An OMNeT++ Project for Content Centric Networking

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***Abstract*—Content-Centric Networking (CCN) represents a paradigm shift in data communication by focusing on the content itself rather than the traditional host-based approach of delivering data from a specific source. In CCN, data is requested and retrieved based on content names, which facilitates more efficient data distribution, particularly in scenarios involving multimedia and large-scale content delivery. This paper delves into the structural and functional aspects of CCN names, offering a comprehensive discussion on their types, purposes, and mechanisms underlying their use in caching and forwarding. We present a performance evaluation of a CCN network simulated using the *inet* framework, analyzing content delivery diversity scenarios. The results emphasize CCN's potential in addressing the evolving content-oriented demands of modern networks, underscoring its scalability and adaptability.**

I. Introduction

The exponential growth of content-driven applications has exposed the inadequacies of traditional IP-based networking, which is inherently location-oriented. The advent of Information-Centric Networking (ICN) shifts the focus to content, providing a more efficient and scalable alternative. Among ICN architectures, CCN and its derivative Named Data Networking (The majority use of today's networks has evolved over time to become networks for content sharing. This evolution is a problem for current host centric networks as what content required by users have to be mapped to where the content is located. Information Centric Networking (ICN) is a new networking paradigm that treats content as the primitive- decoupling location from identity, security and access- to retrieve content by name. Together with built-in capabilities for caching content, multi-path communications, disruption tolerance and security, ICN is able to leverage advancements in technology to address the issues associated with the mismatch between today's network use and network architecture.) have emerged as prominent solutions due to their robustness and adaptability. Content Centric Networking (CCN) is a clean slate ICN architecture for the future Internet, standardized at the Internet Engineering Task Force (IETF), to ultimately replace the host centric Internet protocol suite (TCP/IP). CCN, described first in [5], and its derivative, Named Data Networking (NDN), has been used in many other networking areas to enable content centric communications. Research ranging from flying networks [6] to sensor networks [1] and many other network types in between [3, 7, 4] use CCN or NDN to enable information centric communications. The IETF, through the Information Centric Networking Research Group (ICNRG) has standardized CCN by approving two RFCs, namely RFC8569 [9] and RFC8609 [8] that describe the operation and message formats. Using these RFCs as the basis, we have developed an OMNeT++ framework to evaluate the performance of CCNs. In this work, we describe this framework, called the Phoenix, elaborating on its constituent components and the operations.

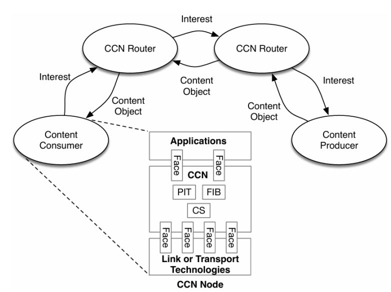

Fig. 1. CCNx Operation and Node Architecture .

II. Methodology

The methodology adopted in this study involves dissecting CCN's operational components, its naming conventions, and its forwarding mechanisms. Furthermore, we utilize the *INET* simulation framework to analyze performance metrics in controlled scenarios. Each aspect is elaborated below.

A. Overview of CCN Names

CCN names are the cornerstone of its architecture. They are structured hierarchically, offering flexibility for applications to encode meaningful data into names. Each name is composed of labeled segments, where labels specify the role or purpose of a segment. This structure facilitates applications such as secure content delivery, version management, and efficient data retrieval. For instance:

- **Versioned Content:** Names can include version identifiers to differentiate between updates of the same content.
- **Segmented Delivery:** Large content can be split into smaller segments, each identified by unique segment numbers.

An example of a CCN name might look like:

```
ccn:/university/course/material/
version=2/segment=5
```

where the labels define the hierarchical structure.

B. Types of CCN Names

Three distinct types of names are used in CCN:

- **Prefix Names:** Represent namespaces, such as `ccn:/content`, encompassing multiple related content objects.
- **Exact Names:** Uniquely identify individual objects.
- **Full Names:** Enhance exact names by including cryptographic hashes to ensure content integrity.

These name types allow applications to interact with the network flexibly, whether requesting a namespace or retrieving specific data.

