Efficient Parallel Multi-path Interest Forwarding for Mobile User in CCN

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***Abstract*— Internet traffic has been dramatically increasing due to development of IT technology and increase in the number of Internet service users. The existing TCP/IP network architecture has problems in terms of scalability and security. Therefore, to solve the traffic, scalability and security problems, novel network paradigms are being surveyed. Among these paradigms, Content-Centric Networking (CCN) is in spotlight and has shown great promise to handle these problems. We can avoid the bottleneck problem caused by many requests through this new paradigm. However, the transmission rate in CCN is a limitation when compared to the existing TCP/IP network. In order to enhance the transmission rate, we can adopt to multiple wireless interfaces available in the modern mobile device. Thus, we propose a scheme namely Parallel Multi-path Interest Forwarding Scheme in which it is possible to receive the contents more quickly compared to the existing CCN.**

Keywords—CCN, Multi-path, Parallel, RTT, Bandwidth

I. INTRODUCTION

The trend of using multimedia contents related services over the Internet is increasing rapidly. Therefore, IT technologies for multimedia contents are being developed and many novel technologies are being studied for providing efficient multimedia contents services. However, the existing TCP/IP network has the limitation of scalability and security etc. In order to solve these problems, various research activities are being carried out and typically, there is a great promise shown in the study of Content-Centric Networking (CCN) [1].

Literally, CCN means the networking architecture with content-centric unlike the existing TCP/IP network architecture. In TCP/IP network, there is end to end communication between client and the server holding the contents, the client knows the IP address of the server and for the content request reaches the server, the intermediate router sends the content request as a result the router searches a routing table that is in the router. However, in CCN, the client does not need to know about the location of the content it send request for. The client sends the Interest to request the content to the nearest router and if the router has the chunk of the requested content, the router sends the chunk to the client. Conversely, if the router does not have the chunk of the content, the router forwards the request message to the neighboring routers. Since the router is able to cache the chunk of the content, the intermediate router can respond first before the request messages reach the server. So it is possible to reduce the bottleneck in the network and the overhead in the server [9].

However, the reason for fast transmission rate in CCN is not related with bandwidth [1]. The same contents can exist anywhere on the network. So it is the major issue for fast transmission to select a path that can receive the contents more quickly [5]. If the client receives the contents from the routers or the servers at the same time, the client is able to receive the contents more quickly. However, since bandwidth in single interface is fixed, the client which has single interface cannot get the transmission rate more than the fixed bandwidth. Accordingly there are researches that the client receives the contents through multiple interfaces [2] [11]. In this paper, we propose the forwarding strategy that sends amounts of Interest packets divided by specific ratio to multiple faces in CCN.

The rest of this paper is organized as follows, In Section II, we review some related works. In Section III, we present our proposed Parallel Multi-path Interest Forwarding Strategy, the algorithm calculating forwarding ratio depending on RTT and available bandwidth and the operation of MIF controller. In Section IV, we represent the simulation environment, the simulation topology and the results of the simulation. Finally, we conclude the paper and mention about future works In Section V.

II. RELATED WORK

A. Content-Centric Networking

CCN is a new paradigm focusing on what is sent. It is different from TCP/IP network focusing on the sender and the receiver. The router in CCN consists of some components. They are Content Store (CS), Pending Interest Table (PIT), Forwarding Information Base (FIB) and Face. CS is the repository to store chunks of the contents. The interface of CCN router is called Face in CCN because packets are not only forwarded over hardware network interfaces but also exchanged directly with application processes within a machine [1]. PIT manages incoming request messages. The CCN router records Face number in which it receives Interest packet in PIT. FIB manages the outgoing packet. A packet requesting the content is called Interest packet. The packet corresponding to Interest packet is called Data packet. When the client sends one Interest packet, the client can receive one Data packet. At first, the client wants to know where the wanted contents are. In order to find out where the contents are, the client sends Interest packet to the neighboring router and the router that receives Interest packet confirms whether the content exists in its own CS or not. If the router has the requested content, it sends back Data packet regarding Interest packet. Otherwise, the router broadcasts Interest packet to all neighboring routers. After that, the router waits for the response and chooses the fastest arrival response for establishing the path for receiving the content. Other responses are discarded. The router sends Interest packets to only this path. This process is equally applicable to all other routers and if the intermediate routers do not have requested content, Interest packet reaches to the server at the end.

