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An Energy-Efficient Collaborative Caching Scheme for 5G Wireless Network

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ABSTRACT CCN (Content-centric network) has emerged as a promising architecture for future 5G network due to its in-network caching capability and receiver-driven content retrieval paradigm. Recently, the explosive increase in energy consumption driven by the rapid growth of network traffic has become a fundamental issue in CCN and caused widespread academic concern. In this paper, we proposed an energy-efficient scheme for the future 5G network. The aim of our scheme is to minimize the energy consumption by considering some important constraints, including limited storage, content popularity, placement and access to contents. Our proposed scheme provides efficient utilization of hotspot cache, minimizing transportation cost by using Zipf and knapsack which ensure local availability of cache contents and minimizing energy consumption. Finally, simulation results reveal that our proposed scheme outperform in term of saving energy, the impact of content popularity, cache size, placement, and device-to-device communication.

INDEX TERMS Caching probability, energy efficiency, content-centric networking, popularity of contents, cache resource allocation.

I. INTRODUCTION

The mobile data traffic has been increasing tremendously over the past years and is predicted to grow almost tenfold within the upcoming few years [1]. Recent advancement in the mobile communication technologies attracted the mobile users with an ever-growing number to enjoy a wide plethora of multimedia services using mobile devices [2]. The use of multimedia services and other interactive applications sharply increases the demand of mobile data traffic [3], [4]. As the continuous growth of mobile data traffic, cellular networks become a major concern for researchers [5]. It is predicted that multimedia contents account for more than half of the mobile data traffic already today and will almost three-quarters of mobile data traffic in a few years [6]. To meet the requirements of mobile data traffic demands, cellular networks are continuously improving by means of a larger number of antennas, higher frequency reuse with smaller cells and the capacity of cellular networks in term of more spectrum [7]–[10]. The growth speed of cellular network lags far behind the ever-increasing data traffic demands that mainly contributed by videos [11].

Smart devices with built-in support for multimedia content causes an increase in video data traffic and energy consumption over cellular networks [12]. In consideration of the foregoing, several studies reveal that video traffic accounts for significant portion of Internet usage. According to Cisco Visual Networking Index[1] that 75 percent of mobile data traffic will be video contents in 2020. This is due to mobile data traffic of video content will increase 11-fold between 2015 and 2020. As a result of the increasing popularity of sharing user-generated data (e.g., YouTube, Youku) and delivering multi-media contents (eg., Netflix) increase demand of video contents. Recently, the growing energy consumption driven by an explosive increase mobile data traffic has become a key issue causing widespread academic concern. It is reported that 10 percent of worldwide energy consumption is consumed by the Internet and keep constantly increasing [13]. The use of Content-Centric Network (CCN)

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[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update,2015 2020.Tech.rep.,.

greatly improves the performance of the network for the end-user. CCN has become a hot research topic recently, as it is proposed as an alternative for the future cellular network [14]. CCN is used as an efficient utilization of network resources, in-network storage, and content-oriented routing. Furthermore, CCN accounts for the reduction of average access latency, data traffic in network and power consumption of overall network [15]–[18].

Basically, the contents are accessing through ISP (Internet service provider) from content servers which are located mostly outside of the mobile cellular network. Delivering popular content from centralized external servers to end users increases bandwidth-mileage and often consumes a large portion of unnecessary transport energy cost [19]. On the other hand, CCN is decentralized and minimizes the transport energy cost by using name-based routing, which enables the popular content to be tracked and stored at intermediate nodes in the cellular network. The aim of using CCN in the future wireless network is that contents are caching in the network hotspot which is close to the end-users. Therefore, transport energy can be greatly reduced. The efficiency of energy cost is directly proportional to transportation cost. Greater transportation cost of contents in the network leads to greater consumption of energy cost by keeping other constraints constant. In the upcoming few years, the improvement in network energy efficiency major concerns with increased data traffic growth. Furthermore, the energy consumption will increase substantially until improved the efficiency of a network such as network management, hardware's and associated architectures improves [20], [21].

In CCN, it is still under debate whether the ubiquitous caching scheme can improve the performance of a network [22]. Fang *et al.* and Parvez *et al.* highlighted that energy-efficient caching is still a bone of contention in the field of CCN. However, CCN inevitably raises issues concern to energy consumption. Luo *et al.* focused on energy-efficient strategies for Mobile Edge Computing (MEC) to minimize the power consumption, satisfying a computation delay cost in capacity-limited cellular network. Furthermore, they studied the impact of joint optimization average download latency and average energy consumption in the cellular network. This scheme only deals with MEC making a trade-off between system average download latency and average energy consumption. In [26], energy-efficient content distribution in-network caching was highlighted. They formulated the content caching problem as a non-cooperative game and proposed an energy-efficient distribution caching scheme. From [26]–[29], some other caching schemes are also proposed to overcome the issue of energy efficiency. These works optimize energy efficiency to a certain extent by limiting energy consumption. However, the impact feature of users generated data traffic and caching contents on network performance are not fully addressed.

