CeforeSim: Cefore Compliant NS-3-Based Network Simulator

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***Abstract*—In this paper, we introduce "CeforeSim", which is an ns-3-based network simulator for Information-Centric Networking (ICN). CeforeSim is compliant with an ICN software platform known as Cefore. This simulator supports the CCNx 1.0 messages specified in the IRTF and inherits the unique features of Cefore such as the transport protocol for real-time video streaming, cache storage separation from the forwarding engine, network measurement using CCNinfo defined in the IRTF, and so on. As one of the example features, we focuses on the CeforeSim function for real-time video streaming and show the low-overhead multicast streaming compared to the conventional ICN approach.**

***Index Terms*—Cefore, ns-3, Simulator, Information-Centric Networking, Content-Centric Networking**

I. Introduction

Information-Centric Networking (ICN) [1], [2], in which users retrieve information by *name* instead of host identifiers, has been proposed as one of the most promising network architectures. One of the important advantages of ICN is in-network cache (or Content Store (CS)), which enables users to retrieve contents from the network to achieve better networking performance.

In order to reveal the efficiency of ICN, performance evaluation is required in numerous situations. Especially in the future Internet, where huge amounts of hosts, devices, sensors, and robots are interconnected, experiments with existing software platforms including network emulators do not scale well. Also, in real-machine experiments, it is difficult to model the mobility of nodes, and the experiments are not reproducible. An ICN simulator needs to be developed to satisfy these demands for performance evaluation.

In this paper, we introduce a network simulator named CeforeSim. It is a fork of *ccns3Sim* [3], which is based on the ns-3 simulator [6], and is *Cefore*-compliant. Cefore [4], [5] is an open-source software platform enabling ICN features. CeforeSim inherits various characteristics from Cefore. It provides unique features such as a transport protocol for real-time video streaming, protocol extension with plugin libraries, and CS separation from the forwarding engine. The main contributions of CeforeSim are (1) compliance with the latest CCNx 1.0 packet format [7], (2) support of Symbolic Interest [8] for efficient real-time video streaming and the other applications equipped with Cefore, (3) implementation of CS separately from the core forwarding engine, (4) provision of a network management tool, CCNinfo [9], which was recently proposed at the IRTF.

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II. CeforeSim

A. Networking

Figure 1 shows the layer abstraction of CeforeSim. CeforeSim is designed in such a way that a single node will have one ICN stack including the ICN core modules, Forwarding Information Base (FIB), and Pending Interest Table (PIT). *Cefnet* is the forwarding engine, and it manipulates these tables to appropriately forward the incoming Interest(request)/ContentObject(response) packets to the outgoing *Interfaces* (neighbors) based on its *Forwarding Strategy*, e.g., shortest-path or multi-path routing.

A significant feature of ICN is that a portion of the nodes holds the cache for close data retrieval. However, the consumption of a large amount of memory for the cache affects the efficient usage of the node resources, which will be a substantial burden. To address this issue, in addition to the original Cefore implementation, CeforeSim implements a *CS manager* (*Csmgr*) that enables data caching in its own memory, which can be separated from the Cefnet. The Cefnet then connects with Csmgr when they use CS. Csmgr is equipped with the nodes according to the network requirements. For example, in resource-constrained sensors, Csmgr implementation might be skipped instead of sharing the cache space with the other nodes using the *External cache* function.

Interest Return is implemented in relation to RFC 8609 [7] in order to convey crucial network events, such as congestion and link failure, as feedback messages. CCNinfo [9] is furnished with Cefnet and utilized to discover the cached contents and/or obtain the name-based routing information. Applications communicate with Cefnet through interfaces.

B. Applications

Client applications in CeforeSim are classified into *Cefgetfile* and *Cefgetstream*. Cefgetfile implements a file download application that reliably retrieves information by using Interest retransmission(s). Cefgetstream is an application for real-time video streaming by leveraging *Symbolic Interest*, which enables low-overhead multicast communications by

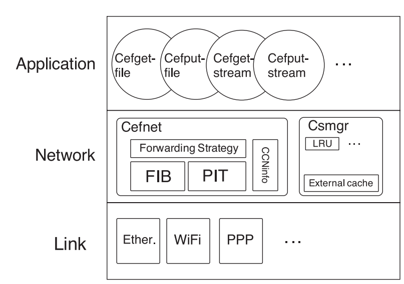


Fig. 1. Layer abstraction of CeforeSim.