The size of Content Store in the router cannot be infinity. For that reason, the size of Content Store is determined as a fixed size. Therefore, the cached chunks of the contents are managed by a particular cache policy. When the router stores the newly hit chunk, the router remove the oldest hit chuck and stores the new chunk using Least Recently Used (LRU) algorithm.

B. *Forwarding strategies*

There are three method for efficient Interest packet forwarding in CCN. The first method is to send multiple Interest packet. The first method is to control the number of Interest packet which is transmitted. This method is related with congestion control. This congestion control method uses Additive Increase Multiplicative Decrease (AIMD) algorithm.

Actually, AIMD adjusts the window size for avoiding the congestion. In case of CCN, AIMD adjusts the number of Interest packets. Fig 1 is showing an example. The client sends a single Interest packet. If the client receives a response successfully, the client can send two Interest packet next time [10]. However, after reaching to the bandwidth capacity of the link, the client cannot further increase its throughput. The second method is multi-path Interest forwarding using multiple Network Interface Cards (NICs) as it is shown Fig 2. Thus, the client can send Interest packet to each path and obtain two times higher bandwidth. This concept is called Multi-homing. The third method is similar with the second method. The client also has multiple NICs, but the client does not establish multi-path with a single server. The client establishes a path with one server per one NIC in Fig 3. The routers connected with the client also can establish multiple-paths with others if the router has multiple NICs. It is assumed that the all servers has same content in the scenario of the third method.

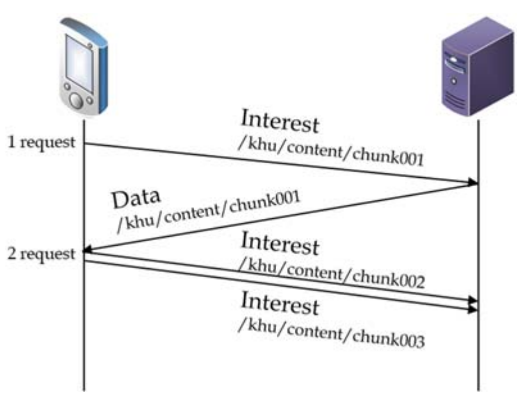

Fig. 1. Client-driven forwarding strategy

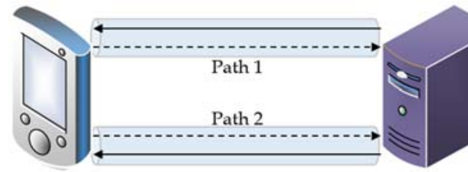

Fig. 2. Multi-path forwarding strategy with multi-homing

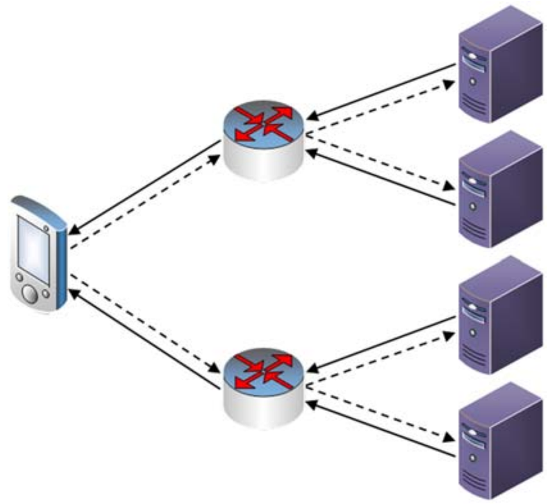

Fig. 3. Multi-path forwarding strategy with server pooling

It is also been researched to find out the optimal interface(s) for send the Interest depending on strength of the signal [3]. However, in this research, the client can consider multi-path from multiple interfaces but the client uses only one path. This also has the limited bandwidth due to the use of a single interface. There is another research to send Interest packets parallel using multiple-paths [4].

III. Parallel Multi-path Interest Forwarding Strategy

In CCN, when Interest packet is sent, the path to send the first response is the optimal path and the client determines the optimal path depending on the first coming response. In other words, the path having the shortest RTT becomes the optimal path. Normally, a client cannot expect faster transmission rate than its limited maximum bandwidth. Conversely, if the client can use multiple interfaces, the client can obtain higher transmission rate. In other words, if the client can obtain the chunks in the content simultaneously from the contents providers that have the same content using multiple interfaces, it guarantees that the client can obtain higher transmission rate to obtain the content. In this paper, we assume that the mobile devices have at least two or more wireless interfaces and the networks that are connected with each wireless interface of the client contain the replica server which has the same content requested by a client.