In terms of caching decision in CCN, a smart caching needs to place and retrieve the contents within hotspot in an efficient way to minimize energy consumption and maximize network performance. In this paper, we proposed a CCN scheme for the future 5G wireless network. The proposed scheme is responsible to minimize energy consumption. The main contributions of this paper are summarized as follows.

- We establish a CCN model for the future 5G wireless network to minimize the energy cost, considering some important constraints, such as limited storage capacity, content popularity, access to content, and placement of contents.
- A probabilistic cache placement strategy based on energy efficiency is proposed. We use a novel mapping of the knapsack problem along with Zipf distribution to index and rank of storing highly popular contents within the future 5G network hotspot.
- Our proposed method is capable to support device-to-device (D2D) communication which minimizes the transportation and energy cost.
- Finally, we study the impact of our proposed scheme from the perspective of energy in 5G hotspot caching and find that efficient utilization of hotspot caching scheme has positive impact on the network.

II. SYSTEM MODEL OF CCN

In this section, we formulate the network model and an energy consumption model for CCN. We use transaction-based model in which the total energy is calculated by adding up the consumption incurred by all equipment used to deliver a given service on the mean transaction basis [19]. To make the presentation easier to follow, we briefly summarize the notations of key parameters in Table 1.

TABLE 1. **Notations of the key parameters.**

Symbol	Notations	Values
N	No. of nodes	Multiple value
σ_i	Request for the *i-th* popular content	Multiple value
s_i	Chunk size of the *i-th* popular content	Multiple value
y_{ij}	*i-th* popular content in *j-th* hotspot cache	Multiple value
Q_j	Cache node within hotspot	Multiple value
x_{is}	*i-th* content in *s-th* external server	Multiple value
Q_s	Cache node at external server	Multiple value
M	Number of content caching replicas	Multiple value
R_i	No. of request k-*th* most popular content	Multiple value
S	No. of hotspot caching contents catalog	Multiple value
P_{ca}	Power consumption of caching	10^{-9}J/bit [30]
P_{st}	Power of storage drive	$8*10^{-12}$W/bit [30]
P_{ca}	Power of caching content	10^{-9} W/bit [30]
RAN	Small Base Station power consumption	150-300W [31]
EPC	Macro base station power consumption	300-900W [31]
Backhaul	External link power consumption	302W [32]

A. OVERVIEW OF CCN

The Fig.1 illustrates the CCN model for the future 5G network hotspot. The evolve packet core (EPC)/ macro base station consists of the packet data network gateway (P-GW), serving gateway (S-GW), and mobility management entity (MME) [33]. The EPC performs as a root node which

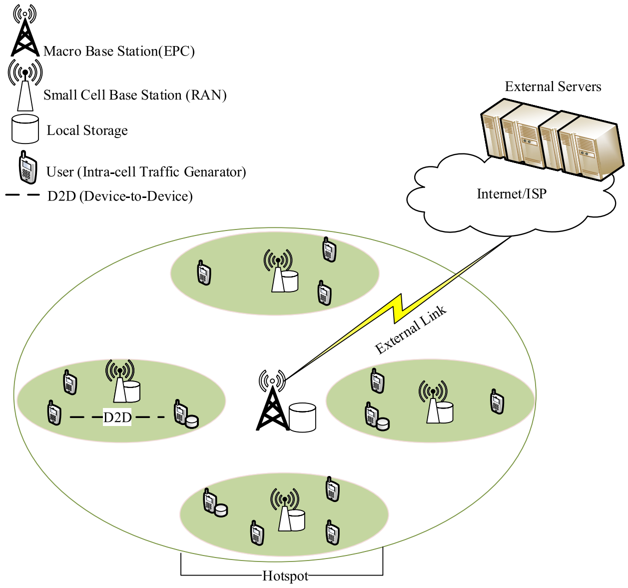

FIGURE 1. **Content-centric network hotspot model.**

provides connectivity to the external core network and serving gateways (S-GW) internally. Each serving gateway connects a set of RANs, which offers wireless services to mobile users within the hotspot. The EPC with larger coverage radius mainly transmits control signals and data to RANs. RANs with smaller coverage radius is mainly used for transmitting data and providing connectivity to the users within the hotspot network [34], [35].

In our considered scenario, we assume that the EPC, all RANs, and partial mobile devices have caching capability within the hotspot. All the cache nodes within the hotspot together form the hotspot cache cluster. RANs have a smaller storage and service capability compared to EPC. All the devices in hotspot which is equipped with cache is denoted by N. Overall cache contents store in network hotspot represent S catalog file, i.e., $(s1, s_i, \ldots, s_n) \subseteq S$ forms the cache cluster. According to [36], the hotspot cache cluster is not a stand-alone network, but a part of a larger tree topology [36]. The RANs and EPC within the hotspot are responsible to send updates periodically and entertain the user's requests. We can call interchangeably RAN and EPC as base station. Furthermore, our proposed method also support D2D (Device -to-Device) communication, if the requested contents not found itself user cache the user will seek it within the range of D2D communication. If it is found in nearest device, the content delivery to the requester by D2D communication and send update to RAN upon successfully delivery of content.For the mobile user's which connected to its nearest base station, we have Corollary 1.

