ACSIJ Advances in Computer Science: an International Journal, Vol. 3, Issue 6, No.12 , November 2014
ISSN : 2322-5157
www.ACSIJ.org

A Game Theoretical Interest Forwarding for Cached Data in Content-Centric Networking

Chengming Li[1] and Koji Okamura[2]

[1,2] Department of Advanced IT, Graduate School of ISEE, Kyushu University
Hakozaki 6-10-1, Higashi-ku, Fukuoka, Japan
Chengming.li.dut@gmail.com

[2] Research Institute for Information Technology, Kyushu University
Hakozaki 6-10-1, Higashi-ku, Fukuoka, Japan
oka@ec.kyushu-u.ac.jp

Abstract

Content-Centric Networking (CCN) has recently emerged as a clean slate approach to rethink Internet foundations, which changes from host-centric communication model to content-centric. It is common that the current router does not have all the information of cached data in network, because of the huge naming space and volatility of Content Store in each router. In this paper, we argue that it is necessary to supplement CCN with mechanisms to make multiple Interests forwarding for cached data. Our goal is to maximize the residual capacity in the network so that users can get the maximum payoff in a definite network situation. We proposed a game theoretical Interest Forwarding Decisions to analysis the properties of user behavior. Evaluation results prove that our proposals improve user's payoff in the light load case for content-centric networking.

Keywords: *Game Theory, Nash Equilibrium, Content-Centric Networking, Interest Forwarding Decisions.*

1. Introduction

The architecture of today's Internet is originally designed as a communication model that is a conversation between exactly two machines. However, content traffic has been increasingly prevalent in the Internet. Some video content providers (CPs, e.g., YouTube and Hulu) have even begun to provide high-definition video streaming services. As demand for highly scalable and efficient distribution of content increases, the TCP/IP architecture may reveal its inefficiency in delivering time-sensitive multimedia traffic [3]. It now mostly serves content-centric applications, e.g., Content Distribution Networks (CDNs) [11] and P2P. The Internet architecture has evolved substantially from host-centric communication model to content-centric model.

There are a number of proposed architectures for Information-Centric Networking (ICN) including the Publish Subscribe Internet Routing Paradigm (PSIRP) [8], the Network of Information (NetInf) from the Design for the Future Internet (4WARD) [4], the Cache-and-Forward Network Architecture [5], the Data Oriented Network Architecture (DONA) [7], and the Content Centric Networking (CCN) [6].

Content-Centric Networking (CCN) (It is also called Named Data Networking) [18] is designed inherently to focus on content distribution rather than host-to-host connectivity. CCN retrieves a content object by its name, instead of its storage location in order to address IP network's limitations in supporting content distribution. This change, decoupling content from hosts at the network layer, has several attractive advantages, such as network load reduction, low dissemination latency and energy efficiency.

It is a challenge that how to efficiently utilize the cached data. In some cases, the content objects are so many that the CS cannot efficiently manage them, which may result in poor caching performance. Forwarding Information Base (FIB) of routers cannot contain all the content as the huge naming space; and as the content cached in Content Store of routers is changing frequently, it is very difficult to update the FIB in time for all content objects in the network. Thus, it is a problem that how to search the cached data efficiently.

Forwarding strategy is a key component in CCN nodes that makes them more powerful than their IP counterparts. Routing of IP network is to calculate a single shortest path for each pair of source node and destination node. The forwarding strategy layer in a CCN node can dynamically select multiple interfaces from the FIB to forward a same Interest packet. Single shortest path can be a candidate forwarding strategy for CCN. However, it cannot perform well as it runs in end to end communication network. In end to end communication network the destination node is definite, but in CCN a content object can have multiple destination nodes (it can be a router) by the form of replicas.

It is necessary to supplement CCN with mechanisms making the Interest forwarding decisions. In the case of sufficient network resources, delivering the Interest packet to multiple interfaces derived for FIB can achieve following advantages:

- The real-time decision enables nodes to fully utilize their rich connectivity and get the best users' payoff;
- It defends against route hijacking attacks (if no data returns over a particular interface for a particular name, that interface may not lead to a valid path for that name);
- It enhances the network instability (frequent oscillation of paths) while maintaining good data delivery performance.

In this paper, we proposed a game theoretical Interest multiple forwarding decisions method to maximize the users' payoff and network's payoff.

The rest of this paper is organized as follows. Background and related work are given in Section 2. Section 3 presents the non-cooperative game analysis for Interest multiple forwarding problems. Section 4 presents simulation setting and simulation results. Section 5 concludes the paper.

