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Research Progress for the Interest Control Protocol of Content-centric Networking

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Abstract: Content-centric networking (CCN) brings a new change in today's Internet communication mode by addressing named-data instead of host locations. Another major feature is the possibility to added storage capabilities into the network. Now, the focus of this work is on the design of a receiver-driven Interest control protocol for CCN. ICP realizes a window-based Interest flow control, achieving full efficiency and fairness under proper parameters setting. In order to research ICP in-depth, in this paper, we summary the recent research progress of it. ICP is divided into several parts: content request process, bandwidth sharing model, content request aggregation, storage sharing model. We make these process modeling, research and analysis in linear and binary tree network topology separately, and confirm the accuracy of the models and its characteristics through the numerical analysis, finally give the research trend for ICP. *Copyright © 2013 IFSA.*

Keywords: Content centric network (CCN), Interest control protocol (ICP).

1. Introduction

The design principle and structure of today's Internet originated in the in the 1960s and ’70s. The goal of network design is to solve the shared hardware resources. Therefore, the main purpose of the communication is to connect the two hosts, and the need to determine the specific location of a device. However, with the rapid development of information technology, computer hardware costs a significant reduction in shared hardware resources demand have faded, and the subject of network applications has turned to text messages and video content, and content services is slowly becoming a main network service body. The content of the Internet service has been more attention. In content services network, people do not care about what computer to provide content information, and is only concerned about the speed of access to the content as well as the reliability and security of the content. So, content service has become the main network services. Under this premise, people do not care which computer provides the content information, but only concern about the speed of access to the content as well as the reliability and security of the content. However, the currently widely used in the Internet's TCP / IP is still a Host-to-Host communication model, this model is obvious shortcoming to post and access to information-based Internet. In this case, the point-to-point (p2p) technology and content delivery network (CDN) technology, to some extent, ease the user's “content / information sharing” needs. However, any content delivery mechanism in the current networking is not completely overcome the defects of the underlying mechanism, resulting in a waste of resources, and requires a complex mapping of the content and "position".

In order to adapt to this change in demand, new network architecture should be established. Therefore, the Information Center Network (ICN, Information Centric Networking) is proposed, and its goal is to solve all the problems existing in the internet today. It has been proved that ICN is better able to solve the various problems in today's Internet. In these future networks research projects, Palo Alto research Center's (PARC) Content-centric networking (CCN) [1] has more advantages.

Currently, many research institutions are involved in the content-centric network architecture, Such as UCLA, and Bell Labs [7], Europe CONNECT project team [2] and so on.

The rest of this article is organized as follows. In Section 2 describes the CCN architecture, the difference between CCN and the TCP / IP protocol. In Section 3 describes the research progress of the ICP protocol requests from the research framework and content transmission bandwidth sharing, shared storage and filtering of the routing nodes several processes to describe. In Section 4 is a summary of the thesis.

2. CCN System Introduction

The basic meaning of the Content-centric networking is that the demand of the entire network is content, not the host. It fundamentally changed the IP packet's encapsulation structure and addressing mode, the packet header no longer identifies the address, but the content name. CCN communication is driven by the consumers of data. There are two CCN packet types [4], Interest and Data (Fig. 1).

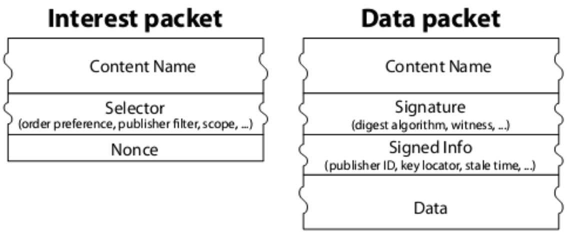

Fig. 1. CCN packet types.

The entire information transmission process is that the request packet defines the title of the contents contained in a packet and the packet is transmitted to all directions, then the device of an adjacent node which can provide the requested content will sent data to the requesting node through the content data package. It can be seen that the CCN entire process is no longer concerned about the location, but quickly get the most from the neighboring nodes in a minimum price. So, CCN provides a new protocol stack (Fig. 2).

Fig. 2 compares the IP and CCN protocol stacks. CCN architecture shape and TCP / IP network is very similar, the lower layer protocols are designed for adaptation of the underlying physical links and communication, the upper layer protocols are designed to correspond to the related application. The main difference is that the CCN using the Content chunks instead of the IP and using named data instead the naming of physical entities. IP protocol's success lies in its relaxed requirements for second layer protocol, CCN inherited it, and CCN can be implemented in any of the underlying protocols, can even architecture above the IP layer. In addition, the content-centric network routing node built storage function used to cache data packets which can speed up access to other users and reduce network traffic.

