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A Cache Placement Strategy with Energy Consumption Optimization in Information-Centric Networking

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Abstract: With the rapid development of cloud computing, big data, and Internet of Things, Information-Centric Networking (ICN) has become a novel hotspot in the field of future Internet architecture, and new problems have appeared. In particular, more researchers consider information naming, delivery, mobility, and security in ICN. In this paper, we mainly focus on the cache placement strategy and network performance of ICN, and propose a cache placement strategy with energy consumption optimization. In order to optimize the energy consumption of the ICN, the best cache placement node is selected from the view of users. First of all, the distance sequence of different nodes arriving at each user is obtained in terms of detection results of network distribution channels, and the corresponding energy consumption of information distribution is obtained from the distance sequence. Secondly, the reward function of the cache node is derived using two factors of energy consumption, which includes the additional energy consumed by the change of the cache node and the energy consumption of the content distribution. Finally, we construct the optimal stopping theory problem to solve the maximum expected energy saving. In simulations, we give the comparison results of energy savings, caching benefit, and delivery success rate. The results show that the strategy proposed by this paper has higher delivery success rate and lower energy consumption than other strategies.

Keywords: Information-Centric Networking (ICN); cache placement; energy consumption optimization; optimal stopping

1. Introduction

The traditional network structure plays an important role for the success of the Internet. However, as the network scale continues to expand, the complex protocols built into closed network devices increase the difficulty for operators to optimize the network. Researchers must spend much time to scale new protocols in the real environment. At the same time, with the rapid growth of Internet traffic (to expected annual traffic in 2020 will reach 2.3ZB [1]) and the emergence of various new services, the cost of network operation and maintenance has been greatly increased. However, users still have a very high demand for the quality of service on the web. Therefore, while ensuring the quality of service, reducing network energy consumption and improving network performance are worthy of our continuous study. Based on the above background, ICN (Information-Centric Networking [2]) is born. In order to overcome the well-known shortcomings of the existing Internet (such as lower transmission efficiency, content distribution, and file sharing), the future network has become a research hotspot, and the ICN is considered as one of the most promising solutions in many scenarios [3–5]. Cache deployment and content caching is applied to ICN [6–8], and nodes are allowed to cache the transferred content. The core idea is that the content is placed in the first place, with the storage location of the content is no longer being of concern, only the content itself, and the content can come from the content server in the network, or it can be cached in any network node [9]. On the one hand, it can lighten the heavy protocol control load of the equipment, and on the other hand, the network can be controlled more flexibly and effectively. The network architecture of ICN is established based on IP protocol, which not only preserves the simplicity and scalability of IP protocol, but also provides better security and delivery efficiency. In addition, it is proved that ICN still needs to continue to be studied and has very large space for development. Under the background of the rapid development of network technology, cloud computing, big data, Internet of things, and other new technologies, the ICN, as the key technology of the next generation network, has been highly valued by the industry. How to improve caching performance and improve energy consumption is a hot topic in the industry. Although caching technology has been widely used in the field of computer networks, considering the generality and versatility of the caching function in ICN, there are still many problems to be solved in the study of caching technology. The current research of ICN cache technology mainly involves cache capacity allocation strategy, cache replacement strategy, cache utilization strategy, and cache placement strategy [10]. Because the performance of ICN network content distribution is directly influenced by the cache policy, therefore cache replacement strategy is also one of concerned topic for researchers. Among them, the problem of cache placement is at the core of ICN cache research.

It is a hot topic to improve caching performance in current related research fields for ICN. Usually, cache management strategies are evaluated with respect to cache hit, stretch ratio, and eviction operations, but at the same time, another energy problem cannot be ignored. Due to economic, environmental, and market reasons, reducing energy consumption has become an important concern of the industry in recent years. Considering the wide application of information and communication technology in daily life, the energy consumption of telecommunication networks accounts for 5% of the total energy consumption, and is increasing at a rate of 10% per year. Therefore, the issue of network energy consumption must not be ignored. In view of the importance of energy conservation, how to reduce network energy consumption is a very meaningful study.

Our paper is organized as follows. The background and significance of research questions are briefly introduced in Section 1. Related work is introduced in Section 2. The energy consumption model is constructed, and a cache placement strategy with energy consumption optimization is proposed in Section 3. The simulation results are given in Section 4, and the advantages of the strategies proposed in this paper are analyzed. The work and research results of this paper are summarized in Section 5.

2. Related Work

Caching strategy is a hot topic for ICN and CCN (Content Centric Network), and researchers have done lots of work on it. In ICN, Leave Copy Everywhere (LCE) cache policy is used as the default policy. That is, all nodes will cache received packets in the network, and it is the basic network cache policy. Although the algorithm is simple and easy to deploy, the network is redundant [11] and the cache utilization is reduced. Due to the lack of default strategies, some improved strategies have been proposed by relevant researchers. For example, in Left Copy Down (LCD) [12], the content is only cached on the direct downstream of the hit node, avoiding repeated caching of the same content, but this means that a certain frequency of access is needed to push the required content from the server to the network edge. A Random cache placement algorithm [13] was proposed by Altmeyer et al., which is improved on the basis of random selection of cache location, realizing the choice of equal probability. This strategy is simple and easy to implement, but its effectiveness is not considerable. The ProbCache strategy was proposed in [14], and the length of transmission path and the caching capability of nodes are taken into account. Since each node is to be calculated, the overhead is large and the implementation is difficult. Cui et al. proposed a caching strategy based on node inversion [15], where the distribution data is stored on the node with the greatest in-position on the path. However, there will be uneven distribution of caching, resulting in some users being unable to get the required content in time. Cho et al. proposed WAVE (popularity-based and collaborative) strategy [16], in which content with high thermal content is stored to nodes close to the users. Not only is the hit ratio of caching improved, but the number of cache replacements is also reduced. However, the complexity of the algorithm is high, and the majority of users cannot be taken into account at the same time. A distributed cache random placement strategy [17] was proposed by Hu et al. As a random caching strategy, data is only cached on a single node, so not only is redundancy of the cache resources avoided, but also the cache performance is improved to some extent. However, ignoring the situation in which content is needed by multiple users, the cache efficiency has not been effectively improved. With the above strategies, the cache effectiveness has been effectively improved to a certain extent, but the choice of placement nodes is limited and related only to the strategy itself, and other factors in the network have not been taken into consideration.