2. Background

2.1 Content-Centric Networking

CCN design assumes a name may be viewed as a hierarchical structure of byte strings, e.g., a movie produced by Youtube may have the name "/Youtube /movies/Example.rmvb". A node in CCN contains three data structures: the Content Store (CS), the Pending Interest Table (PIT), and the Forwarding Information Base (FIB) [18]. The structure of a CCN FIB is similar to that of an IP FIB except that CCN allows a match to multiple outgoing links. In addition, a longest-prefix match in FIB uses a content name instead of an IP address.

Communication in CCN is driven by the receiving end, i.e., the data consumer. To receive data, a consumer sends out an Interest packet which carries a name that identifies the desired data. When the Interest Packet arrives at a CCN router, the node consults the CS, PIT and FIB in sequence. The router first checks whether the data requested have already been cached in the node's Content Store (CS) which is used to store the coming data packet by a cache replacement policy. If there is no matched data, the router will check whether the PIT has included the same Interest. In PIT, each entry contains the name of Interest and a set of interfaces from which the Interest packets have been received. If the PIT already has contained the same Interest, then the node adds the Interest coming interface to the corresponding entry of PIT. Finally, the node remembers the interface from which the request comes, and then forwards the Interest packet by looking up the name in its FIB, which is populated by a name-based routing protocol.

Once the Interest reaches a node which contains the requested data, a Data packet, which carries both the name and the content of the data, is sent back together with a signature signed by the producer's key. This Data packet trace in the reverse path created by the Interest packet back to the consumer.

2.2 Game Theory

John von Neumann and Oskar Morgenstern established game theory as a separate field of science when they published their book in 1944[17]. Since then great strides have been made in this area, mainly in the field of economics and biology. However, game theory can also be applied to many fields of science, where decision makers have conflicting interests. Thus, it comes as no surprise to read papers related to networking that adopt game theoretical concepts to analyze a protocol's performance or propose a solution that corresponds to a Nash Equilibrium (NE) set of strategies [2][12].

Game theory could be defined as "the study of mathematical models of conflict and cooperation between intelligent rational decision makers" [9].

A game consists of a principal and a finite set of players $N=\{1, 2, \ldots, N\}$, each of which selects a strategy $x_i \in X_i$ with the objective of maximizing his utility u_i . The utility function $u_i(s) : X \rightarrow R$ represents each player's sensitivity to everyone's actions. People or entities (decision makers in general) who play the game are called the players.

A strategy for a player is a complete plan of actions in all possible situations in the game. The players try to act selfishly to maximize their consequences according to their preferences. The set of player *i*'s possible actions is called the action space X_i of player i .

Two types of games are distinguished: one is non-cooperative games in which each player selects strategies without coordination with others. The other is cooperative games in which the players cooperatively try to come to an agreement, and the players have a choice to bargain with each other so that they can gain maximum benefit, which is higher than what they could have obtained by playing the game without cooperation [5].

In a static game, the players make their decisions simultaneously at the beginning of the game. In a dynamic or sequential game, the players interact with each other, and they do not decide simultaneously, but they follow a sequence. If the interactions are repeated in time, the game is called repeated, and each interaction corresponds to a stage of the game. In this case, the players have the opportunity to modify their strategies over time.

The equilibrium strategies are chosen by the players in order to maximize their individual payoffs. In game theory, the Nash Equilibrium is a solution concept of a game involving two or more players, in which no player has anything to gain by changing only his own strategy unilaterally. If each player has chosen a strategy and no player can benefit by changing his strategy while the other players keep theirs unchanged, then the current set of strategy choices and the corresponding payoffs constitute a Nash Equilibrium.

One of the first papers that applied game theory to the problem of routing was [10]. They consider a communication network shared by several selfish users. Each user seeks to optimize its own performance by controlling the routing of its given flow demand, giving rise to a non-cooperative game. For a two-node multiple links system, uniqueness of the Nash Equilibrium is proven under reasonable convexity conditions.

Based on the above models for the general network, Altman et al. in [1] provided the necessary conditions in order for the NE to be unique and make the polynomial cost structure attractive for traffic regulation and link pricing in telecommunication networks. They considered a class of polynomial link cost functions adopted originally in the context of road traffic modeling, and showed that these costs have appealed properties that lead to predictable and efficient network flows.

In contrast to previous works, authors in [15] considered the cost function in a multiplicative way and assumed that the cost function is an additive combination of the objectives of routing, namely the maximization of throughput and the reduction of the delay.

3. Design

In this section, we firstly analysis the problem, then construct a game theoretical model to solve it. At last, we proposed Potential Heuristic Allocation for System.

