A Cloud-Assisted Architecture for Content Distribution in Mobile Peer to Peer Networks

LIU Yuan-ni [1*], CHEN Hong-yan [1], GILANI Syed Mashhad Mustuzhar [2]
[1] School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, 400065, China
[2] University Institute of Information Technology, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Punjab, 46000, Pakistan
*Corresponding Author, email: liuyn@cqupt.edu.cn

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ABSTRACT: *Content distribution is a key technology to achieve data sharing among mobile terminals in Mobile Peer to Peer (MP2P) networks. Nevertheless, in the dynamic/mobile environment, the poor computing ability and storage capability of a single node make it difficult to share the content among nodes. In order to enhance the capability of the mobile terminals and improve the efficiency of content distribution, a cloud-assisted architecture to offload the heavy computation load from the mobile nodes to the cloud was put forward. Furthermore, a Multi-Tree Structure of Internal Node Disjoint (MTSIND) data transfer topology was proposed, in which their internal nodes are disjoint, thus each node can take part in the content delivery tasks. Finally, an exclusive-OR (XOR) network coding method based on vertex coloring problem was established to reduce the number of transmissions and power consumption. Simulation and numerical results were provided to support the analyses and results. Results show that the content distribution mechanism can reduce the total number of the data packets and the energy consumption. The study proves that the research of content distribution mechanism on MP2P has a great significance on reducing the number of data transmissions, lowering the power consumption of terminals and increasing the resource utilization of mobile nodes.*

Subject Categories and Descriptors
C.2.4 [Distributed Systems]: Distributed Applications; **H.3.3 [Information Storage and Retrieval]:** Information Search and Retrieval

General Terms
Peer to Peer Network, Data Transfer Topology, Multi-Tree, Network Coding

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1. Introduction

With the rapid development of mobile communication technology, Mobile Peer to Peer (MP2P) technology has opened up a new direction. MP2P is an application layer network that is superimposed on the network layer of mobile Internet applications, which can use a variety of service quality and standard bandwidth access technology to share resources and data among mobile devices through exchange and collaboration [1]. Moreover, as a combination of mobile network and Peer to Peer (P2P) technology, MP2P inherits the advantages of traditional P2P network, such as decentralization, scalability, robustness, high performance and load balancing, which allows every node in MP2P to have the same logical function, and any two nodes can directly exchange information and data. To this end, the MP2P has widely drawn close attention both in the field of application and academia.

However, dynamic/mobile environment and constrained battery, computing ability and storage capacity of mobile devices make it difficult to play its unique advantage in the mobile network. Content distribution is a key technology of MP2P applications, which takes advantage of "peer" to realize date or file sharing among mobile terminals. Nevertheless, the instability of network architecture, the limited capacity of a single node and low efficiency of content distribution make the realization of the process complicated. In order to cope with these problems, a lot of studies on improving the efficiency of content distribution in MP2P network have been focused, but the research on cooperative transmission between nodes and the capacity of mobile nodes is still insufficient. Combined with the characteristics of mobile terminals, such as the mobility and capacity, etc. this paper put forward a cloud-assisted MP2P architecture and constructed an efficient content distribution mechanism based on network coding. Research on the efficient content distribution mechanism in MP2P networks has a great significance on reducing the number of data transmissions, lowering the power consumption of terminals and increasing the resource utilization of mobile nodes.

2. Literature Review

In recent years, a lot of the investigations on content distribution mechanism in MP2P network have been put forward by research institutions and scholars, focusing on architecture, topology, data processing, etc.

2.1 MP2P architecture

Studies on the MP2P architecture are mainly about adjusting the existing P2P architecture to adapt to the mobile environment. Most of them focus on the centralized and hybrid network architecture [2]. Centralized architecture has quite a few advantages in management and controlling. However, the maintenance cost increases with the network expanding, and the centralized structure is vulnerable [3]. Hsiao [4] and Zeng [5] revealed that structured network can effectively reduce the redundant information in the network, and enhance the scalability of P2P networks when using distributed hash table to locate and search. At present, most commercial MP2P systems are based on the hybrid structure, which has improved the performance of the network to a certain extent. When the users are heterogeneous in the network, the hybrid structure combines the advantages of both centralized architecture and structure network [6, 7]. A fully distributed network was raised by Li [8], which indicated that the structured, hybrid and fully distributed architecture prefer to choose mobile devices to provide services like a server. However, considering the computing power and energy of mobile devices, it is unreasonable that the mobile nodes perform much control and computing tasks. Moreover, the mobile access technology is controlled by the Internet Service Provider (ISP), therefore, choosing a controlled network architecture is necessary for MP2P. Although this type is propitious to management, it also causes some load to the server. With the development of cloud computing technology, the great storage ability and computing power can solve the above problems properly. Consequently, a cloud-assisted architecture on MP2P network was introduced in this paper.