Corollary 1: The maximum achievable transmission rate of all users coverage radius (R) of Base station larger than $C_{overage}$.

$$C_{overage} = CH_B(log_2(1 + \frac{P_{bs}\gamma R^{-\epsilon}}{CH_B\zeta})), \qquad (1)$$

where CH_B is bandwidth, ϵ is path loss exponent, γ is the path loss constant, P_{bs} is power of base station and ζ is SINR given by Shannon's theorem. When the user in the hotspot request for content file σ_i, it received SINR from its nearest RAN in Tier-n.

Proof: See Appendix A.

B. ENERGY CONSUMPTION COST FOR CCN

The main task of our research is to build a smart and energy-efficient scheme for the 5G network hotspot minimizing energy cost and improving the performance. In CCN, the total energy consumption E_{total} is divided into two parts: the transport energy E_{Tr} and caching energy E_{ca} [37]. The transport energy includes the energy consumption in RAN, EPC, Internet service provider (ISP) and access server energy cost (E_{st}). Therefore we have

$$E_{Tr} = RAN + EPC + ISP + E_{st}, \qquad (2)$$

where (2) defines the total transportation cost to access and delivery of requested contents. The transportation energy consumption cost to access content within network hotspot is much lower than the energy consumption to access content from the server-side.

Proof: See Appendix B.

We assume that in a specific time duration, *i-th* most popular content of size s_i is downloaded R_i times. If σ_i of the user requested popular content are cached at n cache of hotspot cache cluster, the energy consumed to cache content at n node with having content chunk size s_i of content i within the hotspot, E_{ca} are express as:

$$E_{ca} = \sum_{i=1}^{R_i} ns_i tP_{ca}, \qquad (3)$$

where t denotes time of the *i-th* most popular content having size s_i downloaded R_i-*th* times. P_{ca} is express as:

$$P_{ca} = \sum \lambda\, \Re. \qquad (4)$$

λ is access to content cost while $\Re$ is placement cost of cache contents. Download content from local cache we need to pay λ power consumption cost while downloading contents from outside hotspot we have to pay the cost of $\Re$. The average energy consumption in $E_{hotspot}$ against the user request for content within hotspot is:

$$E_{H_{ca}} = \min_{E_{Tr}E_{ca}} (E_{Tr} + E_{ca}). \qquad (5)$$

Similarly, the average energy consumption cost to access content outside hotspot is:

$$E_{total} = \min_{E_{H_{ca}}} \sum E_{H_{ca}}\ ISP\ E_{st}, \qquad (6)$$

where E_{st}, is the energy of storage devices at server-side and *ISP* refers to the Internet. According to [38], the energy consumption cost of Internet is 1.7 percent of the total global electricity consumption. For content σ_i, the server energy storage E_{st} at the time is given by

$$E_{st}(\sigma_i) = s_i t P_{st} \sigma_i, \tag{7}$$

where P_{st} refers to power of the storage server.

C. THE HOTSPOT CONTENT CACHING

To save transport and cache energy, we have to utilize the hotspot caches in an efficient way to maximize the local-hit. We consider the cellular hotspot with $N1$ RANs, and N users denoted as $N_R = (1, 2, 3, \ldots., N1)$ and $N_U = (1, 2, \ldots, N)$ respectively. Let $\mathcal{Q}_{ij}$ refer to the caching gain within hotspot for the i- *th* ($i \leq M$) content store in the j-*th* node such that ($j \leq N_1 + N + 1$). Define $\mathcal{Q}_i = \sum_{j=1}^{N1+N+1} y_{ij}, 1 < i < M$, then the problem of optimization of hotspot cache cluster ($E_{H_{ca}}$) can be described as:

$$\begin{aligned} E_{H_{ca}} &= \max \sum_{i=1}^{M} \sum_{j=1}^{N_1+N+1} \mathcal{Q}_{ij} y_{ij}. \\ \text{Subject to} & \sum_{i=1}^{M} y_{ij} \leq m1 \ (2 \leq j \leq N_1 + 1) \\ & \sum_{i=1}^{M} y_{ij} \leq m, (N_1+2 \leq j \leq N_1+N+1). \end{aligned} \tag{8}$$

The equation (8) refers to the hotspot caching capacity. In equation(8), the i-th content in the network hotspot is less than or equal to m contents stored on the j-th node. The two specify constraints represent the storage capacity with an upper boundary size limit for EPC and RANs. Furthermore, we formulate an optimization problem which maximizes the number of contents found in local hotspot under the constraint of limited storage of network hotspot. The main task is to design a caching strategy subjected to limited storage capacity and maximizing the local-hit ratio. The increase in local-hit result in lower transportation and cache energy cost [3], [19], [39]–[41]. In this paper, we focus on the placement and distribution of cache contents.