3.1 Problem Description

Forwarding strategy layer, a key component of CCN nodes, make them more powerful than their IP counterparts. Routing of IP network is just to calculate a single shortest path for each pair of source node and destination node. In contrast CCN inherently supports multiple same Interests forwarding simultaneously. The forwarding strategy layer in a CCN node can dynamically select multiple interfaces from the Forwarding Information Base (FIB) to forward an Interest packet.

The simplest strategy is to send an Interest to each interface of a FIB entry in sequence. If there is no response to the Interest, then try the next interface. Single shortest path can be a candidate forwarding strategy for CCN. However, it cannot perform well as it runs in end to end communication network. In end to end communication network, the destination node is definite, but in CCN, a content object can have many destination nodes (it can be a router) by the form of replicas. Thus, sometimes the shortest path record in FIB is not real shortest path for a content object. It is very difficult to update the FIB in time for all content objects in the network because of the huge content name space, especially in chunk level.

We can also send Interests on all the interfaces at once and see which interfaces receive data first. These interfaces will be used for a period of time and their performances are monitored. If we do it for all the Interest packets, it can make the network overload and congestion easily.

A more flexible design is each FIB entry containing a program specialized to make Interest multiple forwarding decisions. In this section, we present the game theoretical Interest multiple forwarding decisions method to solve this problem. The goal of our proposals is fully utilizing the residual capacity in the network so that users can get the maximum payoff in a definite network situation.

3.2 Gaming Analysis

The hierarchical CCN naming convention described in Section 2.1 lends itself to the identification of flows. A CCN flow consists of packets bearing the same object name [19]. In a node of CCN, a set of flows I share a set of parallel paths represented by faces F . Each $F_i \in F$ has a queue length limit on how fast Interest packets can be forwarded over a face and experimented with a simple calculation of the Interest rate limit: $|F_i| = \alpha \times \mathrm{C_i} \div \overline{\mathrm{S_i}}$ proposed in [20]. $|F_i|$ represents the maximum queue length of face *i* in node; C_i is the upstream link capacity of face *i*; $\overline{S_i}$ is an estimate of the size of the Data packets that have been received over *i*, and α is a configurable parameter. Here we define *X* as the total queue length (total available resources) in the node and X_0 as the queue utilization caused by all background traffics. |*F*| denotes the number of total faces in node.

$$X=\sum_{i=1}^{i\le|F|}|F_i| \qquad (1)$$

Each $I_i \in I$ aims to minimize the individual cost and maximize the utilization selfishly by deciding the multiple forwarding degree x_i. F^i is the set of faces for Interest $I_i \in I$, through which the Interest I_i can reach the repository nodes with H hops. We can get F^i from the FIB table of node. The multiple forwarding decisions problem models as I_i selecting the subset $f^i \subset F^i, f^i \ne \varnothing$ to get the best cost. The network model is described in Fig.1.

In our model, the game players are considered as flow *I*. Set the player i using the node resources as $x_i \in X_i$. X_i is a collection of node resources may be occupied by player i . X_i is strategic space of player i . When only discuss faces without considering other types of node resources, x_i is the multiple interfaces f^i used by player i . In our model, we define the $x_i = \{x_i \mid 1 \le x_i \le |f^i|\}$ simply. For an Interest of I flow, we can get the f^i from FIB table in CCN. In FIB table, the interfaces are sorted by the hops which present the distance from the node to repository. The face for an Interest with minimum hops has the highest priority to be selected. The Interest forwarded by the shortest path is called **main Interest**, correspondingly, the Interests forwarded by longer path are called **replica Interest** in this paper. Here, we consider the strategic space as continuously divisible to guarantee the Nash Equilibrium existence.

3.2.1 Payoff function

The Payoff Function of player i specifies the total gains of player i when it takes action x_i , which is a kind of variable showing the worth achieved by players using the node resources.

The general form of Payoff Function consists of two parts: $Payoff = Benefit - Cost$ [21]. Thus, the payoff function U_i of player i is defined as:

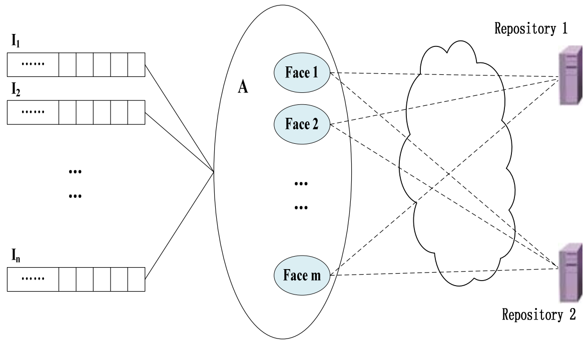

Fig. 1 Network Model.

$$U_i(x_i, X_{-i}) = Benefit_i(x_i, X_{-i}) - Cost_i(x_i, X_{-i}) \qquad (2)$$

Here, x_i denotes the Interest multiple forwarding degree. When there are no external controls, utility function stipulates the gain of player i when it takes action x_i . Due to the related form of action in the game, the utility function of player i is not just the function of x_i , but also is the function of other players.