2.2 Data transfer topology

The proposed data transfer topology can be classified into two categories: mesh-based topology and tree-based topology. The robustness of mesh-based network topology in the mobile environment is better, which can be used for large-scale real-time content distribution [9]. While the tree-based network topology can effectively decrease the redundancy of information [10]. For example, Lai [11] proposed a Heterogeneity-Aware Overlay Technique (HOT) mechanism to create an improved tree-based network topology whose goal was to make the system has a lower average delay, less information and less load.

2.3 Data processing

In the data processing, the random pieces' selection strategy and rarest-first algorithm are both classical algorithm [12]. While energy consumption can be reduced through the introduction of network coding [13]. Bassoil [14] pointed that the pieces' selection algorithm could be simplified to improve the network resource utilization if the network coding technology is applied in P2P content distribution mechanism. Damla [15] and Sprintson [16] exploited broadcast performance for data transmission of MP2P, and implemented the network coding in it for the promotion of network throughput and bandwidth utilization.

In summary, although these studies have made some contributions on improving the efficiency of content distribution of MP2P, there are still some problems: 1) When the nodes are downloading data, they prefer to request data from some stronger or fixed nodes, which lacks cooperation among users to fully utilize each node's resources. 2) The same requests will produce redundancy, which does not take the capability of a node into consideration. Yan [17] proposed an extended network model with constant node density, which is more realistic for the MP2P network. It is the most relevant work regarding technical approach, but there are several key differences in this paper: 1) The heavy computation load of the mobile nodes were offloaded to the cloud by introducing the cloud-assisted architecture. 2) A multi-tree structure of internal node disjointed (MTSIND) method was proposed to construct the data transfer topology to make more nodes participate in the content distribution. 3) The exclusive-OR (XOR) network coding based on vertex coloring theory was introduced to deliver the data packets, which would reduce the total number of data transmissions.

The rest of this study is organized as follows. Section 3 describes the cloud-assisted architecture of MP2P network and discusses the content distribution model and the distribution strategy under this architecture. Simulations and analysis are presented to support the results in Section 4. Finally, conclusions are drawn in Section 5.

3. Methodology

3.1 Cloud-assisted MP2P architecture

In mobile networks, the nodes that have same attributes like social interest or geography position, can be arranged in the same group by some grouping strategies. These nodes may share the same demand, for instance, they may demand the same content from the Internet. In this case, they can cooperate with each other to download different sub-content, and work as peers to exchange these sub-content, until each one of them get the entire content. But due to the limited capability and battery, the complex tasks such as scheduling the sub-content sharing and computing the transfer topology in mobile networks would be great difficulty to perform. So, it is necessary to enhance the capability of the mobile device including the computing ability, storage capacity and the battery working time. Therefore, offloading the complex computing tasks from mobile nodes is the main reason that our cloud-assisted architecture was proposed.

As shown in Figure.1, in this architecture, different mobile devices construct a MP2P network, and they have been divided into various groups according to some certain grouping strategies. The cloud connects to the Internet and the mobile networks for providing the remote services, such as localizing the required content from the Internet and remote computing to mobile nodes. We assume that each node has already downloaded some sub-content from the cloud, and all of which would be added to the whole content that they need. Each node with partial content will exchange data packets with its neighbors until all of the nodes get the entire content.

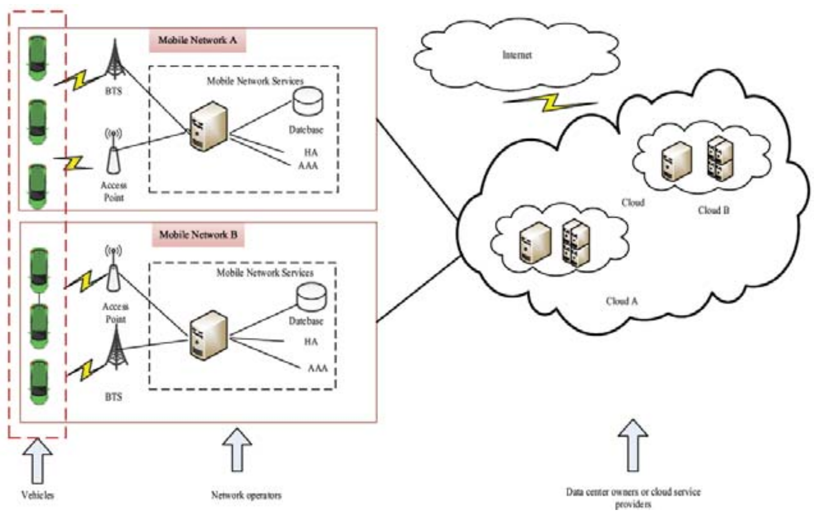


Figure 1. Cloud-assisted Architecture of MP2P

3.2 MTSIND topology construction process

To encourage each node to participate in the content distribution, rather than just delivering or receiving the data content, the MTSIND data transfer topology was put forward. The so-called internal node disjoint is that, N trees are constructed by nodes based on the number of segments the file that has been divided into each group. Each node plays different roles in trees: the node responsible for the delivery of data when it is used as an internal node of a particular tree, and when it is used as a leaf node of the other $N-1$ trees, it responsible for receiving the data.