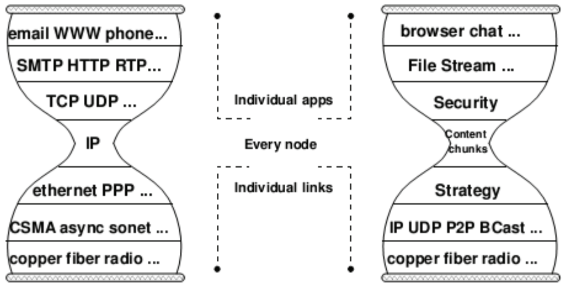

Fig. 2. The compare between TCP/IP and CCN.

The ICP protocol [5] of CCN describes the entire information communication process: fair sharing of the transmission, and the routing node storage and filtration process from the transmission of the request packet, the bandwidth on the link. We will describe the progress of the current study as follows.

3. ICP Introduction

The CCN's ICP protocol [5] describes the entire information communication process. The client sends a request packet, transmitted via the link, reaches a routing node, the routing node of the query sequence are sequentially processed (the detailed procedure as followed), then sends to uplink by a node (in CCN, only the request packets are routed), until retrievals needed data packets, then the packet request reverse transmission path of the packet routing, service receiving end. The ICP process is divided into several parts: content request process, link bandwidth sharing transmission process, storage and filtration process of the routing nodes. For the benefit of research, we model these sub-processes, and discuss the ICP's availability, efficiency and fairness based on linear and binary tree network topologies.

3.1. Node Model Analysis

3.1.1. Interest Packet Routing Analysis

From Fig. 3, the typical CCN node model includes the contents of memory (CS), pending requests table (PIT) and forward forwarding (FIB).

CS is similar to IP routers cache, but uses different caching strategies. Because each of the IP packets belong to a single point-to-point session, no value to the other session, so it uses the MRU replacement strategy which empty the information stored after the completion of a session. CCN each packet is self-identity and self-validation, so there is also value for other users, CCN will uses the LRU or LFU replacement policy to maximize store important information, in order to reduce the content download delay and network bandwidth.

PIT records the uplink routing path of request packets, so the content data package can be backtrack spread back to the requesting node according to PIT recorded information track. When the content requested arrives at the receiving node, PIT will delete this entry.

FIB and the IP router's processing mechanism are similar, but it can be forwarded to the plurality of directions at the same time request.

When an Interest packet arrives on some face, a longest-match lookup is done on its Content Name. The index structure used for lookup is ordered so that a Content Store match will be preferred over a PIT match which will be preferred over a FIB match. The specific operation is as follows:

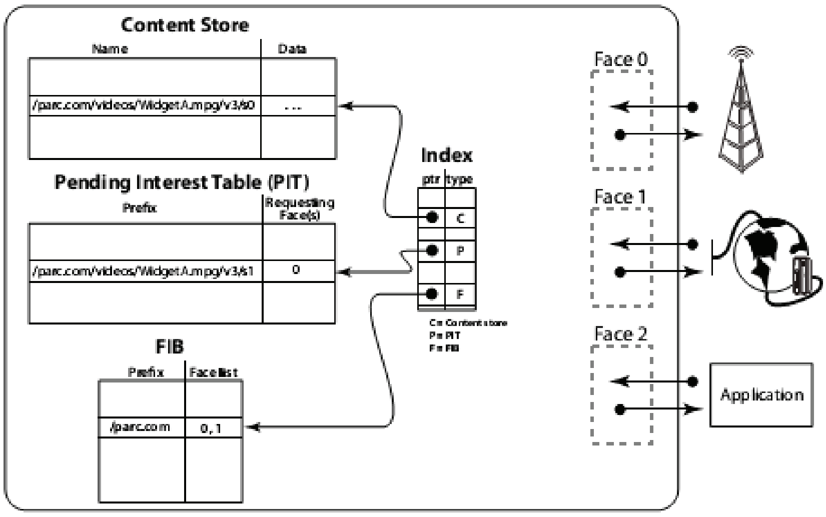

Fig. 3. CCN forwarding engine model.