In order to improve the disadvantages of single-point cache, Syntila and Berger proposed cooperative caching [18] to better meet the growing number of users in the network. Through this algorithm, the caching performance of the network is improved to a certain extent and the load of the network is reduced, but its algorithm is complex and its implementation is somewhat difficult. A content placement algorithm based on cooperative caching [19] was proposed by Liu et al. In this method, the content activity is defined to reflect the frequent rate of the content being requested, and the cache performance is improved. However, the increase in the number of users is not taken into account, and placement nodes are only selected from the perspective of the service but not from the perspective of the user. A caching decision based on stay time [20] was proposed by Wang et al. Content with high popularity is effectively selected and cached, but the cost of staying time is increased. A heuristic caching mechanism based on probability was proposed in [21]. Cache performance and cache service efficiency have been improved, taking into account both cache benefit and content heat. But storage and computing overhead is greatly increased. Liu and others proposed a cooperative cache routing mechanism [22], in which the idea of centralized control is applied to cache management; not only is caching efficiency improved, but load distribution balancing is also improved. Fang and others proposed a hot area control and content scheduling caching algorithm [23]. The node heat is judged according to the node medium and the node access degree, and the number of request hops is reduced effectively. The selection of placement nodes in the above strategies is mainly based on the content popularity and collaboration, and only from the node of view of service; other performance indicators in the network have not been paid attention to.

PSIRP (Publish-subscribe Internet Routing Paradigm) is designed, prototyped, and investigated in clean-slate architecture for the future Internet based on the published-subscribe paradigm [4]. Its architectures are expected to effectively support mobility. Furthermore, based on the ICN paradigm, the authors presents network architecture for the IoT (Internet of Things) [5]. The authors analyze large content in intensive applications and how looped replacement occurs [24]. In one study [25], the authors introduce the Network-oriented Information-centric Centrality for Efficiency (NICE) as a new metric for cache management in ICN. Reference [26] proposes an N-hop content store-based caching policy and routing protocol.

In [27–29], the GreenICN concept has been proposed, and it aims to bridge this gap, addressing how the ICN network and devices can operate in a highly scalable and energy-efficient way. The team is very well positioned to design, prototype, and deploy GreenICN technology, and validate usability and performance of real-world GreenICN applications, contributing to creating a new, low-energy ICN.

In general, we can see that the deficiencies in the above strategies mainly include: (1) The placement of cache nodes is not considered from the perspective of the user; (2) the problem of energy saving in the research of ICN cache placement needs to be further studied. In addition, most of the existing cache placement strategies focus on how to improve cache performance and reduce the load. In our paper, a cache placement strategy based on energy optimization is proposed. From the perspective of the user, the problem is transformed into the maximization problem in the optimal stopping theory.

The goal is to minimize the network energy consumption while the cache performance is improved. The energy consumption problem of the ICN cache placement problem is mainly studied in this paper.

3. An Energy Consumption Optimization for ICN

In ICN, the energy consumption of a complete content distribution between nodes mainly includes two processes: the content is requested by the user and the content is transmitted to the user. The sum of the total energy consumed by these two processes is collectively referred to as complete energy consumption between nodes. Among them, the network energy consumption is closely related to the distance between nodes in the network. Therefore, through the network energy consumption model, the relationship between distance and energy consumption is established, which lays a foundation for the solution of the optimal stopping rule. Because the energy consumption caused by the distribution and reception of content between nodes is the main proportion, the network energy consumption model in this paper is constructed mainly by the energy consumption generated by the distribution and reception of content between nodes. The ICN energy consumption model and related parameters used in this paper are given below.

3.1. Energy Consumption Model for Content Distribution Betwween Nodes

The ICN consists of a plurality of user nodes and a plurality of network nodes connecting the users. Assume that there are m user nodes in the network, and the network nodes connecting these user nodes are n. To simplify the model, the distribution rate of each node is assumed to be τ, and the communication channel between nodes is AWGN (Additive White Gaussian Noise). The network nodes are homogeneous. In order to eliminate the communication interference, CDMA (Code Division Multiple Access) is used in the communication between nodes and the receiving power of the nodes is set to GR (Gain Reduction). According to the network model of ICN, the energy consumed by the user to get the required content is composed of two parts. That is, the energy consumed for receiving the content requested by the user, and the energy consumed for the distribution of the content to the user.

Content is distributed by node v_y to user node u_x. The signal received by node u_x can be represented as:

$$S_x(t) = a_{xy}\phi_y(t) + \omega_x(t) \tag{1}$$

The theoretical basis in the formula is given in [18]. Among them, the amplitude of the signal transmitted by node v_y is $\phi_y(t)$, and the attenuation factor of the channel from node v_y to user node u_x is a_{xy}; $\omega_x(t)$ is the AWGN with normal distribution, the mean value is 0, and the variance is g (noise power). The SNR (Signal Noise Ratio) at the user node u_x can be expressed as:

$$f = G_R/g \tag{2}$$

Among them, the lowest SNR for reliable distribution is f, and the received signal power at user node u_x is G_R, $G_R = fg$, its signal amplitude is $(G_R)^{1/2} * a_{xy}$, and the transmit signal power is:

$$G_T = \frac{G_R}{a_{xy}^2} = \frac{fg}{a_{xy}^2} \tag{3}$$

In Formula (3), ${a_{xy}}^2 = e/d_{xy}$, where the distance from user node u_x to network node v_y is d_{xy}, e is a constant, and thus Equation (3) is changed to:

$$G_T = \frac{fgd_{xy}^2}{e^2} \tag{4}$$

Then, the energy of c_k size is transmitted to the user node u_x by node v_y. The energy consumed is:

$$E_{yT}^{ccn}(c_k) = c_k\tau(G_E + G_T) = c_k\tau(G_E + \frac{fgd_{xy}^2}{e^2}) \tag{5}$$

Among them, the circuit power of the node is G_E.