In order to mitigate the topology computation and the sub-content scheduling burden of the nodes, the cloud divides a file into *N* segments with several data pieces (in this paper we call data or data packages), and each tree transfers data pieces of one segment. The idea of file segmentation is not only for the consideration of the establishment of a multi-tree topology, but also for the consideration of the data processing by using network coding, which aims to fulfill the data sharing in a small area as soon as possible.

Figure.2 gives an example of a MTSIND topology that constructed by a group of 9 nodes. The whole content is divided into four segments, and each tree responsible for sharing the segment content among its internal nodes and then sharing with other trees.

To formalize the description above, we first introduced two binary variables:

δ_{vmk} denotes whether the node v is an internal node in the tree m and at the $k\,th$ layer, and if $\delta_{vmk}=1$ representing that node v is an internal node at a layer k in tree m.

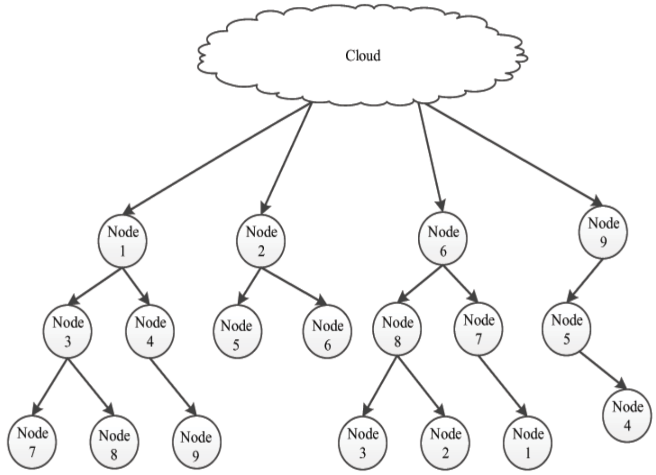


Figure 2. The topology of multi-tree that inner nodes disjoint

θ_{vmk} denotes whether the node v is a leaf node in the tree m and at the k th layer, and if $\theta_{vmk}=1$, representing that node v is a leaf node at a layer k in tree m.

Then the multi-tree topology of internal node disjoint can be defined as:

$$\sum_m \sum_k \delta_{vmk} = 1, v \in V \qquad (1)$$

$$\sum_k (\theta_{vmk} + \delta_{vmk}) = 1, v \in V, 1 \leq m, \leq \mathrm{M} \qquad (2)$$

Eqs. (1) represents that every node can be an internal node, and Eqs. (2) represents that each node in each tree can just play one role (an internal node or a leaf node).

Assuming that the complete file is divided into M segments, and each segment is divided into n pieces. Then the entire content is divided into X pieces as $\{p_1,p_2,p_3,....,p_{X-1},p_X\}$ respectively, so $X=Mn$. For an arbitrary node v, if it lacks data piece $p_j(1 \leq j \leq X)$, which belongs to the section S_m $(1 \leq m \leq M)$, then v will appear in the tree m. In other words, if one certain node is lack of data pieces in a certain segment, then it will become a member of a tree which is in the data segment, so each tree has a node set, represent as T_i $(1 \leq i \leq M)$. Now, it is necessary to discuss how to connect the node in the T_i to construct a tree and finally, the form of the constructed M trees is the internal node disjoint multi-tree.

As mentioned above, when a node joins in the system, it needs to register in the cloud center, reporting itself ability resources to a cloud server (including computing, CPU, storage, etc.) firstly. At the same time, it also needs to report its owned data piece to the cloud regularly. With the resource information of the nodes, the cloud could build topology.

In [18], it has already pointed that, in the creation of the single tree, nodes with high ability should be closer to the root server. However, nodes with high ability in the upper layer may own no data, which would be unable to provide data to the nodes that have lower ability. Therefore, the tree should be built by considering both the ability of a node and the number of data piece in this paper.

The Equation to characterize each node in T_j is:

$$r_{ji} = \alpha \times a_i + \beta \times c_{ji} \qquad (3)$$

Where, a_i and c_{ji} represents the ability of node i and the amount of data it owns in section j respectively, $0 \leq \alpha, \beta \leq 1$ and $\alpha + \beta = 1$. For each tree, it owns a node set T_j, and also a characterization value set $TR_j = \{r_{j1},r_{j2},...,r_{jn}\}$ is owned, in which, $1 \leq n \leq N$, and N represents the total number of nodes. After get these characterization set, the characterization value in the TR_j will be sorted in descending. Then, according to the arrangement TR_j, a corresponding node set arrangement TV_j can be achieved. Arranging the nodes in TV_j to each line of the tree in order according to the sorted maximum number of connections of them. Finally, each tree's each layer can be determined. The purpose of descending order is to arrange nodes that with stronger ability to the upper layer, so that they can complete data sharing as soon as possible, and provide service for more nodes.