C. Node Architecture and Forwarding Mechanisms

The CCN node architecture (Figure 2) incorporates several key data structures:

- **Pending Interest Table (PIT):** Tracks Interests awaiting responses. Each entry includes the Interest name and the interface through which it arrived.
- **Forwarding Information Base (FIB):** Functions like a routing table, mapping name prefixes to network interfaces.
- **Content Store (CS):** Acts as a cache, storing previously fetched data to improve response times and reduce network load.

Forwarding in CCN involves matching Interests against these structures. If the Content Store contains the requested data, it is returned directly; otherwise, the Interest is forwarded based on FIB entries. The PIT ensures that multiple Interests for the same content are aggregated, avoiding redundant network traffic.

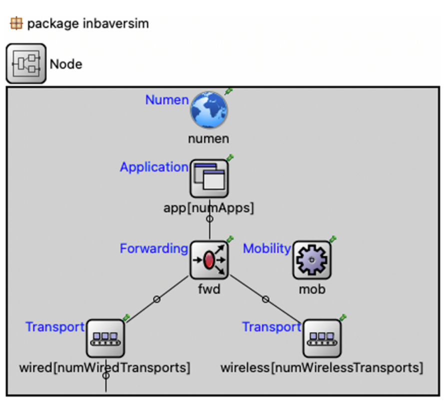

Fig. 2. Protocol Stack of a CCN Node.

D. Simulation Framework: Phoenix

To evaluate CCN, we use the *Phoenix* framework, an OMNeT++-based tool designed for ICN simulations. Its modular architecture supports extensive customization, allowing the evaluation of various scenarios.

1) Simulation Setup:

The simulation network consists of:

- **Clients:** Four CCN clients (two wired, two wireless) retrieve content from servers.
- **Servers:** Two content servers store diverse catalogs for retrieval.
- **Mobility Model:** Wireless clients follow the RandomWaypointMobility model, simulating real-world movement.
- **Content Diversity:** Servers host content catalogs categorized as High, Medium, or Low diversity.

The Simulation parameters are carefully chosen to reflect real-world conditions. The duration spans 48 hours, capturing both transient and steady-state behaviors.

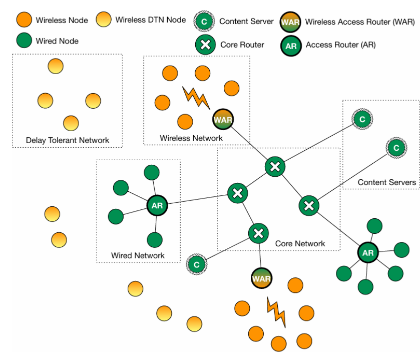

Fig. 3. CCN Network Setup for Evaluation.

E. Node Module

Figure 3 shows these different CCN models and the topologies of the networks they are deployed in.These node models are described below.

- **Wireless Node**-This is a node model that is equipped with a wireless transport to connect to a Wireless Access Router (WAR). Once such a node is in the wireless range of a WAR, it will send and receive CCN messages to and from the WAR.
- **Wireless Access Router (WAR)-**This node model is equipped with two wireless transports, one for direct communications and the other connecting to a WAR. Depending on the nodes in its wireless range, it may communicate over one or both transports.
- **Wired Node-**This is a node model equiped with a wired transport to connect with an Access Router (AR).
- **Access Router (AR)-**This is a node model equiped with multiple wired transports to connect with multiple wired client nodes or other ARs. It is similar in functionality to a router in the Internet.
- **Content Server-** This model is equipped with a wired transport and is deployed with the ContentServerApp to serve content requests arriving from other CCN nodes. These nodes host content.
- **Core Router-** This is a node model that is equipped with multiple wired transports to forward Interests in the direction of where the content are hosted. The content are

hosted in Content Servers and the FIBs of the Content Routers are populated based on the content prefixes hosted in these Content Servers. The PrefixAdvertise applications are deployed in these node models to disseminate content prefixes. They are operate similar to the core routers hosted in the backbone of the Internet.