The amount of energy consumed by the user node u_x for the content of the c_k size is:

$$E_{xR}^{ccn}(c_k) = c_k\tau(G_E + G_R) \tag{6}$$

From Formulas (5) and (6), it is known that the energy consumption between the nodes is proportional to the size of the content and the square of the distance between the nodes, and is proportional to the content distribution rate. To sum up, the total energy consumption required to perform a complete content distribution between two nodes is obtained:

$$E_{xy}^{ccn}(c_k) = c_k\tau(G_E + G_T + G_R) \tag{7}$$

$$E_{xy}^{ccn}(c_k) = c_k\tau(G_E + \frac{fgd_{xy}^2}{e^2} + G_R) \tag{8}$$

3.2. Problem Transformation

In the content centric network, higher utilization and lower energy consumption are pursued under given cache capacity constraints. Generally speaking, the lower the cache utilization is, the higher the average delay will be, and the more energy will be consumed in the network. Due to the complexity of multi-objective optimization, network energy consumption is considered as the optimization objective of cache placement strategy in this paper. The problem of selecting appropriate cache placement nodes from the source node to the destination node is studied in this paper. Obviously, the expected energy saving in the cache policy needs to be obtained to ensure that the content is cached at the energy-efficient node, causing the content to be transmitted along the optimal energy efficiency path to the destination node. The goal of the caching placement decision is to select a node and place the content on this node so that it can save the most energy compared with other nodes. This problem is called the maximization problem, and the optimal stopping rule is used to solve the optimization problem [30].

In ICN, content is transmitted through the connections between the nodes, and the distribution energy needs to be consumed. Content of the same size is transmitted between different nodes with different energy consumption, and the energy consumption between nodes mainly depends on the distance between nodes. Therefore, in order to save the distribution energy consumption, the distance of distribution must be reduced. In this paper, the distance random variable is continuously observed by the user, and then the energy consumption sequence is obtained. The expected energy consumption is used as the basis for deciding whether to select the observed node as the cache placement node. The core idea is that the node is compared with the energy consumed by the current detection and the first time. If the condition is satisfied by the currently observed node, it is selected as a cache placement node, otherwise it is abandoned and the next node continues to be observed. Therefore, the problem of users selecting the best cache placement node is converted into an optimal stopping rule problem. The corresponding relationship between the elements of the problem and the optimal stopping problem is shown in Figure 1.

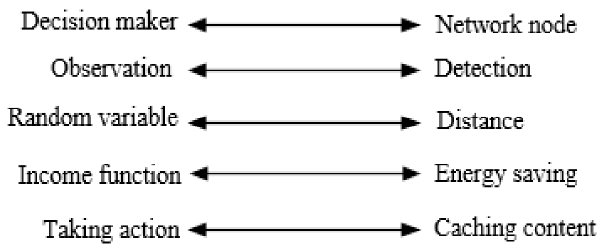


Figure 1. Optimal stopping elements in cache node selection.

3.3. Optimal Stopping Theory Is Used to Select Cache Placement Nodes

The caching placement strategy of this article is proposed by considering a content distribution in a network. The energy consumption sequence can be obtained according to the distance sequence of random variables. Suppose the independent and identically distributed random variable $P_{u\to v}$ is composed of the energy consumed by the user node u_x to the network node v_y. Compared with the content being obtained at the first randomly selected node, the energy savings of the content obtained at the other nodes are represented by Y_N. In order to make the model closer to the actual situation, it is assumed that each time the cache node is re-selected, it will consume a certain amount of energy, which is defined as P_c. Then Y_N can be expressed as:

$$Y_N = \sum_{x=1}^{m} P_{u_x\to v} - \sum_{x=1}^{m} P_{u_x\to v_N} - NmP_c \tag{9}$$

Among them, the mP_c is used to detect the energy consumed at one time in the case of multiple users, and the number of user nodes is m.

For the selection of cache nodes, the purpose of maximization (9) is to find the optimal stopping time N^* that can get the best expected reward. The optimal stopping rule is derived using the energy consumption sequence $P_{u\to v}$ calculated for each observation and the resulting reward sequence Y_N. That is, the choice of a time N^*, so that:

$$N^* = \arg\frac{\max}{N = 0, 1, 2, \ldots} E(Y_N) \tag{10}$$

Here,

$$Y_N = \sum_{x=1}^{m} P_{u_x\to v} - \sum_{x=1}^{m} P_{u_x\to v_N} - NmP_c = X_N - NmP_c \tag{11}$$

Formula (9) is brought into Formula (11). For simplicity, the user base is viewed as a whole, so we can get:

$$\begin{aligned} Y_N &= m(c_k\tau(G_E + \tfrac{fgd^2_{u_x\to v}}{e^2} + G_R) - c_k\tau(G_E + \tfrac{fgd^2_{u_x\to v_N}}{e^2} + G_R) - NP_c) \\ &= m(\tfrac{c_k\tau fg}{e^2}(d^2_{u_x\to v} - d^2_{u_x\to v_N}) - NP_c) \\ &= m\ \ (\tfrac{c_k\tau fg}{e^2}(d^2_{u_x\to v} - d^2_{u_x\to v_N}) - NP_c) \\ &= my_N \end{aligned} \tag{12}$$

Here,

$$y_N = \frac{c_k\tau fg}{e^2}\left(d^2_{u_x\to v} - d^2_{u_x\to v_N}\right) - NP_c = \frac{c_k\tau fg}{e^2}x_N - NP_c \tag{13}$$

The reward function for the problem of maximizing energy savings is shown in Formula (13); $d_{u\to v1}$ is a fixed value and $d_{u\to v}$ is a random variable, assuming that it obeys uniform distribution.