Corollary 2: User in hotspot requested for content (σ_i) found in within hotspot called local-hit. Otherwise, the request will entertain outside of hotspot which is called server-hit. The local-hit can be formulated as:

$$\sigma_i = \begin{cases} 1, & \text{if } y_{ij} \geq 0 \ i \in S \\ 0, & \text{otherwise.} \end{cases} \tag{9}$$

Proof: See Appendix C.

Remarks 1: To enhance the energy efficiency, we need such scheme to increase the local hit-rate such that entertain the users within hotspot.

III. THE PROPOSED DESIGN SCHEME

In this section, we build an energy-efficient scheme minimizing the transportation and caching cost to enhance the content delivery with the enhancement of content placement. Conventional CCN schemes are not capable to enhance the energy efficiency and maximize the local hit-rate. The local hotspot hit-rate is directly proportional to the optimization of energy cost [24], [41], [42]. More cache-hit within hotspot results in less power consumption. In this work, we focus on building an efficient scheme which ensure local availability of contents.

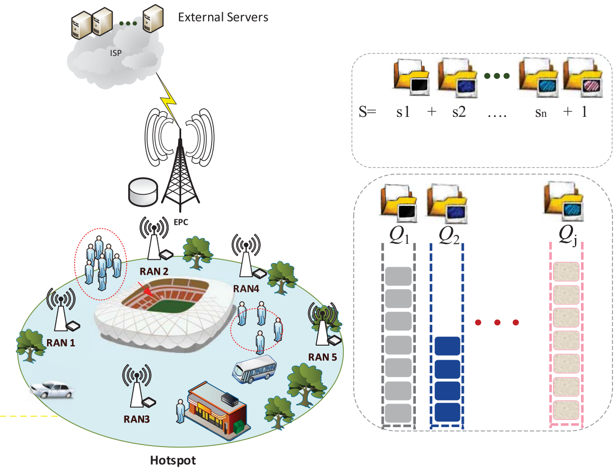

FIGURE 2. Contents distribution and placement model.

A. PRELIMINARY SETTING

The CCN network operates in two distinct phases which are content placement and delivery [24], [43]–[46]. In the content placement phase, the contents are replicated on the hotspot caches based on the statistics of the user's demands. While in the delivery phase, user's requests are served using caches and transmission from the central server via EPC. Fig. 2 shows the procedures of placement and retrieval of cache contents in the 5G network hotspot. The EPC in the network hotspot consists of contents and catalog (S) which includes all indices of the popular contents store in the network hotspot accordingly given value to content. The RANs and partial users devices in the hotspots have a subset of contents ($m1, m2, \ldots., m$) and its catalog like ($s1, s2, \ldots, s_n$). In the update cycle, the EPC update content catalog from RANs when any change occurs. Similarly, the request can be also served by the user cache node via D2D. The user cache node updates its contents catalog and also send an update to RAN where it connected. According to Fig. 2, the cache nodes ($\mathcal{Q}$) in the network hotspot together form cache cluster or hotspot network. In our proposed scheme, the content's popularity follows a Zipf distribution while the decision of the placement contents is formulated as to knapsack problem. Like the previous studies, the code cache is useful for achieving optimal performance and maximizing local hit-rate. In code caching each request is pre-assigned to a specific cache [47]–[49]. In contrast, we add flexibility in our proposed scheme for matching users request to cache and eliminate the need of code cache. Our proposed scheme cache highly popular contents close to the user nearest connected RAN. If the nearest RAN cache is out of space, one can move its cache contents to neighbour RAN upon the availability of space. In Fig. 2, if $RAN1$ runs out of space, it can move some cache contents to $RAN2$ or $RAN3$ using D2D communication. In the update cycle, all the RANs and EPC content catalog and value to the contents are update.

B. CONTENT DELIVERY

In the content delivery when the user requests a content σ_i, the requested content will be associated with nearest RAN or other nodes cache i.e. EPC in a hotspot that caches σ_i content and then attempts to download the file from it. We assume that only when the user received SINR above at prescribed threshold, can be successfully downloaded the requested file. In contrast, if the user requested file is not cached within hotspot it will download from an external server via ISP using EPC as a gateway as shown in Fig. 1.

In the proposed method, we follow Zipf distribution along with Knapsack. Many studies show that Zipf distribution is an efficient distribution scheme for content popularity [12], [41], [50], [51]. We consider that the content library consists of M different content files stored on ($\mathcal{Q}_1$, $\mathcal{Q}_2 \dots \mathcal{Q}_j \dots \mathcal{Q}_n$) caches. To stack P_m, we can get the probability density function (PDF) i.e., $\{ P_m : m = 1 \dots M \}$ of requesting M files. The probability of requesting file P_m can be model as the Zipf distribution. Furthermore, the content library F_M requested probability P_m is written as:

$$P_m = \frac{\frac{1}{m^\beta}}{\sum_{i=1}^{M} \frac{1}{i^\beta}}, \tag{10}$$

where β is the refers to content popularity rank, if $\beta \leqslant 1$ as $M \longrightarrow \infty$, the P_m tends to be zero. It converges to constant value when $\beta \geqslant 1$. As we know that the caches nodes within the hotspot have limited storage space therefore, we assume that the content library is partition into non-overlapping subset files store within the hotspot. The probability of $\mathcal{Q}$ that the user requests for content is given by