For the client receives the content using multiple wireless interfaces, the client should forward Interest packet requesting the content to each wireless interface. In this paper, we propose Parallel Multi-path Interest Forwarding Strategy that distributes Interest packet efficiently to the wireless interfaces depending on RTT and available bandwidth to receive a single content

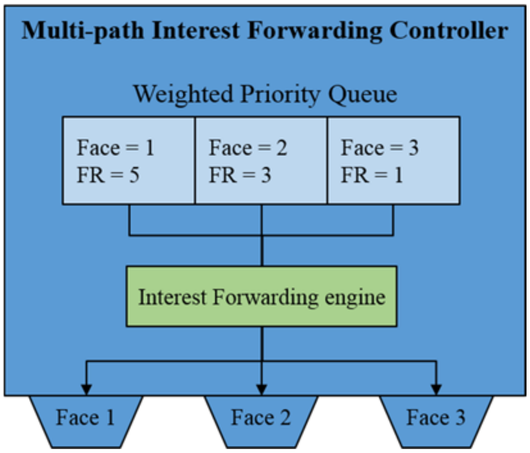

Fig. 2 Operation example of MIF controller

more quickly. RTT is the time delay that consists of the propagation times between the replica server and the client.

In this proposal, we use RTT and available bandwidth for calculating Weighted Priority (WP). Weighted Priority is the weighted value of the wireless interface for calculating Forwarding Ratio (FR). Forwarding Ratio indicates the ratio that how many Interest packets should be assigned to each wireless interface. This is done by a controller. The controller is used for controlling this strategy. The detailed explanation about the controller operation, WP and FR is given in the next section.

A. *Mupti-path Interest Forwarding Controller*

Multi-path Interest Forwarding controller (MIF) that controls and operates the proposed strategy exists in each mobile device. MIF controller follows default caching policy and security policy of CCN, except for the forwarding strategy. MIF controller contains the Weighted Priority Queue (WPQ) in order to store Forwarding Ratio (FR) and Face number. WPQ updates Weighted Priority (WP) value each time it receives a Data packet, and sorts WP values in the queue using a descending order. After this sorting, FR value is re-calculated. An operation example of MIF controller is presented in Fig 4. As seen in the Fig. 6, the FR value corresponding Face 1 is five, MIF controller sends five Interest packets to Face 1. Its five Interest packets contain the chunk number from 1 to 5. In next step, three Interest packets that contain the chunk number from 6 to 8 are forwarded to Face 2. Similarly, one Interest packet having the chunk number 9 is forwarded to Face 3. However, there is a possibility to have a changed RTT value and available bandwidth after receiving Data packets. Then WP will be changed and the order of WPQ is also changed using the descending sort method. If this happens, FR is re-calculated. This process is carried out iteratively until all chunks are received.

B. *Round Trip Time in Weighted Priority*

As the client receives the response about Interest packet, the client can know the information i.e., total number of the chunks, the size of the chunk and the RTT value. Table 1 represent an example of the information that can be obtained from the response.

TABLE I. EXAMPLE OF THE INFORMATION FROM THE RESPONSE

Field	Total chunk	Chunk size	RTT	⋯
Data	10,000	1000 bytes	150ms	⋯

Basically, the router or the client accepts the response having the shortest RTT for the optimal single path in CCN. Other responses are discarded. However, in this paper, MIF controller accepts the best responses. The number of acceptable responses are equal to the number of the wireless interfaces in order to establish multi-path and create a queue that has the size of the number of the wireless interfaces. The reason of creating a queue is to store Weighted Priority value calculated for transmission. At first, Total RTT is calculated by sum of RTT from all wireless interfaces. Total RTT is divided by RTT of each path. These values are the weighted value of RTT of each path. The value of k in (1) means total number of paths.

$$\frac{\sum_j^k RTT_j}{RTT_i} \quad (i = 1 \dots k). \tag{1}$$

The values produced by (1) represent the ratio of RTT of each wireless interface in total RTT. Higher value indicates lower RTT. This value presents the proper ratio to send Interest packets to each wireless interface.