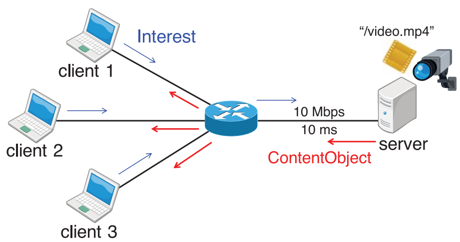


Fig. 2. Evaluation model.

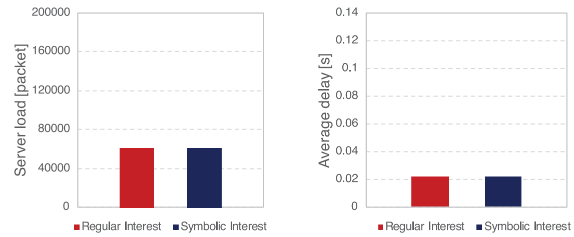
aggregating multiple Interest packets to one Symbolic Interest packet. Server applications that provide contents are *Cefputfile* and *Cefputstream*. Cefputfile is a server class for Cefgetfile and Cefputstream is a server class for Cefgetstream. These applications can the read program syntax of Cefore and load the files that really exist to create ContentObject packets.

III. Evaluation

Figure 2 shows the evaluation model of multicast video streaming. The bandwidth of each link is 10 Mbps, and the RTT is 40 ms. The server node provides an actual video "/video.mp4", whose size is about 60 MB. The payload size is 1,000 bytes. The application is evaluated with different types of data requests: "Regular Interest" and "Symbolic Interest." Regular Interest is a representative request method of CCN [1]. A client application transmits Interest packets without aggregation and sends an Interest packet one-by-one to retrieve a corresponding ContentObject packet. Symbolic Interest is a way to reduce the number of Interest transmissions. The transmission rate is set to 3.33 Mbps with a constant bitrate.

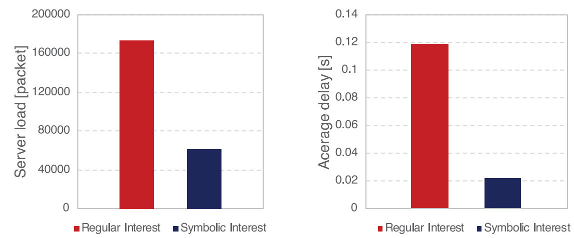
The evaluation metrics are the server load and delay. Server load is defined as the number of ContentObject packets transmitted by the server node. Delay is defined as time interval from when a ContentObject packet is generated by the server application until the ContentObject packet is received by a client application. In the evaluation, we assume two scenarios for the start times of the three clients. In the first scenario, *synchronization*, all the clients simultaneously start Interest transmission. This scenario is unrealistic, but it can confirm the original multicast performance of the CCN. The second scenario, assumes a more realistic situation with a slight time lag for starting the Interest transmission. Applications on client 1, client 2, and client 3 start transmission every 100 ms. We call this scenario as *out-of-synchronization*.

Figure 3 shows the performance in the synchronization scenario. As shown in Fig. 3(a), the server load performance of Regular Interest is comparable with that of Symbolic Interest, because the Interest packets are successfully aggregated at the router and the multicast performs well. As a result, the average delay of both request methods is very short as shown in Fig. 3(b). However, Fig. 4 reveals that this performance dramatically changes in the realistic scenario. Figure 4(a) shows that the server load of Regular Interest significantly increases. Regular Interest packets are not aggregated at the router even if there is only a slight time lag at the start time, which results in failure of the multicast. Hence, as shown in Fig. 4(b), the average delay of Regular Interest increases due to network congestion. Symbolic Interest significantly improves the delay performance by taking advantage of multicast techniques and mitigating the congestion. It provides high performance for real-time video streaming in a stable manner.



(a) Server load. (b) Average delay.

Fig. 3. Performance in the synchronization scenario.



(a) Server load. (b) Average delay.

Fig. 4. Performance in the out-of-synchronization scenario.

IV. Conclusions

In this paper, we developed CeforeSim, which is a Cefore compliant ns-3-based ICN simulator. CeforeSim inherits the important features of Cefore. It updates the latest packet format that is compliant with RFC 8609, supports applications such as Symbolic Interest for real-time video streaming equipped with Cefore, provides a cache management system, Csmgr, which is separated from the ICN core forwarding engine, and is equipped with a network management tool, CCNinfo. In the evaluation, we focused on a real-time video streaming and showed low-overhead multicast streaming with Symbolic Interest compared to the original CCN. As our future work, we plan to enable CeforeSim to adapt to hybrid-simulation environments where the simulated nodes forward packets from the simulator world to the real world and communicate with Cefore running on real hosts, and vice versa.

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