$$\mathcal{Q}_n = \sum_{m, for F_m \in \sigma_i} P_m. \tag{11}$$

In our proposed scheme the content popularity follows $\beta > 1$ such that

$$\mathcal{Q}_j = \begin{cases} |mp_i|, & \text{for } 1 \leq i \leq (\dfrac{m}{log\ m})^{\frac{1}{\beta}} \\ 0, & \text{otherwise.} \end{cases} \tag{C1}$$

$$\mathcal{Q}_s = \sum_{i=1}^{\frac{m}{log\ m}+1} (\sigma_i - \mathcal{Q}_j) + \sum_{\frac{m}{log\ m}+1}^{M} \sigma_i. \tag{C2}$$

The σ_i is the number of request for content i in a given time period. In C1, the $\mathcal{Q}_j$ is the serving cache within hotspot while the popularity follows $\beta > 1$. In C2, indicate the transmission of requested content σ_i from an external server outside of hotspot while $\mathcal{Q}_s$ refers to server storage. The focus of our works is minimizing the cost of CCN network. We store the contents according to the popularity of contents which results to save cache and transmission cost and maximize local-hit ratio.

1) ALGORITHM FOR DELIVERY OF CONTENT

In this phase, we serve the users requests σ_i within hotspot which associate with the content catalog S. In contrast, the requested content file would be transmitted to the external server from a remote content provider, which means that the data should flow across hotspot network, cellular network, and Internet as shown in Fig.1. Furthermore, the user request served within the hotspot will greatly reduce the transmission delay and energy consumption cost. To serve, the user requested mostly from network hotspot, we cached those contents which are highly popular i.e. ($\beta \geqslant 1$). Algorithm 1 is used for the delivery of user requested content (σ_i). The user in the network hotspot requested (σ_i) for content (i) will be served by local hotspot network caches or core network (i.e. ISP, external servers). As we know that the users request generated randomly at Δt time will be either normal content or multimedia content. Normal content means those request which are is a concern with security and privacy or less popular content lies in this category. In our proposed scheme, those content which can be reuse at specific time period will be save in hotspot cache. The delivery of contents be either local-hit or server-hit. If the requested content (σ_i) found in local hotspot cache node called local-hit as define in Algorithm 1 step 4 that the request content (σ_i) found at j-th node of hotspot. If the requested content (σ_i) not locally available in hotspot cache called server-hit which is defined in step 6 of algorithm 1. So our concern is optimization and efficiency of energy within hotspot in term of cache and transportation cost. The normal contents can not utilize the cache cost within hotspot and popular content minimizing the transportation cost due to the increase in local-hit ratio.

Algorithm 1 Procedure for Content Delivery

```
1: Initialization: $\sigma_i$ requests for content $i$ generate at the $\Delta t$ time.
2: if $\sigma_i$ is normal content not popular content.
3: goto step 9
4: elseif $\sigma_i \in S$ catalog and $\sigma_i \subseteq y_{ij}$.
5: goto step 8
6: else  $\sigma_i \notin S$ such that $\sigma_i \subseteq x_{is}$.
7: Update $\mathcal{Q}_s$.
8: Update $\mathcal{Q}_j$, $S$.
9: Request served to user.
10: end
```

C. CONTENT PLACEMENT

In the content placement phase, the content decision is to be made to store on which caches within hotspot based on the statistics of user demands. To store content in hotspot is selected by knapsack where content popularity follows Zipf distribution. The knapsack indicates to choose those content such that the cumulative value (serve the requested content frequency) is maximized, while ensuring that the cumulative weight (storage capacity of all contents within hotspot) is no more than the knapsack capacity. Formally, if the capacity of knapsack i.e. hotspot cluster is W (i.e., item i with weight w_i and value v_i is defined as:

$$\begin{aligned} & max \sum_{i=1}^{\mathcal{I}} y_i v_i \\ & \text{s.t. } y_i w_i \leq W \\ & \quad 0 \leq y_i \leq 1, \quad \forall_i. \end{aligned} \tag{12}$$

In equation (12), we kept those content in the knapsack with maximum value. Here value means the frequency of request made by users for accessing content i. Furthermore, the store capacity content i is less or equal to the overall storage capacity of network hotspot. In [43], [47], [52], where code caching are used for optimal performance, each request is pre-assigned to a specific cache. In our proposed scheme we use knapsack to add flexibility in matching requests to caches and eliminating the need of coding for optimal performance. knapsack determines the goal to store incoming request within hotspot caches to minimize the expected transmission rate from the external server needed to serve all the requests arriving in a given time period. Minimizing expected transmission from external server contributes to saving energy cost of accessing the contents locally.

Remarks 2:

The time complexity of knapsack problem can be computed in $O(n \log n)$ time. Here, n is contents catalog of hotspot caching contents.