In summary, the problem of selecting the cache placement nodes in ICN has been transformed into the problem of maximizing energy savings, and a corresponding mathematical model has been established. Before solving the problem, it is proved that there is an optimal solution to the proposed problem.

3.4. Existence Proof and Solution of Optimal Stopping Rule

Proposition 1: *Equation (10) has an optimal stopping rule.*

Proof: According to [19], the optimal stopping rule exists when the following two conditions are satisfied:

$$\begin{array}{ll} ① & E\{\sup_N Y_N\} < \infty \\ ② & \limsup_{N\to\infty} Y_N \leq Y_\infty \end{array} \tag{14}$$

According to (11), the value of the reward function Y_N changed at the Nth node is known as $Y_N = X_N - NmP_c$, for any $N = 1, 2, 3, \ldots$, $\{sup_N\ Y_N\} < \infty$, and because N, m and P_c are positive values. Therefore, $E\{sup_N\ Y_N\} < \infty$ is set up, and condition ① is satisfied. When $N\to\infty$, $NmP_c\to\infty$, otherwise $-NmP_c\to\infty$, then $Y_N\to-\infty$. Therefore, it is clear that $Y_\infty\to-\infty$, $lim\ sup_{N\to\infty}Y_N\leq-\infty = Y_\infty$, condition ② is satisfied. □

When the maximum expected benefit W^* is obtained by the user group, the stop time N is the solution of the optimal stop problem (Formula (10)). According to the problem solving method in [30], we can see that when $X_N < W^*$, the node needs to be replaced and the user continues to observe other nodes. When $X_N \geq W^*$, the node should stop observing and caching content. Therefore, the stop rule is converted to:

$$N^* = \min\left\{N \geq 1 : \left(d^2_{u_x\to v} - d^2_{u_x\to v_N}\right) \geq W^*\right\} \tag{15}$$

Here, the maximum expected benefit W^* satisfies the best equation:

$$W^* = E[\max(d^2_{u_x\to v}, W^*)] - P_c \tag{16}$$

According to the optimization formula of Theorem 3.1 in [30], the stopping rule W^* is solved by:

$$\begin{aligned} W^* &= E[\max(d^2_{u_x\to v}, W^*)] - P_c \\ &= \int_0^{W^*} W^* \cdot dF(x) + \int_{W^*}^{L} x \cdot dF(x) - P_c \end{aligned} \tag{17}$$

Here, L is the distance between the user node u_x and the network node v. Let $W^* = \int_0^L W^* \cdot dF(x)$. By combining it with Formula (16), we can get:

$$\begin{aligned} &\int_0^L W^* \cdot dF(x) = \int_0^{W^*} W^* \cdot dF(x) + \int_{W^*}^{L} x \cdot dF(x) - P_c \\ &\Rightarrow \int_0^{W^*} W^* \cdot dF(x) + \int_{W^*}^{L} x \cdot dF(x) - \int_0^L W^* \cdot dF(x) = P_c \\ &\Rightarrow \int_{W^*}^{L} (x - W^*)dF(x) = P_c \end{aligned} \tag{18}$$

Where, F is the distribution of X_N. In this paper, F is assumed to be a uniform distribution. For discrete random variable x_N, we can have:

$$E(x_N - W^*)^+ = P_c Z \tag{19}$$

3.5. Cache Placement Algorithm Based on Energy Consumption Optimization

Firstly, the first node v is randomly selected. Each user observes the energy consumed for obtaining content from the node. The second node v_y is randomly selected, and the user group observes the energy consumption needed to obtain the content from the node. Comparison of energy consumption observed at two different nodes results in energy saving. If the energy saving is greater than or equal to the maximum expected energy benefit W^*, node v_y is selected as the cache node and the user stops the observation. If the node meeting the requirement has not been found within a limited number of node changes, the first node v is selected as the cache node by default. In ICN, this caching strategy is used to select the best cache placement node for caching content. To ensure that the content is transmitted on the most energy efficient routing, the cache placement strategy based on energy optimization is implemented. The cache placement policy based on energy consumption optimization is specifically described as follows (Algorithm 1).

Algorithm 1. ESCPS

Input: c_k, m, $area$, P_c, τ, etc;
Output: v; /* Cache placement node */
Begin
W^* $=L$-$area$^2/3-P_c; /* Calculate expectation */
$n \leftarrow 1$, $E^* = 0$; /* Number of node and energy savings initialized */
for $1 \le i \le n$ **do**
Observation of random variables d_i;
stop← false; /* observing */
if $(d_1 - d_i) \ge W^*)$ **then**
$r_i = E_1 - E_i$;
if $E^* < r_i$ **then**
$E^* = r_i$;
$v \leftarrow v_i$;
endif
stop← true;
break;
endif /* stop detecting */
endfor
if (!stop && $i = n$) **then** /* The node is satisfied and the condition is not found */
$v \leftarrow v_1$;
endif
return v
end
End

4. Simulation Results and Analysis

In this section, the proposed cache placement strategy based on energy consumption optimization (ESCPS) is simulated. And MATLAB tool is used to numerically calculate the model of ESCPS policy and to compare it with the other two buffer strategies (LCD (Leave Copy Down) [6], Random [7]). We analyze and evaluate the comparison results of energy savings, caching benefit, and delivery success rate when the number of the user m, distribution content size c_k, and node distribution range *area* are changed. The parameters in simulations are given in Table 1.

Table 1. Simulation parameters.