- If CS contains a request packet, it will directly sends the corresponding content to the requested port, and discards the request packet, otherwise it will continue to query the PIT.
- Otherwise, if PIT contains entries associated with the content name, it will let request port added to the request port list, and discards the request packet, otherwise it will continue to query the FIB.
- Otherwise, if FIB contains entries associated with content name, it will forward the packet to the next CCN node in accordance with the instructions of the FIB. If the rest of the port is not empty, then it will forward request to all the rest, and format new list of entries and ports in the FIB.

If there is no match for the Interest it is discarded (this node does not have any matching data and does not know how to find any)

3.1.2. Data Packet Routing Analysis

Data packet processing is relatively simple since Data does not require routing, followed by only PIT port records the request data packet transmission trajectory to reach the initial client. When a packet arrives routing nodes, the longest match its content name query. Described in the PIT match the packet after the request when the CS match the packet duplication, to remove it; PIT port of the FIB matching the node does not match, the packet is unsolicited delete it; packet forwarding path, request the end through the node to accept.

3.2. Assumptions and Notation

For the various parts of the ICP protocol, we reference [5, 7, 8] and summarize all of the models. The main assumptions are the following:

1. M different content items are equally partitioned in K classes of popularity, i.e. k is requested with probability q_k , k≥1. We assume a Zipf popularity distribution, $q_k = \frac{c}{k^\alpha}, c = (\sum_{k=1}^{K} 1/k^\alpha)^{-1}$, with $\alpha > 1$.
2. Content items are divided into chunks (P size) and the content size distribution is geometric with average σ chunks.

3. N network nodes (or levels for tree topologies). Node i is equipped with a cache of size x_i chunks.
4. The request arrival process is modeled as a Markov Modulated Rate Process (MMRP) [3] and the process is according to a Poisson process of intensity $\lambda_k = \lambda_{q_k}$
5. We define virtual round trip time of class k, $VRTT_k$, is similar to the round trip time for TCP connections in IP networks. It describes the average time of a chunk to send the request and is accepted.

$$VRTT_k = \sum_{i=1}^{N} R_i (1 - p_k(i)) \prod_{j=1}^{i-1} p_k(j), \qquad k = 1,\dots,K \qquad (1)$$

$VRTT_k$ is defined as a weighted sum of the round trip delays R_i associated to node i, and the weights are related to the stationary hit probabilities $1 - p_k(i)$.

3.3. Content Request Process

Notation

N	Number of network nodes
M	Number of different content items（m=M/K）
x	Cache size
$\lambda, \lambda(i)$	Total content request rate at first node, at node i>1
$\mu(i)$	Content miss rate at node i
λ_k	Content request rate for class k with no filtering
λ_k^f	Content request rate for class k with filtering
$q_k, q_k(i)$	Content request rate for class k with filtering
σ	Average content size[chunks]
$\gamma(i)$	Max-min fair share on route i [bps]
$VRTT_k$	Virtual round trip delay of class k with no filtering
R_i	Round trip delay between client and node i
$p_k(i)$	Miss probability for class k at node i
$p_k^f(i)$	Miss probability with filtering for class k at node i
Δ, Δ_k	Imposed and effective filtering time window for class k

The content request process is structured in two levels, content and chunk. The process is modeled as a Markov Modulated Rate Process (MMRP): the request for content items is according to a Poisson process of intensity: $\lambda_k = \lambda_{q_k}$. A request for content is exactly the content of the first chunk, and when a chunk is received, the other new chunk is going to sent until the contents of the last chunk.

ICP realizes a window-based Interest flow control, and it uses the AIMD (Additive Increase Multiplicative Decrease) mechanism to adapt the Interest window size to attain the maximum available rate allowed on the network path.

- Interest window increase: W is increased by η/W at Data packet reception.
- Interest window decrease: The protocol reacts by multiplying W by a decrease factor β< 1, no more than once for a duration equal to the timer as in Fig. 4 (b).
- Interest timer value: τ should be set larger than the minimum network delay, and a minimum τ value is necessary to guarantee high utilization of the available bandwidth. In the case of variable τ, ICP maintains round trip delay estimates at every data packet reception. Each flow adapts its timer τ according to

$$\tau = RTT_{\min} + (RTT_{\max} - RTT_{\min})\delta, \qquad \delta = 0.5 \qquad (2)$$