Now, let u is the value bit can be expressed as

$$v_{iu} = 1 - (1 - P_i)^{\widetilde{m}}, \tag{13}$$

where P_i is the probability that content i is served from local hotspot at least once in time-slot. $\widetilde{m}$ is the batch request generated by the users within hotspot in a given time period. Furthermore, we assume that the batch requests generated will not exceed the network threshold. The weight of content i,

$$w_{iu} = \lceil \widetilde{m} P_i \rceil, \tag{14}$$

where $\lceil \widetilde{m} P_i \rceil$ refers to the number of expected requests for content i in a give time period. $y_{iu} = 1$ if the contents are selected by the knapsack else 0.

Considering equations (12)(13)(14), the optimization of content placement be described as:

$$\max_{v_{i,u}} \sum_{i=1}^{M} y_i v_{iu}$$

$$\text{s.t. } s_i \sum_{i=1}^{M} y_i v_{iu} \leq \sum_{j=1}^{n+1} \mathcal{Q} \tag{$\widetilde{C}1$}$$

$$\sum_{i \in \mathcal{Q}_j} y_i \leq 1, \forall i \in H_{ca} \tag{$\widetilde{C}2$}$$

$$H_{ca} = \{\lfloor y_i \rfloor w_i \text{ store content if } 1 \leq i \leq \sum_{j=1}^{n+1} \mathcal{Q} \tag{$\widetilde{C}3$}$$

In $\widetilde{C}1$, the contents are selected by knapsack which has higher value in the network hotspot caches. While in $\widetilde{C}2$, y_i refers to content i stored by knapsack which requested by the user at least once time from the local cache and belong to content catalog S. In $\widetilde{C}3$, those content which is selected by knapsack and is stored in a cache cluster with higher value in network hotspot.

1) ALGORITHM FOR CONTENT PLACEMENT

The content placement scheme is an important part of CCN design. As discussed in the above section using an efficient content placement scheme reduces the transportation and caching energy cost. Furthermore, due to cache cluster storage limitation, we store those contents which are highly popular. The popular contents are replaced by lower popular contents. In our proposed scheme content set S are arranged as increasing order of content index by considering storage limits of hotspot cache cluster. For order sequence on cache cluster refer to $v - 1 \ mod \ m + 1$, where v is frequency rank of occurrence and m is the number of hotspot cache. Algorithm 2 shows the steps involved in the content placement. In Algorithm 2, it is shown that the procedure steps of content placement in hotspot network selected by knapsack. In Algorithm 2, those content will be stored in network hotspot which follows Zipf popularity. Regarding step 2, those contents are selected by knapsack which follows Zipf distribution and served to a user for at least one time. If the knapsack has out of space it replaces the higher rank content with lower one in the network hotspot as shown in step 6 to store the new cache content selected by network hotspot.

Algorithm 2 Procedure for Content Placement

```
1: Initialization: $i \leq S$ indices and $i \leq M$ set of available contents storage in hotspot cache cluster.
2: if $i > 0$ of Zipf parameter which mean $i$ satisfied Zipf parameter. Then
3: $H_{ca} = \{\lfloor y_i \rfloor w_i$ store content if $1 \leq i \leq \sum_{j=1}^{n+1} \mathcal{Q}$
4: go to step 8
5: elseif condition $\widetilde{C}1$ and $\widetilde{C}2$ not satisfied Then
6: $i = i - 1$ with lowest value rank in knapsack accordingly.
7: return to step 2
8: Update $\mathcal{Q}_j$ having $s_i$ units block size in network hotspot cache cluster .
9: end
```

IV. RESULTS AND DISCUSSION

In this section, we present the simulation results to evaluate the performance of our proposed scheme. In our proposed scheme, we enhance the performance and reduce the backhaul energy by the proposed scheme with respect to 5G hotspot storage and content popularity. Backhaul means connectivity from hotspot to external content server using ISP. To access the content outside of hotspot through backhaul, the energy cost is described in (6). Here, backhaul means the energy consumption upon local hotspot cache-miss or

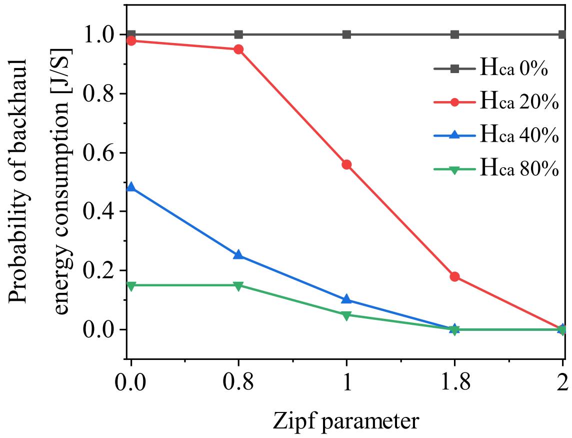

FIGURE 3. Contents distribution and placement model.