Parameters	Description	Value
m	Number of users	100~1000
P_c	Extra energy consumption	0.1~1
τ	Distribution rate	5
c_k	Content size	10~100
g	Noise power	3
f	Noise ratio	1
G_R	Node receiving power	3
area	Node distribution range	1~20

Here, the number of users in the network is m, and it changes in 100~1000 (number). The energy consumption of the node change is P_c. That is the energy that the user needs to consume in the process of finding the cache node and the value is a random number of 0.1~1 (J). The average rate of content distribution in the network is τ and its value is 5 bps. The average value of the node distribution in the network is *area* and the distance is 1 to 20 (m). The total number of simulations is 10,000.

The two strategies used for comparison in this paper are: (1) Down replication reservation policy LCD—based on the classical full cache LCE (Leave Copy Everywhere) policy, the redundancy of the strategy is greatly reduced, and the content is cached only to the next hop of the hit node. (2) Random caching strategy Random—the network nodes are selected by random equal probability. In these three strategies, the energy consumed by the replacement of the cache node also has a certain effect on energy savings besides the parameters of m, c, and *area* change. The effect of node energy consumption (P_c) on the energy savings of the three strategies is shown in Figure 2.

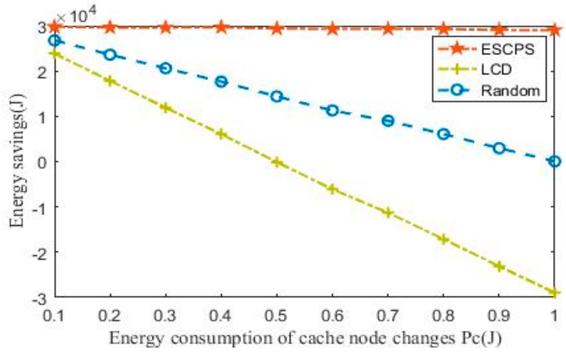


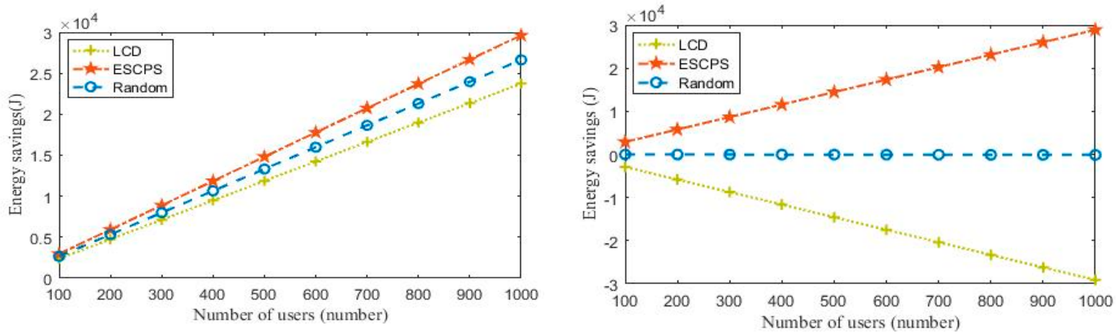
Figure 2. The effect of cache node change energy consumption on energy savings.

From Figure 2, we can see that there is a common characteristic—when the value of P_c is small, the energy consumption that can be saved is large, and when the value of P_c is large, the energy consumption that can be saved is small for three strategies. The reason is that P_c is the main factor in the cost of energy consumption. The larger the value is, the more energy is consumed when the node changes. Among them, LCD is the most affected by P_c, because each time the next node that selects the hit node is used as the cache placement node, the first method is oversimplified, and the number of node changes cannot be made in conjunction with the network conditions and other factors. In this way, the cost energy consumption is almost linearly increased when P_c is continuously increased. Ultimately, the saved energy is less than the cost of energy, and the saved energy is negative. It shows that the placement node of this policy selection is not only saving but also consuming more energy than other nodes. For Random, it is a random selection of equal probability. It is slightly less affected by P_c than LCD, but it is not targeted when selecting the best cache placement node, so the effect of saving energy is not as good as ESCPS. In these three strategies, it can be clearly seen that ESCPS has the best energy-saving effect. In the continuous increase of P_c, the decrease is the smallest and the energy consumption is always higher than the other two strategies. The choice is very selective, making it almost unaffected by the power consumption of node changes.

4.1. Energy Savings

Energy savings are the energy saved by the content being acquired at the cache node compared with the other nodes. In this paper, the process of obtaining information includes the user sending a request and the content being returned. The more energy is saved, the better the cache strategy is used.

The comparison results of the energy savings of each strategy are shown in Figure 3a,b when the number of user m changes (100 to 1000). The analysis is performed under the parameter configurations of the best and worst case conditions. That is to say, P_c is 0.1 and 1, respectively.



(**a**) (**b**)

Figure 3. (**a**) The effect of the number of users on energy savings (P_c = 0.1); (**b**) the effect of the number of users on energy saving (P_c = 1).

From Figure 3a, we can see that the order of saving energy consumption from high to low is: ESCPS > Random > LCD. With the increasing number of users, the three curves show an increasing trend. Among them, the increase of ESCPS is the largest, indicating that these three strategies have their own effects in terms of energy saving, and all save a certain amount of energy consumption. By comparison, the LCD's energy-saving effect is not good, with the smallest increase. The main reason is that the location of the selected cache is narrowed by one jump relative to the user to the source server. The essence is to move the content forward to a node and not make a choice according to the specific situation of the network. The choice is too limited. Compared with LCD, the placement of cache placement nodes in Random is equal probability, which has better flexibility so that the deficiency of simplification is made up. Therefore, the achieved energy saving effect is slightly better than LCD. After comparison, it can be clearly seen that ESCPS has the best energy saving effect. Because it is based on energy consumption optimization, the sum of energy consumed by each user for content acquisition is taken into consideration. Therefore, when the number of users increases, the growth rate is the largest, and a good energy saving effect is always maintained. At the same time, LCD and Random have not considered the placement of cache from the perspective of the user [6,7], and the importance of user distribution is ignored.