Denote $X = (x_1, \cdots, x_i, \cdots, x_n)$ as the vector constituted by all the players' actions, and $X_{-i} = (x_1, \cdots, x_{i-1}, x_{i+1}, \cdots, x_n)$ as the vector constituted by other players' actions except user i . Then the utility obtained by player i is $U_i(x_i, X_{-i})$, can also be abbreviated as $u_i(X)$. The utility function of player i is the mapping from the set of action X_i to the set of real number R^1 , $u: X_i \to R^1$, which defines the preferences of players on the set of actions. For all $x, y \in X_i$, if and only if $U(x) > U(y)$, players prefer the action x than the action y .

Here we assume that $|F^I|$ is continuously divisible, and can be represented by a real number. Strategic space X_i is the real axis of a non-empty closed space and is a non-empty compact convex set. It is used to guarantee the Nash Equilibrium existence. Actually, the players do the action by the rounding of x_i in the simulation section.

We define the *Benefit* function of player i as:

$$Benefit(x_i, X_{-i}) = t_m \times P_i \times (x_i - 1) \qquad (3)$$

Here, the t_m denotes unit time gain for player *i* doing the action of sending replica Interest; P_i represents the probability of a replica Interest retrieving a cached data faster than main Interest. The purpose of players who send replica Interests is to more stably retrieve the data faster.

ACSIJ Advances in Computer Science: an International Journal, Vol. 3, Issue 6, No.12 , November 2014
ISSN : 2322-5157
www.ACSIJ.org

We use $t_m \times P_i \times (x_i - 1)$ to denote the estimated benefits for players who send $x_i - 1$ replica Interests.

Cost function specifies the punishment given to players from the network when player i takes action x_i. The Cost function is defined as:

$$Cost\left(x_i, X_{-i}\right) = t_q \times \frac{x_i}{\sum x} \times e^{(\sum x + X_0)/X - 1} \tag{4}$$

Where the t_q denotes unit time cost for queuing because of player i doing the action of sending replica Interest; In this expression, the deterministic term $1/X - (\sum x + X_0)$ represents the expected congestion delay on a link for an M/M/1 delay function [22]. We use $e^{(\sum x + X_0)/X - 1}$ to express the normalized queuing time factor and adopt $\frac{x_i}{\sum x}$ to present the proportion of queuing time for player *i*.

From the network's perspective, the nodes adopt some mechanism to transport packets efficiently and fairly. Usually the nodes use Max-Min fair queue to implement transmission fairly. We also proposed a Potential Heuristic queue method to consider efficiency and fairness in Section 3.3.

Thus, the utility function can be described as following:

$$U_i\left(x_i, X_{-i}\right) = t_m \times P_i \times (x_i - 1) - t_q \times \frac{x_i}{\sum x} \times e^{(\sum x + X_0)/X - 1} \tag{5}$$

U_i is a increasing function of x_i and it is diminishing marginal returns. A higher x_i does not necessarily yield better performance for player i. On the condition of $\sum x \le X$, user can get an optimal $\overline{U}_i$ to meet $\frac{\partial \overline{U}_i}{\partial x_i} = 0$ through adjusting x_i. The unilaterally optimizing behaviors of user i meet:

$$\frac{\partial Benefit_i}{\partial x_i} = \frac{\partial Cost_i}{\partial m_i} \tag{6}$$

Here, we assume the amount available resources of node is X. The resources allocation accords player's need. We adopt a simple resource allocation method which is denoted as following:

$$x_i = \frac{|F^i|}{\sum_{j=1}^{n} |F^j|} X \tag{7}$$

3.2.2 Nash Equilibria

A NE is a set of strategies where each player has no incentive to deviate, in other words, given the strategies of all other players, if he changes his strategy he can only decrease his utility. More specifically, if x_i is an arbitrary action of player i and X_{-i} is the set of actions of all other players, then the action profile $x^* = \left(x_i^*, X_{-i}^*\right)$ constitutes a NE if for every player i, $U_i\left(x_i^*, X_{-i}^*\right) \ge U_i\left(x_i, X_{-i}^*\right)$, $\forall x_i \in X_i$, $\forall i \in [1, n]$. We set the action vector $x^* = \left(x_1^*, \cdots, x_n^*\right)$ is Nash Equilibrium, then we can get outcome: $U_i\left(x_i^*, x_{-i}^*\right) \ge U_i\left(x_i^*, x_{-i}^*\right), \forall x_i \in X_i, \forall i \in [1, n]$.

