bidding process if it does not fulfill the visibility score requirement. Second, to ensure the bidder ICNs' truthful participation in the bidding and maintain economic stability between the producers and ICN cache service providers, *SEMRA* adopts a second-minimum price mechanism by rewarding the winning minimum-cost ICN bidder with second lowest price.

Fig. 2b depicts that *CCAP* attains the lower cache hits than *SEMRA* as it considers only the caching cost while ignoring offered visibility score for winning ICN selection. As both the caching cost and the visibility score impact the number of cache hits, the performance of *CCAP* degrades for ignoring the visibility score of the availed cache nodes. *SEMRA* generates a higher number of cache hits compared to *CCAP* as it considers both the caching cost and the visibility score for winning ICN cache service provider selection.

Fig. 2c illustrates that *CCAP* performs worse than *SEMRA* requiring the higher number of hops to traverse to get the requested contents. *CCAP* performs worse for disregarding the visibility scores in terms of hop distance, replacement ratio, and centrality values of the cache nodes while winning ICN provider selection. *SEMRA* performs better than *CCAP* as it considers the visibility scores of the ICN providers before allowing them to compete in the bidding process.

Fig. 2d shows that *CCAP* incurs the lower caching cost as it selects the minimum-cost ICN provider as the winning ICN



(a) Producer's unit cost (b) Total cache hits

(c) Required hop ratio (d) Producer's unit cost

(e) Total cache hits (f) Required hop ratio

Fig. 2: Performance comparison of the schemes for varying cache capacity percentage and popularity skewness value

provider. *SEMRA* incurs higher caching cost than *CCAP* as it selects the ICN providers to be allowed to compete in the bidding while ensuring the visibility score requirement, and it adopts a second-minimum payment mechanism to ensure ICN's truthful participation while sacrificing the monetary gain of producers.

Fig. 2e shows that *SEMRA* produces the higher number of cache hits than *CCAP* because of considering both visibility score and caching cost. *CCAP* does not take into account the visibility score to select the winning ICN provider while attaining the lower cache hits than *SEMRA*.

Fig. 2f illustrates that *SEMRA* requires a lower number of hops to traverse for content retrieval compared to *CCAP* as it considers both the visibility score constraint and caching cost. *CCAP* requires the higher number of traversed hops as it does not consider any cache node attribute while winning ICN cache service provider selection.

VII. Conclusions and Future Work

This paper addresses the dynamic cache allocation and pricing problem in ICNs. Both *SEMRA* and *CCAP* aim to maximize the benefits of content producers while dynamic cache allocation and price determination. *SEMRA* performs better than *CCAP* by generating a higher number of cache hits and requiring a lower number of hops to retrieve requested contents. Although *SEMRA* incurs higher producer costs than *CCAP*, it ensures the bidder's truthfulness and brings economic stability between the buyers and the sellers.

The dynamics of producer-driven caching can consider many competing design attributes to increase caching gain. In *SEMRA*, producers ensure the quality of attained cache services in terms of the non-monetary attribute before considering their monetary gain. However, in certain scenarios, producers may prefer to adapt their priorities to consider monetary and non-monetary attributes and may want to consider both their monetary and non-monetary gains while making caching and pricing decisions. In the future, we plan to propose a producer-driven scheme that can adapt the priorities to consider monetary and non-monetary attributes instead of strictly disallowing some ICN cache service providers to compete.

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