C. *Bandwidth in Weighted Priority*

Each wireless interface has different bandwidth. Since each wireless interface also has different communication range, it has different bandwidth depending on the position of the mobile device. According to the survey in OpenSignal, LTE network in Korea Telecom (KT) has bandwidth of maximum 34 Mbps [6]. IEEE 802.11a Wi-Fi at 5 GHz band has bandwidth of maximum 54 Mbps and IEEE 802.11b Wi-Fi at 2.4 GHz band has a bandwidth of maximum 11 Mbps [7]. IEEE 802.15.1 Bluetooth 4.0 has bandwidth of maximum 24 Mbps [8]. Therefore, the wireless interfaces of the mobile device have different bandwidth depending on the type of the interface. So when the mobile device sends Interest packets to the nearest access point router, it is practical to consider bandwidth. Then, the mobile device immediately is able to react to increase or decrease of bandwidth occurring while the mobile device is moving. The weighted value depending on bandwidth is determined through dividing the available bandwidth of each wireless interface by the chunk size of the requested content. Formally, this can be expressed as follows:

$$\frac{BW_i}{chunk\ size} \quad (i = 1 \dots k). \tag{2}$$

The bandwidth in (2) is updated through measuring bandwidth of each wireless interface every time an Interest packet is sent.

D. *Forwarding ratio*

MIF controller creates a Weighted Priority Queue (WPQ) to store Weighted Priority (WP) that represents the ratio of sending Interest packets. The size of WPQ is equal with total number of routing paths. Initially, Face number having the shortest RTT are stored in beginning (i.e., first index) of WPQ. In other words, the shortest RTT is stored first and others are stored in order of short sizes.

$$WP_i = \frac{\Sigma_j^k RTT_j}{RTT_i} \times \frac{BW_i}{chunk\ size} \quad (i = 1 \dots k). \tag{3}$$

(1) multiplied by (2) determines WP. WP value by (3) represents the priority of each wireless interface considering RTT and available bandwidth. If the order of the priority is changed by calculating the priority each time a Data packet is receiving, Weighted Priority Queue (WPQ) should be re-sorted in a descending order. The reason for this is that MIF controller first sends Interest packets to the path stored in beginning (i.e., first index) of WPQ. The calculated WPs are likely to contain the point number. Therefore, it is difficult to determine that how many Interest packets are sent by the priority value containing decimals. So it needs to convert WP decimal values into integer values.

$$FR_i = \left\lfloor \frac{WP_i}{WP_k} \right\rfloor \quad (i = 1 \dots k) \tag{4}$$

In (4), *k* means the last index of WPQ. In order words, *k* means the index of the smallest WP in WPQ after descending sort. WP value by (4) can be integer ratio which is called Forwarding Ratio (FR). The overall operation of MIF controller is represented by pseudo-code in Algorithm 1.

Algorithm 1. Operation of MIF Controller

```
k : the number of all faces
WP : weighted priority value in WPQ
FR  : forwarding ratio value in WPQ
Receiving_Res and Engine_MIF works simultaneously
create_weighted_priority_queue (k);
Send_Interest (all faces, 1, content_name);
Procedure Receving_Res(response)
   chunk_size = chunk size of a chunk;
   RTT (i) = RTT from a replica;
   total_RTT += RTT (i);
   BW (i) = calc_bandwidth (RTT (i));
End Procedure
Procedure Engine_MIF
   Repeat For i = 1 to k
      WP (i) = calc_weighted_priority ( total_RTT,
                                 RTT (i), BW (i), chunk_size );
      If WP are changed Then
         desc_sort(&WP);
      End If
      RF (i) = floor (WP (i) / WP (k));
      Send_Interest (Face in WPQ(i), FR (i),
                                             content_name);
   End For
End Procedure
```

TABLE II. CONFIGURATION PAPAMETERS

Parameters	Value
Chunk size	10 KB
Number of repository	3
Number of replicas	3
Number of clients	3
File size	1
Object size	10,000
Zipf exponent	1
Cache decision	LCE
Cache replacement	LRU
Cache size	1% of object size
Arrival rate	5, 10, 15

IV. PERFORMANCE EVALUATION

A. Simulation Environment

In order to evaluate the performance of the proposed scheme that is Parallel Multi-path Interest Forwarding scheme, we used the chunk-level simulator, ccnsim [12] which is developed under Omnet++ simulator. ccnsim 0.3 version is used for the simulation. We modify ccnsim 0.3 for evaluation of the proposed strategy. Table 2 shows configuration parameters of ccnsim 0.3 for the simulation. The chunk size is defined with 10 KB in our simulation. One server having one repository exists in one network. Only one content is in the repository of each server. We choose Leave Copy Everywhere (LCE) as a policy of cache decision and select Least Recently Used (LRU) as a policy of cache replacement. Cacheable size in Content Store is allocated as 1 % of Object size. In this simulation, cache size in Content Store is 100 because Object size is 10,000. This simulation is repeated three times under different Arrival rates i.e., 5, 10 and 15.