The existence of the Nash Equilibrium [9] is constrained as following: In game $G = \left[n, \{x_i\}, \{u_i(\cdot)\}\right]$, the necessary and sufficient conditions of the existence of the Nash Equilibrium is: for all $i = 1, 2, \cdots, n$, there is: i) X_i is a non-empty, compact convex set on Euclidean space; ii) $U_i(x)$ is continuous in the x, and is quasi-concave function of x_i.

The optimal payoff of player i is recorded as $\overline{U}_i$. $\overline{U}_i$ can be assumed as increasing functions of x_i (Allocated more faces, get the greater utility), and meet diminishing marginal returns (the speed of utility increasing reduces with the increase of the forwarding degree x_i):

$$\frac{\partial \overline{U}_i(x_i)}{\partial x_i} > 0, \quad \frac{\partial^2 \overline{U}_i(x_i)}{\partial x_i^2} < 0 \tag{8}$$

$$Max \sum_{i=1}^{n} \overline{U}_i(x_i) \quad s.t. \quad \sum_{i=1}^{n} x_i \le X \tag{9}$$

The solution of our model can be represented as Eq. (9) to solve the maximum value of payoff of all players. Using Lagrange Method of Multiplier for solving, suppose a Lagrangian function $L(x_1, x_2, \cdots, x_n)$ where exits:

$$L = \sum_{i=1}^{n} \overline{U}_i(x_i) + \lambda\left(X - \sum_{i=1}^{n} x_i\right) \tag{10}$$

In which λ is a specific unknown constant. The optimal solution should satisfy the condition that the partial derivatives that L for all unknowns is 0:

$$\frac{\partial L}{\partial x_i^*} = \frac{d\overline{U}_i}{dx_i^*} - \lambda = 0, i = 1, 2, \cdots, n \tag{11}$$

That is:

$$\frac{d\overline{U}_i}{dx_1^*} = \cdots = \frac{d\overline{U}_i}{dx_i^*} = \cdots = \frac{d\overline{U}_n}{dx_n^*} \tag{12}$$

From Eq. (5), we see that the utility function U_i is concave function. Thus, Eq. (12) has unique solution. This solution is the best Interest forwarding decisions.

3.3 Potential Heuristic Allocation for System

In our proposed model, when the node receives a set of Interest flow I with corresponding multiple forwarding decision x_i , how to allocate the queue resources for each player $I_i \in I$ is a key issue. The allocation according to user's need and fairness allocation method are not the best method because that they do not consider the system utility.

Usually, there is no global objective function of networking outcome in our proposed model or other similar models [16]. In order to improve the efficiency of whole networking, we proposed a Potential Heuristic Allocation (PHA) method using for our model. We define the global objectives of networking are 1) considering fairness of each player, 2) maximizing the player's utility and 3) improving the global networking cache hit rate.

The key idea of PHA method is that the Interest i with more potential hit has higher priority to allocate resource. For this purpose, we redesign the FIB table to record some metrics used to calculate the potential values. We add a column into FIB table named *hits* which represents the number of hits for a Content ID by interface f_j^{ID} . An example of FIB table is illustrated in Fig. 2.

In our model, k_j^i denotes the hits of player i through the face j . The corresponding potential value ρ_j^i is defined as following:

$$\rho_j^i = \frac{k_j^i}{\sum_{x=1}^{x<|f^i|} k_x^i} \quad (13)$$

The potential value ρ_j^i implies the probability of hit for Interest i through interface j . The interface list for Interest I is sorted by the value ρ . Thus, ρ_1^i has the highest priority for player i .

In PHA method, 1) the node sorts x_i . The player I_i with smallest x_i has the highest priority. 2) The node sort the ρ_j^i for the players who have same x_i value. The sorting algorithm compares two ρ by priority firstly. If the priority is same, then compare the real value of two ρ . 3) The node allocates the resources for each ρ_j^i by the sorted sequence until the capacity of each interface reaches the threshold $|F_i|$ or all ρ_j^i has been allocated.

Content Name	Interfaces	Fits	Potential
Youtube	A	k_1	ρ_1^{You}
	B	k_2	ρ_2^{You}
	C	k_3	ρ_3^{You}
Facebook	B	k_1	ρ_1^{Face}
	D	k_2	ρ_2^{Face}
	F	k_3	ρ_3^{Face}
...	...	...	...

Fig. 2 An Example of FIB Table.