3.3 XOR network coding based on data processing

After establishing the multi-tree topology, another problem is to reduce the number of data transmissions in the whole network. Here, XOR network coding is used to improve the efficiency of content distribution. XOR is a kind of random network coding whose coding coefficient is 0 or 1, thus its codec is easier and occupies less computing resources. Its encoding complexity is $O(X)$, which is same as network coding with random coefficients, nevertheless, its decoding complexity is reduced to $O(X/M)$. After the file is cut into M segments, the encoding complexity becomes to $O(X/M)$, as well as the decoding complexity.

Let $G = <V,E>$ be a simple undirected graph and S is a set of vertices $(S \subseteq V, S \neq \varnothing)$. If any two vertices in S are not adjacent, then this vertex set S is called the independent set of graph G. Furthermore, if any increase of a vertex would break its independence, the independent set S will be a maximum independent set.

This paper utilized the above concept to establish the *XOR* network coding model to classify the data pieces owned by nodes, i.e. to decide which pieces should be grouping into a coded packet to deliver together. It should be noted that nodes can decode the packets immediately with the precondition that the node who receives the encoded packet has all the other data pieces expect a certain one. The detail introduction of this *XOR* network coding model is as follows:

Suppose there is a set of users $C = \{c_1, c_2, ..., c_n\}$, the set of entire file pieces (that is owned by the father node) is $P = \{P_1, P_2, ..., P_m\}$, we define $L(p_j) = \{c_i \mid$ the receiving node c_i that missing the piece P_j, $1 \leq i \leq n\}$.

Then, the graph $G = < V,E >$ can be built base on the following standard:

$$V = \{ V_j \mid W(p_j) \neq \varnothing, 1 \leq j \leq m \} \quad (4)$$

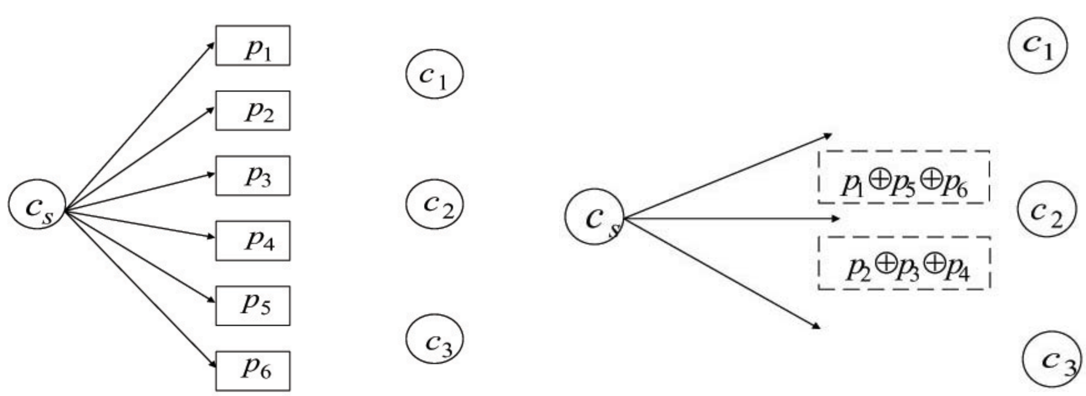
$$E = \{(v_i, v_j) \mid W(p_i) \cap W(p_j) \neq \varnothing, v_i, v_j \in V\} \quad (5)$$

Eqs. (4) means that as long as there is a child node lack of a certain piece, the piece will exist as a vertex, and Eqs. (5) means if the node missing pieces p_i and p_j at the same time, the pair of these two pieces will exist as an edge.

In graph G, the maximal independent set expresses there are no nodes that lack two different pieces of the set simultaneously. Encoding all the piece pairs in the set, then any node that has received the coded packet can decode it to the desired data pieces. Thus, the encoding problem is converted to find out the maximal independent sets of pieces disjoint, which means that the entire pieces can be divided into several maximal independent sets. Thus the problem becomes a vertex coloring problem. It can prove that the number of encoded packets will not exceed the maximum number of data pieces, which are absented by all the lower layers' child nodes. Hence, nodes can take advantage of *XOR* coding to encode data pieces

Suppose $G = < V,E >$, $V = \{v_1, v_2, ...v_x\}$, The code sets are C, R is an empty set, I is packets number	
1.	*Sort the degree of nodes $\Delta(v_i)$, get a descending node arrangement set V', $V' = \{V'_1, V'_2, ..., V'_x\}$*
2.	$k = \lvert V' - R \rvert$, $k = \lvert V' - R \rvert$, $i = 1$
3.	$v'_1 \in C_i$
4.	*for* ($j = 2$; $j \leq k$; j+ + begin
5.	*if* v'_j is adjacent *to elements in* C_i *do*
6.	add v'_j *to* C_i *and* R
7.	*end if*
8.	*if* $V' - R \neq \varnothing$ *do*
9.	*let* $i=i+1$, *then go to step*
10.	*end if*

Table 1. The encoding algorithm



(a) no network coding (b) with network coding

Figure 3. Two-layer tree to deliver data pieces

to reduce the number of data transmissions. The specification of the coding algorithm is shown in table.1.