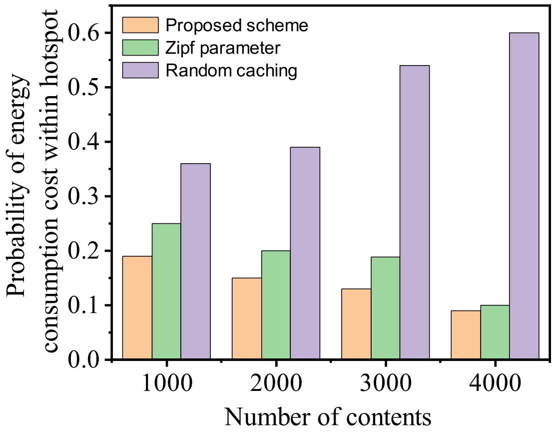

FIGURE 4. Hotspot energy consumption.

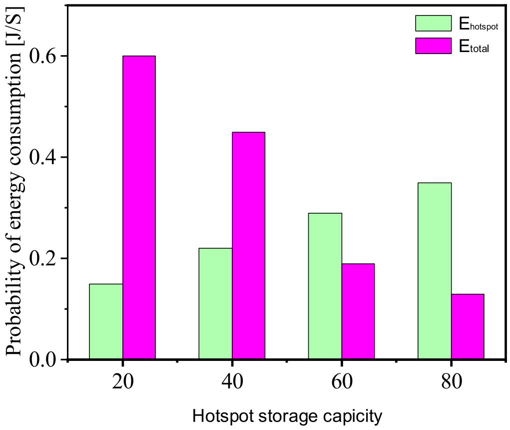

FIGURE 5. Proposed scheme effect on transport energy cost.

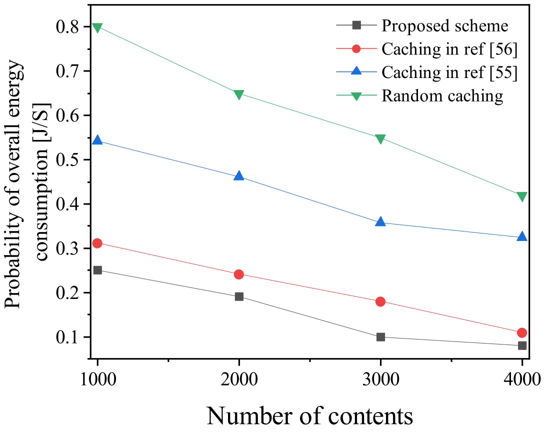

FIGURE 6. Overall energy consumption.

accessing content from an external server. Fig. 3, shows the probability of backhaul energy consumption with having different Zipf parameters and hotspot cache (H_{ca}) storage. As shown in Fig. 3, the increase in hotspot cache storage is proportional to the probability of hotspot cache-hit and minimize backhaul energy as a result. As we know that cache cluster has limited storage capacity and it is difficult to accumulate all the contents within the hotspot cache cluster. We use the word of hotspot cache and cache cluster interchangeably. By increasing the popularity of caching content, we can improve our hotspot cache-hit result and minimize backhaul energy consumption.

Fig. 4, shows the probability of energy consumption of contents within hotspot under the different number of batch requests generated by the hotspot users. The batch request means that the arrival of user requests for contents in a specific time period. Here, the storage capacity of the cache cluster is limited to one-fifth batch request generates at a specific time period. It can be seen from Fig. 4 that the hotspot energy consumption of our proposed scheme is lower than Zipf distribution and Random caching. In [53] and [54], where only Zipf distribution is used our proposed method outperform than these existing schemes. This is because of using Zipf distribution along with knapsack we add flexibility where each request can be matched to any cache of cache cluster as described in Section III-A.

Fig. 5 shows the probability of energy consumption serving hotspot users request contents from hotspot versus serving from external server as described in (5) and (6). As shown in Fig. 5 that our proposed caching scheme has significantly reduced the overall transportation cost describe in (2) under different hotspot storage capacity. Furthermore, the Fig. 5 shows that efficient proposed cache scheme thus reducing the overall transport cost.

Fig. 6 shows the cumulative energy consumption of our proposed scheme compared with the caching schemes in [55] and [56] and random caching. Here, the storage capacity of cache cluster is limited to one-fifth of batch request generated by the hotspot users at a specific time period. In [55], proposed an energy-efficient distributed caching scheme, where each content router only needs locally available information to make caching decisions considering both caching energy consumption and transport. Furthermore, Fang *et al.* formulated the content placement problem as a non-cooperative game, where they used the pure Nash equilibria in the non-cooperative game, and with a payment scheme the game can always implement the social optimum in the best case by giving content routers incentive to replicate. In [56], uses proactive caching algorithm which determines the prioritization of the content items and corresponding weighting factors. By using proactive caching algorithm, the authors investigated the energy consumption of edge-caching by considering different configuration such as caching size limitation, caching period and popularity (Zipf distribution). From Fig. 6, it can be seen that the overall energy consumption probability of our proposed scheme is lower then the caching schemes used in [55] and [56] and random caching for a different number of batch requests. Our proposed method is performing better than the existing schemes mentioned in Fig. 6 because in our proposed method we add flexibility for users request to cache cluster and eliminate the need for code caching. The elimination of code caching possible because we use knapsack for placement decision of cache, where content popularity follows Zipf distribution. Furthermore, our proposed method also supports D2D communication. With the help of D2D communication we optimize the transportation cost. Moreover, the proposed scheme performs efficiently because it maximizes local cache hit-rate which results in minimizing the overall energy consumption.