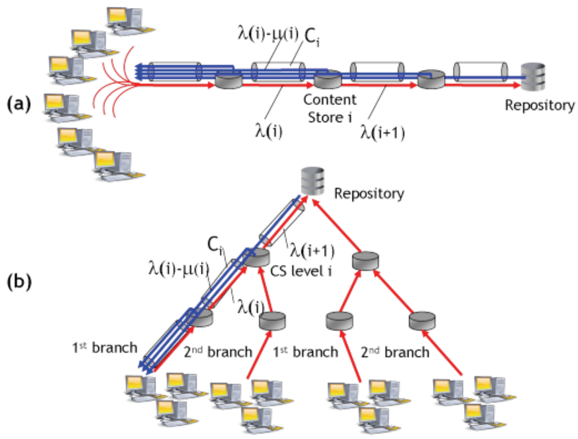

Fig. 4. Linear (a) and binary tree (b) topologies with bandwidth-limited down-link.

3.4. Content Request Aggregation

CCN's a basic feature of blocking requests flood is the aggregation, which it can prevent the transmitted request for the same data again by the node of the PIT records pending requests chunk trajectory. PIT time window Δ: the value is used to limit the number of packets in its pending request. The larger of the value, the more the number of filter out a request packet; smaller the value, means that there are more unnecessary requests continue to be routed.

The request aggregation clearly impacts the miss rate of a given cache. In fact, when a request chunk arrives at a node, if the corresponding chunk is stored in the node, it will generate a hit, otherwise it generates a lost. For the latter, the request is filtered only if a previous request for the same chunk has been emitted and the chunk has not been received yet. Given the request process, the filtering probability associated to class k at the first hop is,

$$p_{filt,k}(1) = \frac{1 - b_k}{1 - (1 - 1/\sigma) b_k} \qquad k = 1,\dots,K$$
$$b_k = e^{-\Delta_k \lambda_k} \qquad (3)$$

The proof is reported in [11].

3.5. Bandwidth Sharing Model

In CCN, a receiver can download data from multiple nodes and share bandwidth with other concurrent transfers. User-perceived performance depends on the parallel download bandwidth sharing. A generally accepted fairness objective is max-min, which can achieve rate equalization.

Every route *i* is characterized by a number of parallel transfers, N_i , sharing the same route and therefore the limited bandwidth. N_i is a random process that varies according to the demand λ and the service rate each transfer in progress gets.

N_i is a birth and death Markov process,

birth rate: $\mu(i-1)-\mu(i),\ (\mu(0)\equiv\lambda)$

death rate: $n_i\gamma(i)/(\sigma)$

$\mu(i-1)-\mu(i)$ denotes the rate of the Poisson process of content requests satisfied by node *i*, under the assumption of a MMRP miss process of intensity $\mu(i)$ at node *i*. The death rate, $n_i\gamma(i)/(\sigma)$, is determined by the max-min fair shared bandwidth $\gamma(i)$ in bps associated to each of the n_i content transfers in parallel over route *i*.

3.6. Storage Sharing Model

The research about storage sharing model is based on above three models: content request process, content request aggregation and bandwidth sharing model, so we validate numerical analysis through the storage sharing model.

Except 3.2 assumptions, we give the others as follows:

1. K popularity classes with the same number of content items m = M/K in each one.
2. Non-unitary content size (σ).

3.6.1. Storage Model Analysis at Node 1

We first analyze the first node which means the first from the content request point. Given a MMRP request arrival process with intensity λ, and average content size σ, be x > 0the cache size in number of chunks, then the stationary miss probability for chunks of class k is,

$$p_k \equiv p_k(1) \sim e^{-\frac{\lambda}{m}q_k g x^{\alpha}}$$

$$1/g = \lambda c\sigma^{\alpha}m^{\alpha-1}\Gamma(1-\frac{1}{\alpha})^{\alpha} \qquad (4)$$

We use an ad-hoc C++ event-driven simulator[8] to confirm the accuracy of the model and assume a simple transport protocol which it uses a fixed window size for chunk requests as in CCN. Nodes' forwarding tables are implemented by Carzaniga et al. in content-based networking simulator [6].

For the case of a single node, we present the experimental case is that a population of M = 20000 content items, and K = 400 classes, each one with m = 50 items. Content items are split in chunks of 10 kB each. Users generate content requests according to a Poisson process of intensity λ= 40 content/sec, and the interest transmission window size is W = 1. The cache of size x = 200000 chunks (2 GBs) which implements the LRU replacement policy. Each cache is assumed to be initially empty, while statistics are collected in steady state only.