Figure.3 gives an example of a two-layer tree that constructed by four nodes, where c_1, c_2 and c_3 are children of the node c_s, and in Table.2, the value 0 or 1 represents whether a node c has the data piece P respectively, where 0 corresponds node c has data piece P, and vice versa.

The father node c_s requires six times to send the total data pieces to its children nodes as shown in Figure.3(a), while in Figure.3(b), it shows that c_s only needs two times to complete this process when the *XOR* network coding mechanism is introduced, due to $p_1 \oplus p_5 \oplus p_6$ and $p_2 \oplus p_3 \oplus p_4$ can be chosen as coded packets.

Parameter	p_1	p_2	p_3	p_4	p_5	p_6
c_1	0	1	0	0	0	1
c_2	0	0	1	0	1	0
c_3	1	0	0	1	0	0

Table 2. The data pieces a node lacks

To reduce the number of data transmissions, it just needs to find out the maximal independent sets of graph G base on our vertex coloring method. As shown in Figure.4, graph G contains two maximal independent sets, $\{v_1, v_5, v_6\}$ and $\{v_2, v_3, v_4\}$, which corresponding to $p_1 \oplus p_5 \oplus p_6$ and $p_2 \oplus p_3 \oplus p_4$ respectively. The maximal independent sets could also be $\{v_4, v_5, v_6\}$ and $\{v_1, v_2, v_3\}$, which corresponding to $p_4 \oplus p_5 \oplus p_6$ and $p_1 \oplus p_2 \oplus p_3$ respectively. Finally, it just needs to choose one of the above combinations according to the coding strategy.

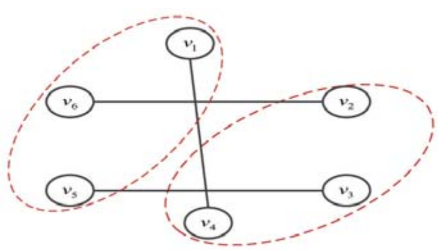


Figure 4. XOR network coding based on vertex coloring

4. Simulation Expertments And Analysis

4.1 Simulation experiment

This paper analyzed the performance of the content distribution mechanism in MP2P networks based on XOR Network Coding (XNCT) by the number of data transmissions, transmission power consumption and the time consumption, and the experiment is based on the Eclipse environment and the Global Positioning System (GPS) [19] platform.

The graph.alt configuration files were applied to create a real underlying topology, including the ID and the coordinate position of the access points of Internet and the mobile users. The access point is denoted by p, and the mobile node is denoted by c, the bandwidth between p nodes is 100Mbps, and the delay is 10ms, whereas the bandwidth between p and c is 5Mbps, and the delay is proportional to the distance between them.

Table.3 sets simulation parameters about the network and the downloaded contents.

Parameter	*Value*
Number of nodes N *(piece)*	*50,100,150,200,300,500*
the whole file size P *(MB)*	*50,100,150*
the file pieces' size P *(KB)*	*256*

Table 3. The simulation parameters setting

4.2 Analysis of simulation experimental results

4.2.1 The number of data transmission

The number of data transmission refers to the sum times of delivering data by all the nodes in the network during the general process of content distribution. This section shows the simulation results of downloading a 100MB file under the different scales of network, and compares the results of our solution XNCT with other algorithms: RANDOM-based algorithm and Random Linear Coding (RLC)-based algorithm [20].

Figure.5 shows the total number of transmissions with different scales of network. In Figure.5, the total number of data pieces transmissions increase with the growths of the network size. RANDOM is largest, since it leads to a lot of redundancy information, whereas network coding can avoid repeated transmission. RLC will encode all pieces the node owns, thus the node has to decode enough data pieces that are linearly uncorrelated to achieve the original pieces, while the XNCT can decode the combination immediately. Therefore, the number of transmissions of XNCT is less than RLC's.

As shown in Figure.6, we have simulated the number of transmissions when a 150MB file is being downloaded by 50 nodes and the entire file is divided into different numbers of the segment. The horizontal axis is the scale of the network, and the vertical axis means the total number of transmissions, and different colors represent the different number of the segment. The result reveals that the number of transmissions decrease with the increase of segments, for the reason that when the number of nodes participate in coding is raised, the opportunity of coding is also increased, which reduce the total number of transmissions. Note that when the number of the segment is three, the effect becomes more obvious. It is due to the nodes who hold the information will influence the downloading process when they leaving the network, which increases the complexity of maintaining the topology. In other words, the online time of nodes affects the efficiency of transmission.