V. CONCLUSION

To ensure the energy efficiency and high cache performance of CCN caching system, an energy efficiency based in-network caching scheme is proposed in this paper. To analyze energy consumption, we first design an energy efficiency judging condition to reduce the total energy cost of content access in term of transportation and caching cost. The proposed scheme provides an efficient utilization of cache cluster storage capacity by using of Zipf parameter and knapsack. Furthermore, our scheme also support D2D. By efficient placement, popularity of contents and D2D support in network hotspot. We optimize overall transportation and caching cost which make significantly impact on the enhancement of overall hotspot network energy consumption. Simulation results show that our proposed scheme can outperform the existing scheme in term of content popularity, placement, local hit-rate which significantly improved energy efficiency in 5G network hotspot. As future work, we can consider our investigation with the effect of other factors on cache cluster performance which are link bandwidth, throughput, mobility of users, service (QoS) guarantee and service migration optimization model.

APPENDIX A
PROOF OF COROLLARY

The request user received SINR from its nearest Base Station can be formulate as:

$$\zeta_n(d) = \frac{Ph_{\mathcal{Q}_0} d^{-\alpha}}{\sum_{\mathcal{Q}_j \in \phi/\{y_o\}} Ph\mathcal{Q}_j \parallel \mathcal{Q}_j \parallel^{-\alpha} + \varrho^2}, \tag{15}$$

where ϱ^2 refer to Gaussian noise power, d denote the distance between user and its nearest RAN in Tier-n, $\mathcal{Q}_i$ represents the location of the interfering RANs, ϕ denotes the set of simultaneously active RANs, $\mathcal{Q}_j$ is the location of the serving RAN at a distance of d. Moreover, $\parallel \mathcal{Q}_j \parallel$ denotes distance between serving RAN and user, while $h\mathcal{Q}_o$ and $h\mathcal{Q}_j$ refers the corresponding channel gains. The minimum SINR (δ) required for successful transmission D_n probability is

$$Pr(D_n) = Pr[\zeta_n(d) \geq \delta]. \tag{16}$$

The average probability of users within hotspot can successfully download content from the hotspot storage, as

$$Pr(D_n) = \sum_{n=1}^{N} \mathcal{Q}_n . Pr(D_n). \tag{17}$$

Basically, $Pr(D)$ quantifies the weight of the successful download probability while the weights are the request probabilities reflecting the importance of the content file.

APPENDIX B

To analyze the total RAN consumption model is presented as:

$$\Psi_R = \frac{\Psi_A . N_{T_R} + \Psi_{R_F} . NT_R + \Psi_{BB}}{(1 - \varrho_{DC})(1 - \varrho_{AC})(1 - \varrho_{Cool})}, \tag{18}$$

where Ψ_A is the power of antenna, R_F is chain power per antenna, P_{BB} is power consumed at Base band unit (BBU), ϱ_{DC} is direct current (DC) to DC converter, ϱ_{AC} power loss rate of the alternating current supply, and ϱ_{Cool} power loss rate of cooling. According to [57], [58], a large portion of power is consumed by base station antenna by using power amplifier and antenna interface converter. Similarly the power consumption of EPC is:

$$\Psi_{EPC} = \Psi_R + G_W + MME. \tag{19}$$

The power consumption (P_R) of ECP is higher than power consumption of RAN because coverage area of EPC is much higher then coverage area of RAN. MME represent mobility management entity while G_W is boarder gateway to access content from outside of hotspot. The total transportation energy consumption of accessing content within hotspot is:

$$P_{hotspot} = \sum \Psi_R + \Psi_{EPC}. \tag{20}$$

Similarly, the total power consumption to access content from server size we have

$$P_{Tr} = \sum P_{hotspot} + ISP + \Psi_{server}. \tag{21}$$

As we know from (21), the transportation cost of access content from server side is too much higher than accessing contents within hotspot.

APPENDIX C
PROOF OF COROLLARY

The feasible placement vector $y = y_1, y_2, y_i....ym$ and the average requested probability $P_1, \ldots P_i \ldots\ldots P_m$ refer probability to average user preferences of the *i-th* content, the hit-rate can be formulate as:

$$\Phi(\sigma_i) = \sum_{i=1}^{M} (P_i(1 - (1 - \frac{r^2}{R^2})^y i), \tag{22}$$

such that

$$y_i \in \Pi^{(\mathcal{Q}_i+1)}$$

where R is radius of EPC and r is communication radius of RANs. The (22), refers to hotspot cache hit-rate. In case of hotspot cache-miss $y_i \notin \Pi^{(\mathcal{Q}_i+1)}$.

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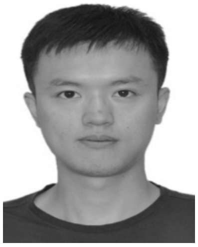

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