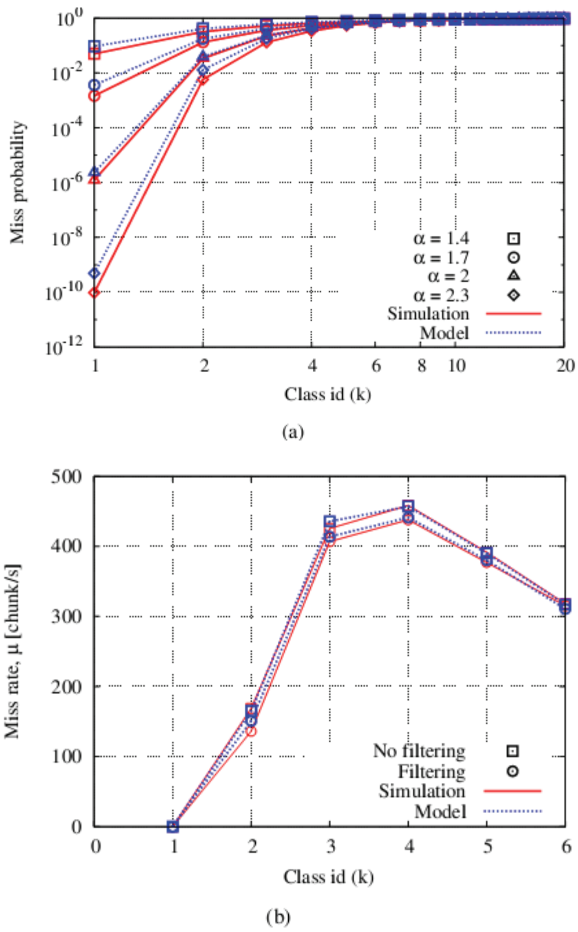

Fig. 5. Miss probability as a function of class popularity (a); miss rate with and without request filtering for α= 2 (b) [8].

In Fig. 5 (a) [8] we can see that the greater the value of α, the miss rate is lower, and for high popular level (1 is the highest) of the content, it's miss rate is low, while the lower popular Level of the content, it's miss rate is getting higher and higher, almost, that is certainly lost. Fig 5 (b) [8] shows the miss rate with request filtering is lower than without. Through these two simulation graphics, we can confirm the accuracy of the *eq.4* for predicting the probability of loss.

3.6.2. Storage Model Analysis at Network Topologies

In this section we consider the topologies reported Fig. 4, in order to derive the stationary miss probabilities $p_k(i)$ at hop i > 1, we need the following auxiliary result.

Given a MMRP request arrival process with rate *λ(i)* and popularity distribution: $q_k(i) = \prod_{j=1}^{i-1} p_k(j) q_k / \sum_{l=1}^{K} \prod_{j=1}^{i-1} p_l(j) q_l, \quad k = 1,...K$ and defined Si(0, t) the number of different chunks requested in the open interval (0, t] at the i^{th} node. Be *μ(i)* the miss rate at node i $\mu(i) = \lambda(i) \sum_k p_k(i) q_k(i)$, then it holds

$$1/g(i) \equiv \lim_{t\to\infty} \frac{\mathrm{E}[S_i(0,t)]^\alpha}{t} = \frac{\lambda(i)}{\mu(i-1)} \lambda c \sigma^\alpha m^{\alpha-1} \Gamma(1-\frac{1}{\alpha})^\alpha \quad (5)$$

i.e. $g(i)/g \equiv \mu(i-1)/\lambda(i)$, being $g(1) \equiv g$. The proof is reported in [9].

3.6.2.1. Miss Rate Characterization without Request Aggregation

Given a cascade of N caches as in Fig. 4 (a) and a MMRP request arrival process, then ∀ 1 < *i*≤ N it holds

$$\log p_k(i) = \frac{g(i)}{g(1)} \prod_{l=1}^{i-1} p_k(l) \log p_k(1) = \prod_{l=1}^{i-1} p_k(l) \log p_k(1) \quad (6)$$

Similarly, one can study the binary tree topology in Fig. 4 (b), that has no difference with the line topology in the homogeneous case expect that λ(*i*)=2μ(*i*-1).