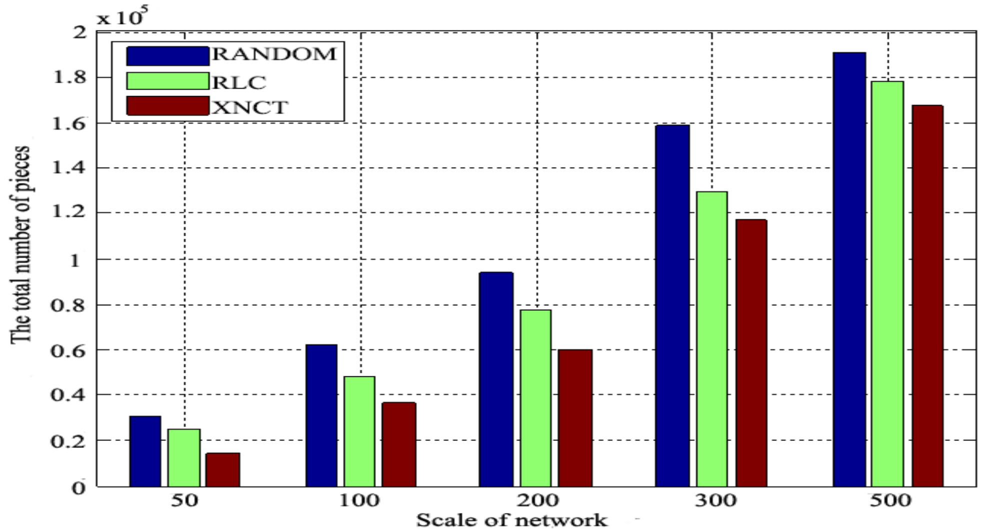


Figure 5. Total number of transmissions comparison

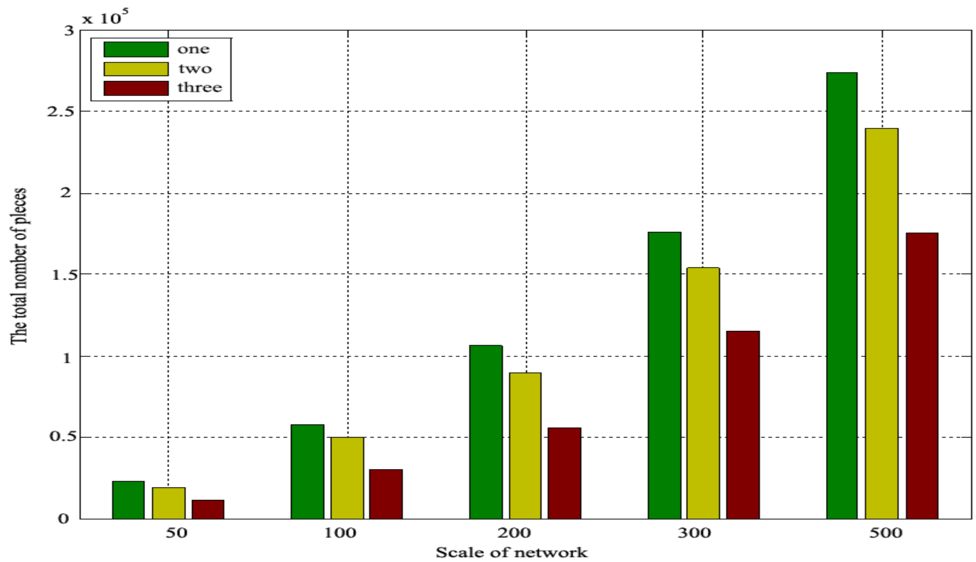


Figure 6. Total number of transmissions comparison with different numbers of the segment