An example is described in Table. 1. The actions of all players are $x_1 = x_2 = x_3 = x_4 = 4$. In our PHA method, we use the priority queue to represent the fairness. This parameter keeps that network resources can be allocated to each user fairly. The parameter ρ denotes the network utility. Under the premise of ensuring fair, we consider the network efficiency. We allocate the network resources to the players who have more probability to get cached data.

Table 1: An Example of PHA Method

Priority Queue	Players			
Q_1	ρ_1^1	ρ_1^3	ρ_1^2	ρ_1^4
Q_2	ρ_2^2	ρ_2^1	ρ_2^3	ρ_2^4
Q_3	ρ_3^1	ρ_3^2		
Q_4	ρ_4^2			

4. Evaluation

In order to assess the effectiveness of our scheme for CCN, We implemented the game theoretical Interest forwarding scheme by extending ccnSim [14] simulator which is the OMNET++ based CCN simulator. We run our simulation on an Intel Core 2 Duo CPU T9400 running at 2.53 GHz and 4 GB of memory.

4.1 Simulation Settings

In simulation, a network is modeled as a graph $G(n,p)$, where n is the number of nodes in the network and p is the probability of a connecting link exists between two nodes. GT-ITM [23] is used to generate a topology simulating the Internet, whose n = 50, p = 0.3. Links between nodes are characterized by their bandwidth and propagation delay.

The bandwidth of each link is set to 100Mbs and link propagation delays range from 1ms to 5ms.

In our network, we adopt the chunk size is 10KB; file size is about 10^3 chunks; catalog size is up to 10^7 files. We select cache sizes of 10 GB and keep the ratio of cache over catalog on the order of 10^{-5} ($Cache / Catalog = 10^{-5}$). The routers use standard replacement method LRU (evicts the least recently used packet) and decision polices ALWAYS (caches every chunk it receives) [13]. The parameters of our simulation are showed in Table 2.

Table 2: Simulation parameters

Para	***Value***	Explanation
n	50	Number of nodes
p	0.3	Connectivity probability
b	100Mbs	Link bandwidth
d	[1,5]ms	Link delay
α	1	Content popularity distribution skewness
q	0.25	Content popularity distribution skewness
Chunk size	10KB	CCN chunk size
Cache size	10GB	Cache size of each node
Catalog size	10^8 files	each file is 10^3 chunks
(Cache/Catalog) ratio	$1*10^{-5}$	C/(|F|F)

There are two repositories which store the same content. Among the nodes, we randomly select 2 nodes which are connected to repository. We use the Mandelbrot-Zipf distribution model to calculate the content popularity, where $\alpha = 1.5$ and q=0.25. The network has 10 client users which are connected to its border nodes. Users perform File-level requests according to a Poisson process with exponentially distributed arrival times at a 1 Hz rate.

4.2 Simulation Results

We do the evaluation and analyze the effectiveness of CCN with three different Interest forwarding algorithms:

- IFD: A node forwards the Interests by game theoretical multiple Interest Forwarding Decision method;
- CCN-S: A node forwards the Interests by the shortest path algorithm;
- CCN-B: A node forwards the Interests to all interfaces through which the Data is available.

We compare the four schemes by focusing on the metric: average data retrieve time, which denotes the user's benefits directly.

Fig. 3 shows date retrieve time as function of cache over catalog ratio with content popularity distribution skewness α = 0.8 in CCN with three different Interest forwarding methods. Abscissa is the cache over catalog ratio. Ordinate is the average data retrieve time. We can see that with the cache size increases, data retrieve time sharply decreases. When the cache size is small, the IFD has slightly better performance than CCN-S. However, as the cache size increases, the gap between three forwarding mechanisms is becoming smaller until same. IFD has dramatically better performance than original CCN-B. This is due to the fact that CCN forwards Interest to all reachable service instances, which takes up the large of bandwidth and makes the network congestion.

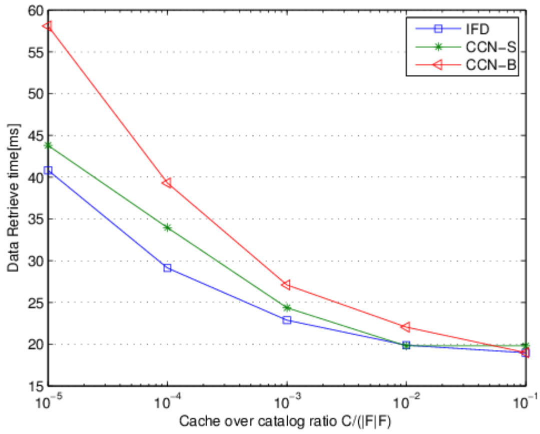

Fig. 3 Date retrieve time as function of cache over catalog ratio.