From Figure 3b and the above comparison, we can see that when P_c increases, the number of the users' increases, the energy consumption of LCD is significantly reduced or even negative, and the energy saving effect has not been achieved. This is because LCD consumes a certain amount of energy consumption of cache nodes when selecting nodes, and it is related to the number of users; that is, mP_c. Then, when the number of users is increased and P_c is also increased, the cost and energy consumption will also be greatly increased, thus saving energy consumption will be greatly reduced to negative value. It is shown that the cache node selected by this strategy can no longer achieve energy saving in content distribution. Compared with other placement nodes, energy is not only saved, but it also consumes more energy. Compared with LCD, Random is slightly better in energy saving stability, but the energy saving of the cached node is greatly reduced when the energy consumption and the number of users are increased. This is due to the random probability of randomness of Random, which is also affected by the energy consumption of replacement of cache nodes. Therefore, when both P_c and m increase, we can see that this is because the random probability of Random is also affected by the replacement energy consumption of the cache node. Therefore, when both P_c and m increase, Random has almost no negative value but the energy-saving effect is almost zero. Compared with the other two strategies, ESCPS can still maintain a good energy-saving effect and is particularly prominent in stability. In comparison, the ESCPS strategy has more advantages in saving energy consumption when hotspot information erupts and the user requests are mostly consistent. As the location of the cache in the ESCPS policy is selected from the user's point of view, the energy saving can still be kept at optimal when the number of users increases.

The comparison results of the energy savings of each strategy are shown in Figure 4a,b, when the content size of the distribution changes (10 to 100). The analysis is performed under the parameter configurations of the best and worst case conditions. That is to say, P_c is 0.1 and 1, respectively.

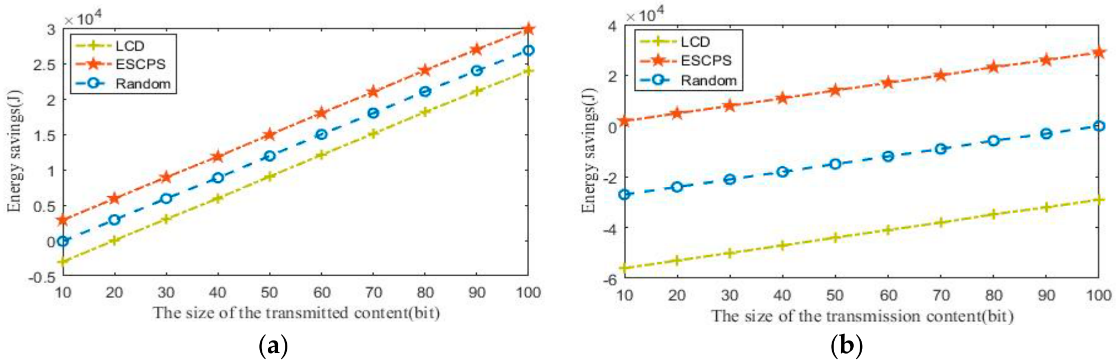
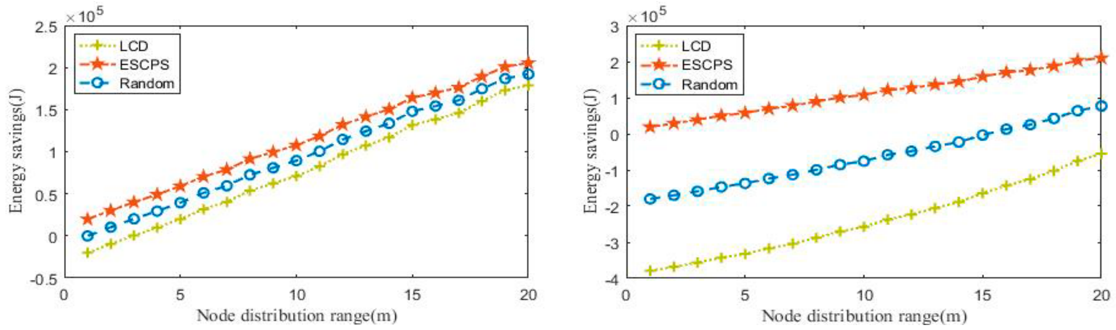


Figure 4. (**a**) The effect of distribution content size on energy savings (P_c = 0.1); (**b**) the effect of distribution content size on energy savings (P_c = 1).

From Figure 4a, we can see that in the process of increasing the size of the distribution content, the order of saving energy consumption from high to low is: ESCPS > Random > LCD. The energy consumption saved by all three strategies is increased. This is because the cache space is small, and the cache is replaced frequently. As the space increases, the number of replacements is reduced, the hit rate is increased, and the energy saving effect of the cache nodes becomes more apparent. Among them, ESCPS has the largest increase. In ESCPS, the content of distribution is an important parameter in the income function. Therefore, when the content of distribution is increased, the benefit function of saving energy is increased. As the content of distribution increases, the energy saving is almost linearly increased. Compared with ESCPS, Random and LCD have less growth and less energy savings. Because cache placement nodes are randomly and singularly selected, they cannot guarantee the optimization of the selected placement node in terms of energy efficiency.

Comparing Figure 4a with Figure 4b, the energy savings of all three strategies have been reduced when the size of the distribution content and the energy consumed by the node change are increased at the same time. Among them, the energy saving effect of ESCPS is still the best, showing good stability. Since the size of the distribution content is taken into account in the reward function, even if the distribution content size and the node replacement power consumption are increased at the same time, it is reduced to the smallest extent, and the energy that can be saved is still the largest. Among them, the change of LCD is the most obvious. Because the location of cache placement is too simplistic, the number of node changes cannot be chosen well. Therefore, when P_c is increased, the energy consumption of the consumed nodes is increased linearly, resulting in a sharp drop in energy savings. There is no effect of saving energy, but it consumes more energy. To some extent, Random is similar to LCD, as its method of selecting placement nodes is not targeted, the refinement of nodes is not considered, and the nodes in the network cannot be well utilized. Therefore, the energy saving effect of the selected placement node is not achieved, but the energy consumption is lost. In summary, among these three cache placement strategies, only ESCPS has strong adaptability to changes in the network environment, and the effect of saving energy consumption is always achieved.