B. Topology

The topology for the simulation is shown in Fig 5. A client has three wireless interfaces. In order to evaluate performance, we deploy three clients. Each client connects with three different wireless networks. The three different wireless networks are LTE, Bluetooth and Wi-Fi. We assume that first network link in LTE network has a bandwidth of 36 Mbps, second network link in Bluetooth network has a bandwidth of 24 Mbps and third network link in Wi-Fi network has a bandwidth of 11 Mbps. Each replica server has one repository having one content. The number of hops in each network is assumed to be 5. Each client requests only one same content complying with Parallel Multi-path Interest Forwarding strategy. Three clients connect with three different network.

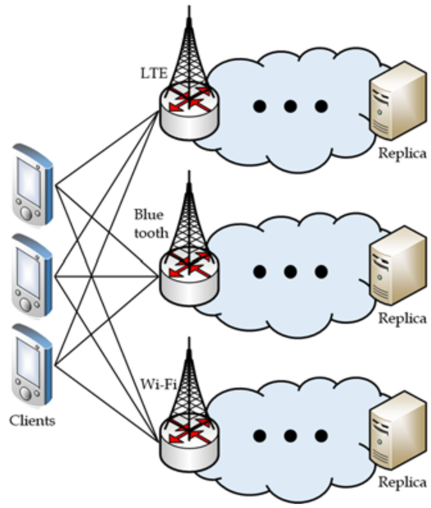

Fig. 5. Topology used in simulation

C. Simulation Results

The result of the simulation through ccnsim simulator are represented in Fig 6. X-axis is the Arrival rate and Y-axis represents the average delay to receive one chunk. Average delay is determined through dividing total of the time for receiving one content by total number of chunks. Average delay of three clients receiving same content is represented in Fig 6. The delay is lower with case of LTE + Bluetooth networks having much higher bandwidth than the case with only LTE network. The delay is lowest with the case of LTE + Bluetooth + Wi-Fi networks than the case with LTE + Bluetooth networks.

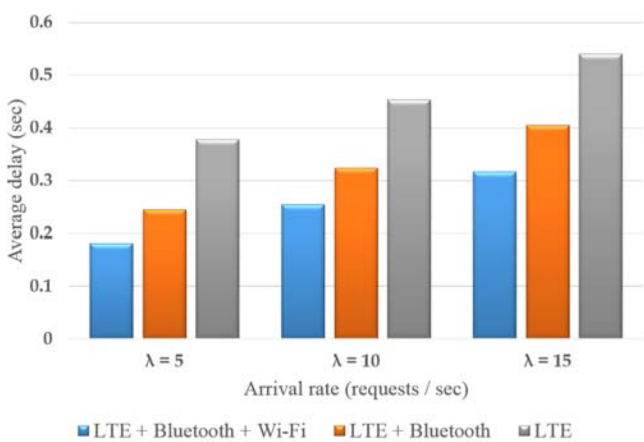

Fig. 6. Average delay of three clients receiving one chunk

V. Conclusion

In this paper, we proposed Parallel Multi-path Interest Forwarding scheme for efficient delivery enabling a multiple interface environment. This scheme adjusts the ratio of Interest packets depending on RTT and available bandwidth to send on each interface for receiving the content with the lowest delay. We tested a particular scenario using ccnsim simulator for performance evaluation. Simulation results reveal that the use of two interfaces lower the delay compared to the case where a device had one interface. Naturally, the use of three interface brought much lower delay than other cases. We utilized the complete bandwidth of multiple links of wireless interfaces by adjusting the amount of Interest packets corresponding to the real-time RTT and available bandwidth through proposed scheme. In future work, we plan to build an algorithm that deals with disconnection of link or connection of link caused due to mobility of clients.

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