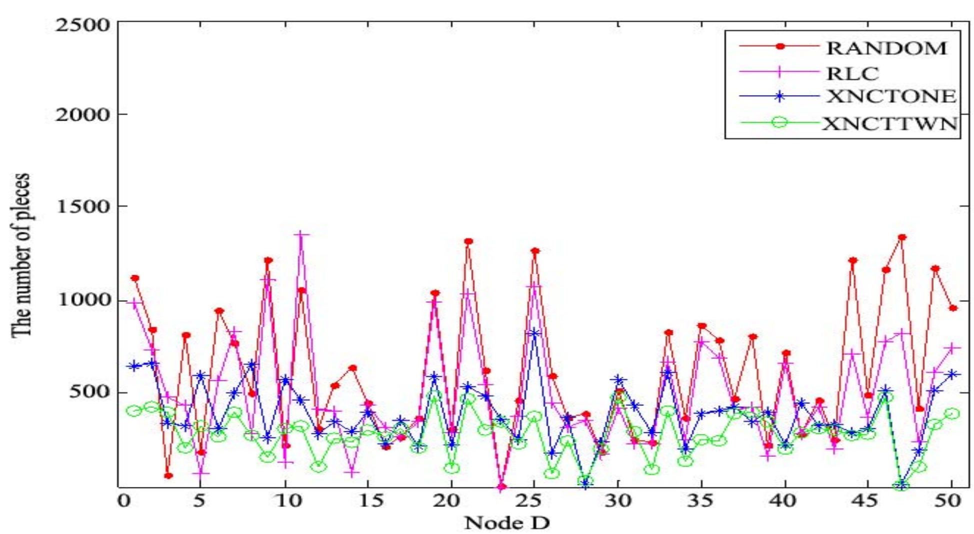


Figure 7. The number of data transmissions comparison of a single user

Figure.7 describes the number of data transmissions of each node under the scenario of 50 nodes sharing a 100MB file. The x-coordinate represents the node ID, and the y-coordinate represents the transmission number of a node. As shown in this figure, the numbers of data transmission in RLC and RANDOM are both bigger. In addition, their trends of amplitude are more or less alike, and the values are big. In our algorithms, they follow the relatively smooth curves, which due to the reason that more nodes take part in forwarding information. The results prove that our algorithm can indeed encourage more users to contribute their resources.

4.2.2 The energy consumption of data transmission

The energy consumption of data transmission refers to the total energy consumption for completing the file sharing. In our strategy, tree-based topology is a multi-hop topology, the failure of some nodes would affect the quality of the performance, and mobile nodes are energy constrained devices.

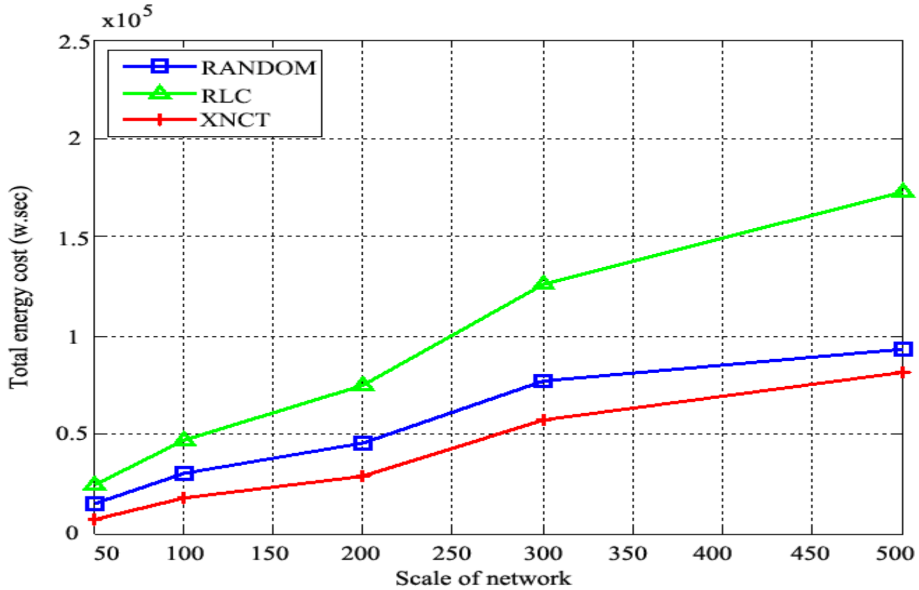


Figure 8. The total energy consumption

Figure.8 plots the total energy consumption under different network size, the horizontal axis represents the scale of the network, the vertical axis is the total energy consumption, and different curves represent different algorithms. This graph clearly shows XNCT can reduce the power consumption, due to network coding can compress the data. The packet size of RLC algorithm is largest, and the energy consumption is proportional to the size of the packet, so RLC algorithm causes highest energy consumption. On the other hand, RANDOM

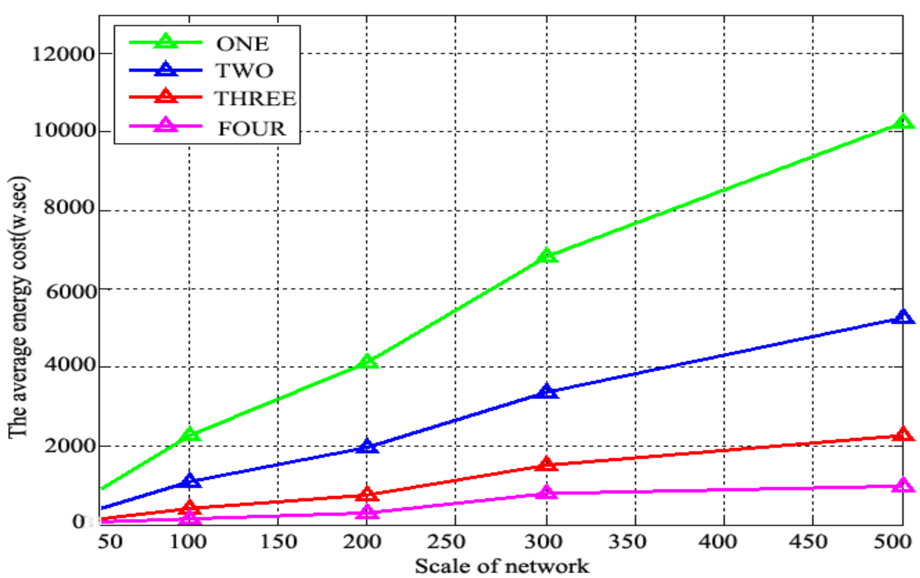


Figure 9. The average energy consumption with different numbers of the segment

algorithm uses point to point transferring, which generates massive redundancy in the network. Therefore, its energy consumption is also higher than ours.