Given a homogeneous binary tree with $2^N - 1$ caches (that is with N levels) as in Fig. 4(b) and a MMRP requests arrival process, then ∀ 1 < *i*≤ N it holds

$$\log p_k(i) = \frac{\lambda(i) g(i)}{\mu(i-1) g(1)} \prod_{l=1}^{i-1} p_k(l) \log p_k(1) = \prod_{l=1}^{i-1} p_k(l) \log p_k(1) \quad \textbf{(7)}$$

3.6.2.2. Miss Rate Characterization with Request Aggregation

Given a cascade of N caches as in Fig.4 (a), a MMRP request arrival process and an aggregation timescale Δ, then it holds

$$p_k^f(i) = p_k^f(1)^{\prod_{l=1}^{i-1} p_k(l)} = p_k(i)^{1-p_{filt,k}(1)} \quad (8)$$

For the topology in Fig. 4 (b) the request aggregation can take place at several hops depending on traffic and cache parameters.

Given a binary tree with $2^N - 1$ caches (that is with N levels) as in Fig. 4 (b) and a MMRP requests arrival process and an aggregation timescale Δ, then it holds

$$p_{filt,k}(i) = \frac{1 - b_k(i)}{1 - (1 - 1/\sigma) b_k(i)}, \quad k = 1,...,N \quad (9)$$

with

$$b_k(1) = e^{-\Delta_k \lambda_k / m}, b_k(i) = e^{-\Delta_k 2\mu_k^f(i-1)/m}, \quad i > 1 \, .$$

$$\mu_k^f(i) = \begin{cases} \lambda_k p_k(1)(1 - p_{filt,k}(1)) & if\ i = 1 \\ 2\mu_k^f(i-1) p_k^f(i)(1 - p_{filt,k}(i)) & if\ i > 1 \end{cases} \quad (10)$$

The proof is provided in [9].

For the case of topology, we present the experimental case is that N = 3 levels binary tree, where data is stored at the root of the tree. Each link has the same capacity of 10 Gbps and the same round trip delay equal to 2 ms. The Zipf parameter α= 2, and chunk size is 10 kB. Other parameters are same to the above case.

Fig. 6 compares the miss probabilities at different nodes (from the 1st to the 3rd level) without request aggregation. The comparison summarizes the good match between model predictions Eq.(4) at level *i* = 1, Eq.(6) at level *i* > 1. we can be see that the requests for content items of the most popular class are almost completely served by caches of first nodes, so the miss probability for class *k* = 1 is nearly 1 at *i*>1. Content items of class 2 are mainly cached at first and second level, whereas less popular classes, represented in the queue of the curves, are very rarely cached as hardly requested.

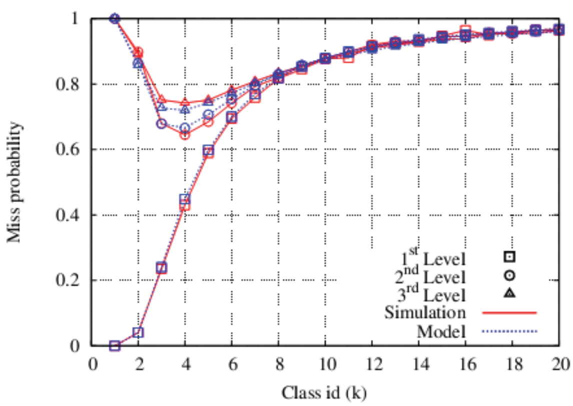

Fig. 6. Miss probability at different levels for binary tree topology, with no filtering [8].

4. Conclusions

Content-centric networking is the research focus of the next generation network. In this paper, we summary the recent research progress of ICP. We make these process modeling, research and analysis in linear and binary tree network topology separately, and confirm the accuracy of the models and its characteristics through the numerical analysis, finally give the research trend for ICP.

Through the research, we find that ICP protocol's a significant feature is the storage functions embedded in the network, it can help reduce content download latency and network bandwidth usage greatly improve bandwidth utilization performance. Another is that CCN transport provides Disruption Tolerant Networking. The multipoint nature of data retrieval by Interest provides flexibility to maintain communication in highly dynamic environments. Any node with access to multiple networks can serve as a content router between them. These characteristics do provide effective help to resolve the current Internet problems.

But, CCN technology is still in its beginning stages. So, the ICP protocol is not very mature, and the protocol's process and topology are relatively simple, and the protocol traffic control problem also needs more in-depth study. The next step of the research is continues to improve the ICP protocol, and over a period of time it will also be the hot issues of the next generation network research.

Acknowledgements

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