The comparison results of energy savings of each strategy at node distribution distance variation (1~20) are shown in Figure 5a,b. *Area* refers to the distance between nodes in the network, which reflects the impact of network size on energy savings. The analysis is performed under the parameter configurations of the best and worst case conditions. That is to say, P_c is 0.1 and 1, respectively.



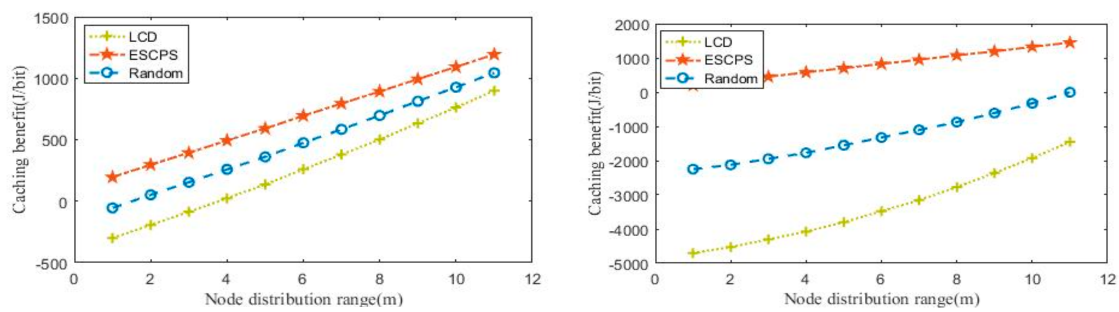
(a) (b)

Figure 5. (**a**) The effect of node distribution on energy savings (P_c = 0.1); (**b**) the effect of node distribution on energy savings (P_c = 1).

From Figure 5a, we can see that as the *area* is continuously increased, and three strategies show an upward trend. The order of growth and energy savings from high to low are: ESCPS > Random > LCD. An increase in the *area* means that the distance of the nodes in the network is increased, and the energy consumption required to transmit the content is closely related to the distance between the nodes. Therefore, when the *area* is increased, the three strategies are enhanced in the energy saving effect. However, when the node change power consumption P_c becomes large, it can be seen from Figure 5b that the energy saving effect of LCD and Random has undergone a significant change, in which LCD is always negative. When the content is placed at the cache node selected by the strategy, the energy consumption cannot be saved, but it consumes more energy than putting content on other nodes. The reason is known from the above, and it is related to the method of selecting cache nodes. It lacks flexibility and cannot select the best placement node. Compared with LCD, Random starts to save energy when the *area* reaches 16. As the distance between nodes increases, the role of cache nodes becomes more apparent. Because it is chosen by equal probability in the method, it is more flexible than LCD, and the single choice is avoided, so when *area* is large enough, the effect can be restored.

4.2. Caching Benefit

The energy saved by the content of the distribution unit capacity is called the caching benefit. The energy saving effect of three different strategies can be shown more concretely. The comparison results of caching benefit of each strategy at node distribution distance variation (1~11) are shown in Figure 6a,b. The analysis is performed under the parameter configurations of the best and worst case conditions. That is to say, P_c is 0.1 and 1, respectively.



(a) (b)

Figure 6. (**a**) The effect of node distribution on the caching benefit (P_c = 0.1); (**b**) the effect of node distribution on the efficiency of caching (P_c = 1).

From Figure 6a,b, it can be seen that the caching benefit of these three strategies is affected by the distribution of nodes; that is, the greater the distance between nodes, the more effective the cache policy is. As the *area* is constantly increased, all three strategies are on the rise. The order of cache effectiveness from high to low is: ESCPS > Random > LCD. Among them, ESCPS has the greatest energy consumption for the saving of the unit bit. This is because the choice of cache placement node is from the perspective of the user, therefore the best placement node can be better selected, and energy can be effectively saved. After P_c became larger, ESCPS still has a good cache effect, although its rate of increase became slower. When P_c is small, compared with ESCPS, Random and LCD can also have good cache benefits as the *area* is increased, but after P_c becomes larger, the caching benefit of the two policies becomes negative, even when the distance between nodes is increased. It is illustrated that the selected cache placement node does not achieve the effect of saving energy, but consumes more energy. This is because the two policy cache nodes are selected in a way that is not targeted, and the placement of the cache is not considered from the perspective of the user, resulting in a poor adaptability to changes in the network environment.

After analysis, we know that ESCPS has better energy saving effect on the content of the unit in the selection of cache placement nodes.

The comparison results of the caching benefit of each strategy when the content size of the distribution changes (10 to 100) are shown in Figure 7a,b. The analysis is performed under the parameter configurations of the best and worst case conditions. That is to say, P_c is 0.1 and 1, respectively.