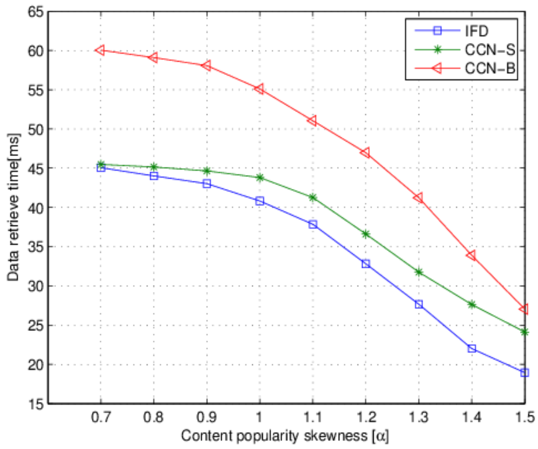

Fig. 4 Data retrieve time as function of content popularity skewness [α].

ACSIJ Advances in Computer Science: an International Journal, Vol. 3, Issue 6, No.12 , November 2014
ISSN : 2322-5157
www.ACSIJ.org

Fig. 4 depicts the Data retrieve time as function of content popularity skewness α with cache size C = 10GB. It can be seen that data retrieve time decreases as the content popularity distribution skewness alpha increases, especially when alpha more than 1.0, there is a sharply decline. CCN with IFD has similar performance with CCN-S when the skewness α is small. As skewness α increase, IFD has better performance than CCN-S. This is because that IFD forwards the Interest to multiple paths which can get higher cache hits than CCN-S when the popular data increase.

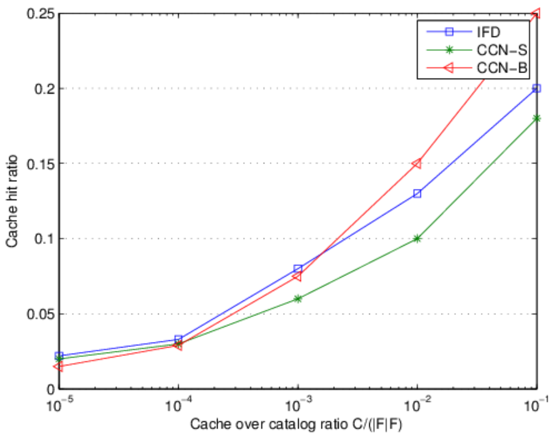

Fig. 5 Cache hit ratio as function of cache over catalog ratio

We also evaluate the cache hit cache hit ratio as function of cache over catalog ratio for three forwarding schemes. As showed in Fig. 5, with the increase of cache over catalog ratio, the cache hit radio of all schemes increased. Furthermore, IFD scheme has higher cache hit ratio than the other two schemes when cache over catalog ratio is smaller than 10^{-3}; when cache size over catalog ratio is bigger than 10^{-3}, IFD scheme has lower cache hit than CCN-B, but better performance than CCN-S.

5. Conclusions

This paper investigates Interest forwarding strategy in Content-Centric Networking where a set of Interests sharing a multiple interfaces from which the Interest can get the response from repository. Users are assumed to be self-regarding and make their decisions with the sole goal of maximizing their perceived quality. We presented a game theoretical multiple Interest Forwarding Decision (IFD) method to improve the users' payoff when the network is not in the high traffic. IFD used non-cooperative game theory to analysis the multiple Interests forwarding decision. We took the Interest flow *I* as the game player. Each game player maximizes his payoff cost. In the network perspective, we proposed a Potential Heuristic Allocation (PHA) method to queue the replica Interests which considers the fairness and network efficiency simultaneously. IFD improved the utilization rate of network resources.

We did evaluation for CCN with three different Interest forwarding methods. The simulation results show that our proposals improved the CCN performance. It can be adaptively make the multiple Interest forwarding decisions in different network traffic scenarios.

In the future, we are planning to discuss different game theory models for Interest forwarding decisions in CCN. Furthermore, we will consider the multipath Interest forwarding for CCN.