Figure.9 represents the relationship between segment numbers and energy consumption, the horizontal axis is the network size, the vertical axis is the average energy consumption, and different curves mean the file is divided into different numbers of the segment respectively. According to the picture, the energy consumption is decreased with the increase of the segments. This trend can be explained by some factors: First of all, the number of data transmissions decrease with the increase of the numbers of the segment. Secondly, the size of encoded packets decreases with the increase of the numbers of the segment.

4.2.3 Time consumption

The time consumption represents the period of the data pieces' exchange until all the nodes obtain the full file content. Figure.10 shows the cumulative distribution function of file distribution time under different algorithms. The horizontal axis is the Cumulative Distribution Function (CDF) and the vertical axis is the average energy consumption. We can draw the conclusion that the RANDOM and RLC algorithms cost less time than our XNCT algorithm. The reason may be that our algorithm costs much time on the maintenance of the multi-tree, the construction of the XOR network coding matrix, and the computation of the node weight, all of which may require time consumption additionally.

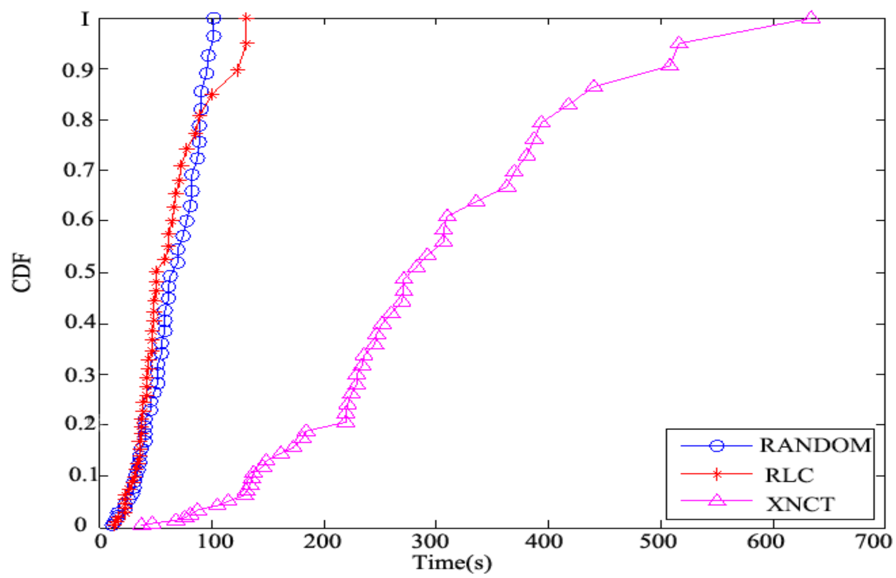


Figure 10. Cumulative distribution function of content distribution time under different algorithms

5. Conclusion

To enhance the capability of the mobile terminals and improve the content distribution efficiency in MP2P network, a cloud-assisted content distribution mechanism was proposed, whose specific process is as follows: First, to release the complex computation load of the mobile nodes, the system leveraged the cloud-assisted server to offload the nodes' overload to the cloud. Second, data segments were transmitted among mobile nodes, and the MTSIND data transfer topology were constructed to incentive more nodes to participate into the content delivery tasks. Finally, the XOR network coding were established based on vertex coloring method to reduce the number of data transmissions and power consumption. The following conclusions were obtained:

(1) MP2P content distribution architecture is exploring: Compared with RANDOM and RLC, the total energy consumption of the proposed mechanism is reduced by more than 50% and 70% respectively.

(2) The cooperative data transfer topology MTSIND: The number of data transmissions among different nodes is less when the tree-based MTSIND data transfer topology is used, which means that the proposed cooperative strategy can indeed promote more users to contribute their resources, and the effect becomes more apparent when the number of trees increases.

(3) Energy consumption: The total number of data transmissions in our proposed mechanism is significantly less than that of the RANDOM and RLC methods, when XOR network coding method is used under a certain network scale.

We have shown that building such a cloud-assistant MP2P content distribution scheme is not only feasible but also introduces limited overhead regarding mobile terminal power consumption, data transmission. Moreover, this architecture can be incrementally deployed. However, there are still many deficiencies in our mechanism, and the proposed algorithm should be improved for the further improvement. For instance, the simulation environment is ideal, and the influence of real physical topology on data transferring hasn't been considered. In the future, these problems will be taken into consideration. Additionally, when we analyzed the energy consumption, the session process among the nodes and the sessions between node and cloud hasn't been considered, so further analysis is required to study the mobile terminal's energy consumption in the future.

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