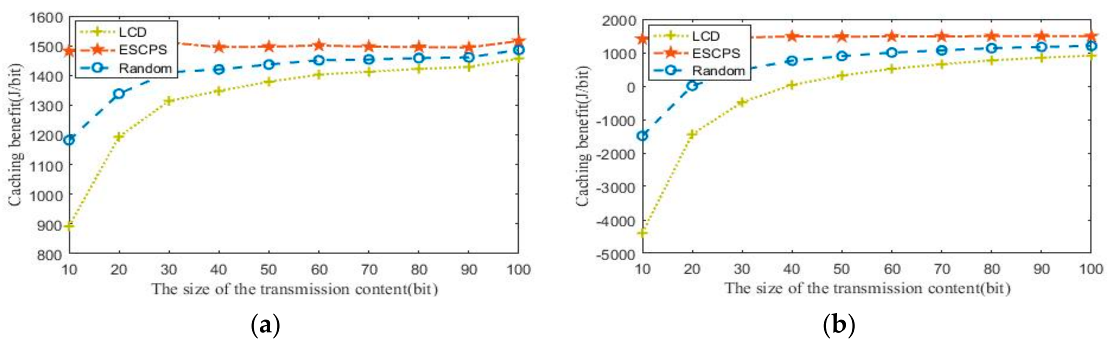


Figure 7. (**a**) The effect of distribution content size on content the efficiency of caching (*Pc* = 0.1); (**b**) the effect of size on the efficiency of caching (*Pc* = 1).

From the comparative analysis of Figure 7a,b, it can be seen that the caching benefit of the three strategies is affected by the size of the distribution content. As the content of the distribution increases, the caching benefit of the three strategies is ranked from highest to lowest: ESCPS > Random > LCD. In the ESCPS, no matter when the size of the distribution content changes or the energy consumption of the node change is increased, the higher caching benefit is always maintained without significant fluctuations. It shows that this strategy can hardly be affected by the content of distribution, and has better stability for the energy consumption saved by unit content. Compared with ESCPS, LCD and Random are greatly influenced by the size of the transmitted content and P_c. When P_c is small, the caching benefit of the two strategies is still positive, indicating that the unit content is energy-saving. After P_c is increased, the caching benefit of LCD and Random is reduced to negative values, even when the content is large. It shows that the energy saving effect on the unit content has not been done, but the energy consumption is increased, and the energy saving function needs to be brought up when the content of the distribution is large enough. In the process of changing the entire network environment, the use of the Random strategy is better than the LCD policy, which validates the effectiveness of the improved method of Random for the selection of caching nodes on the basis of LCD. However, because the energy consumption of the network is not taken into account in both strategies, and the choice of cache placement node is not taken from the perspective of the user, it is easily affected when the network environment is changed, and the stability of the performance cannot be guaranteed.

In summary, among the three strategies, ESCPS has better advantages in cache efficiency and performance stability.

4.3. Delivery Success Rate

The probability to find the optimal cache placement node within a limited number of nodes is called the success rate of delivery. The higher the value is, the better the timeliness of the strategy being used. The delivery success rate of ESCPS is shown in Figure 8, when the node distribution range (1~10) and the node change energy consumption P_c (0.1~1) change.

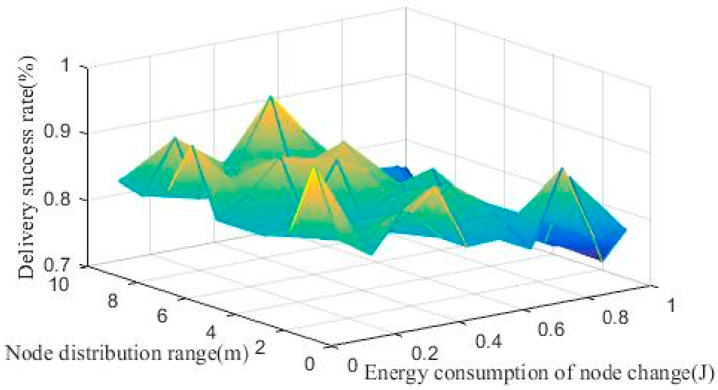


Figure 8. The influence of node change energy consumption and node distribution range on delivery success rate.

From Figure 8, we can see that the success rate of delivery is affected by the distribution range of nodes and the energy consumed by the change of nodes in ESCPS strategy. When P_c is a fixed constant, the success rate of delivery will increase as the distance between nodes increase. The reason is that *area* is the main factor in the selection of cache nodes in ESCPS. That is to say, the larger the node's distribution range is, the farther the node's distance is. If the probability of the node which can be observed to satisfy the energy saving condition is higher, the observation times will be less and the success rate of delivery will be higher. If the node distribution range is a fixed constant, as P_c is continuously increased, the success rate of delivery will decrease slowly. The reason is that P_c is the extra energy consumed for each observation. The extra energy consumed will increase and the effect of the energy saving will downgrade when P_c is increased. In addition, the energy saving is less if the probability of being observed to satisfy the conditions is smaller and the number of observations used to find the best placement node is bigger. That means the success rate of delivery is lower. After analysis, we can see that there is no significant fluctuation in ESCPS under the condition of the change of parameters, and the success rate of delivery can always maintain better.

5. Conclusions and Further Work

In this paper, a cache placement strategy with energy consumption optimization has been proposed according to the built-in cache characteristics of content center network. Firstly, the network energy consumption model is constructed under the ICN architecture, and the problem of maximizing energy saving is transformed into the optimal stopping rule problem. Then, the optimal stopping problem is proved and solved, so the maximum expected value of energy saving is achieved. The energy saving of the current node is observed by the user group and compared with the maximum expected value to select the cache placement node so that the content distribution with low energy consumption and high cache efficiency can be realized. The simulation results show that the ESCPS strategy proposed in this paper obtains a larger caching benefit and higher delivery success rate, and has a better energy saving effect.

In future work, the energy consumption model is defined more accurately with the actual situation of the network, and other performance factors will be optimized on the basis of the optimization of energy consumption.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, X.Z. and G.W.; methodology, Q.Z.; writing—original draft preparation, G.W.; writing—review and editing, X.Z.; supervision, G.W.; project administration, X.X.; funding acquisition, G.W.".

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Abbreviations

τ	Distribution rate
G_R	Received signal power
$\phi_y(t)$	Amplitude of the signal transmitted
f	SNR
G_T	Transmit signal power
W^*	Maximum expected benefit
c_k	Data size to be transmitted
g	Noise power
G_E	Circuit power
m	Number of user nodes
P_c	Extra energy consumption
area	Node distribution range

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