References

[1] Altman, Eitan, et al. "Competitive routing in networks with polynomial costs." Automatic Control, IEEE Transactions on 47.1 (2002): 92-96.
[2] Charilas, Dimitris E., and Athanasios D. Panagopoulos. "A survey on game theory applications in wireless networks." Computer Networks 54.18 (2010): 3421-3430.
[3] Choi, Jaeyoung, et al. "A survey on content-oriented networking for efficient content delivery." Communications Magazine, IEEE 49.3 (2011): 121-127.
[4] Dannewitz, Christian. "Netinf: An information-centric design for the future internet." Proc. 3rd GI/ITG KuVS Workshop on The Future Internet. 2009.
[5] Gopinath, Snehapreethi, et al. "An experimental study of the cache-and-forward network architecture in multi-hop wireless scenarios." Local and Metropolitan Area Networks (LANMAN), 2010 17th IEEE Workshop on. IEEE, 2010.
[6] Jacobson, Van, et al. "Networking named content." Proceedings of the 5th international conference on Emerging networking experiments and technologies. ACM, 2009.
[7] Koponen, Teemu, et al. "A data-oriented (and beyond) network architecture." ACM SIGCOMM Computer Communication Review 37.4 (2007): 181-192.
[8] Lagutin, Dmitrij, Kari Visala, and Sasu Tarkoma. "Publish/Subscribe for Internet: PSIRP Perspective." Future Internet Assembly 84 (2010).
[9] Myerson, Roger B. "Game theory: analysis of conflict." 1997. Cambridge: Mass, Harvard University.
[10] Orda, Ariel, Raphael Rom, and Nahum Shimkin. "Competitive routing in multiuser communication networks." IEEE/ACM Transactions on Networking (ToN) 1.5 (1993): 510-521.
[11] Pallis, George, and Athena Vakali. "Insight and perspectives for content delivery networks." Communications of the ACM 49.1 (2006): 101-106.
[12] Pavlidou, Fotini-Niovi, and Georgios Koltsidas. "Game theory for routing modeling in communication networks—a survey." Communications and Networks, Journal of 10.3 (2008): 268-286.

[13] Rossi, Dario, and Giuseppe Rossini. "Caching performance of content centric networks under multi-path routing (and more)." Relatório técnico, Telecom ParisTech (2011).
[14] Rossini, Giuseppe, and Dario Rossi. "Large scale simulation of CCN networks." Large scale simulation of CCN networks (2012): 1-4.
[15] Sahin, Ismet, and Marwan A. Simaan. "A flow and routing control policy for communication networks with multiple competitive users." Journal of the Franklin Institute 343.2 (2006): 168-180.
[16] Shenker, Scott J. "Making greed work in networks: A game-theoretic analysis of switch service disciplines." IEEE/ACM Transactions on Networking (TON) 3.6 (1995): 819-831.
[17] Von Neumann, John, and Oskar Morgenstern. "Theory of Games and Economic Behavior (60th Anniversary Commemorative Edition). " Princeton university press, 2007.
[18] Zhang, Lixia, et al. "Named data networking (ndn) project." Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC (2010).
[19] Oueslati S, Roberts J, Sbihi N. "Flow-aware traffic control for a content-centric network." INFOCOM, 2012 Proceedings IEEE. IEEE, 2012.
[20] Yi, Cheng, et al. "A case for stateful forwarding plane." Computer Communications 36.7 (2013): 779-791.
[21] Sahin I, Simaan M A. "A flow and routing control policy for communication networks with multiple competitive users." Journal of the Franklin Institute, 2006, 343(2): 168-180.
[22] R.J. La, V. Anantharam. "Optimal routing control: repeated game approach. " IEEE Trans. Autom. Control 47 (2002) 437–450.
[23] Zegura E W. "GT-ITM: Georgia Tech internetwork topology models (software)." Georgia Tech," http://www. cc. gatech. edu/fac/Ellen. Zegura/gt-itm/gt-itm/tar. gz, 1996.

Chengming Li received the B.S. degree in software engineering from Dalian University of Technology and M.S. degree in computer application technology from Dalian University of Technology in 2009 and 2011，respectively. Now he is a Ph.D. candidate in Kyushu University, supported by China Governmental Scholarship. His research interests include virtualization technologies and future internet.

Koji Okamura is a Professor at Department of Advanced Information Technology and also at Computer Center, Kyushu University, Japan. He received B.S. and M.S. Degree in Computer Science and Communication Engineering and Ph.D. in Graduate School of Information Science and Electrical Engineering from Kyushu University, Japan in 1988, 1990 and 1998, respectively. He has been a researcher of MITSUBISHI Electronics Corporation, Japan for several years and has been a Research Associate at the Graduate School of Information Science, Nara Institute of Science and Technology, Japan and Computer Center, Kobe University, Japan. He is interested in Internet and Next Generation Internet, Multimedia Communication and Processing, Multicast/IPv6/QoS, Human Communications over Internet and Active Networks. He is a member of WIDE, ITRC, GENKAI, HIJK projects and Key person of Core University Program on Next Generation Internet between Japan and Korea sponsored by JSPS/KOSEF.