These are the basic node models. But, new node models with different combinations of transports are possible due to the extensibility of the model framework. For example, a new Wired CCN Node with multiple wired transports can be created to evaluate the performance of multi-path content deliveries in CCN.

III. Results and Analysis

In this section, we present a simple evaluation of a CCN network. The objective of the evaluation is to understand the diversity of the content catalog on the network. Diversity refers to the scale of the variety of content present in the network for users to download.

A. Interest Sending and Receiving

Figure 4 shows the network created to evaluate the effects of content diversity. The evaluation scenario consist of four CCN clients (two wireless and two wired) retrieving content from two content servers. Mobility of the wireless nodes are realized using the RandomWaypointMobility model of the INET model framework. The variation of content diversity is handled by changing the content catalog sizes of content at content servers. Three levels of content catalog variations are considered, referenced as High, Medium and Low. The simulations are run for a 48-hour period.

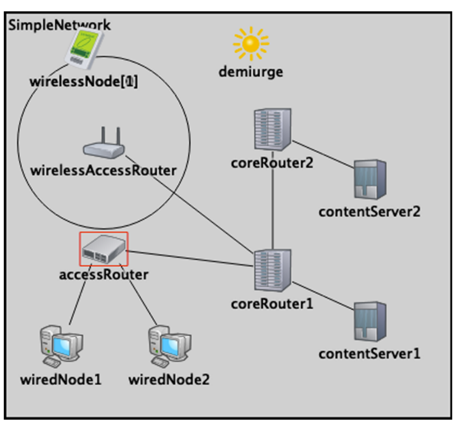

Fig. 4. Content delivery scenerio

B. Throughput Statistics

As depicted in Figure 5, the performance statistics were analyzed to determine the overall performance of the network, including how much content was delivered successfully within a given time frame. Here ,we analyzed interest transmission,retransmission, segment download duration, objects sent byte and more.

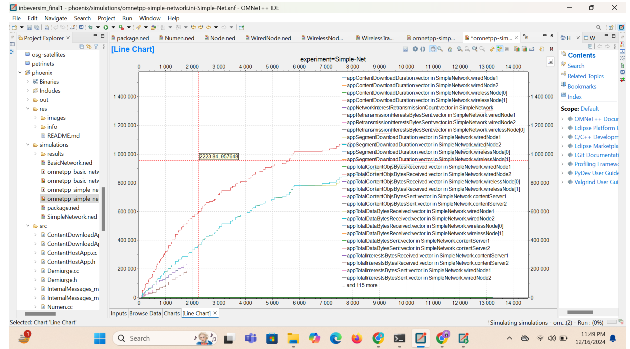

Fig. 5. Progression of Interest.

C. Latency and Bandwidth Implications

High content diversity also has implications for latency and bandwidth usage. As seen from the simulations, increased diversity leads to more traffic directed toward servers, increasing latency and reducing overall bandwidth efficiency. In contrast, networks with lower diversity benefit from higher cache reuse, reducing server dependency and ensuring smoother data flows. This finding underlines the potential of CCNx to optimize bandwidth in high-demand scenarios.

D. Histogram

Figure 6 illustrates the average of every metrics in this network.

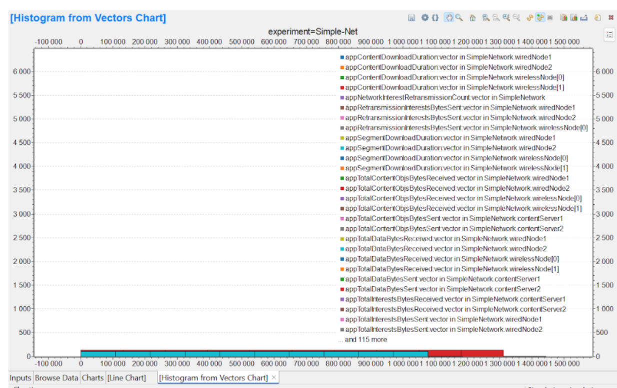

Fig. 6. Histogram.

IV. Future Work

This study demonstrates CCN's versatility, but its potential extends further. Key areas for future exploration include:

- **Dynamic Environments:** Testing CCN in Delay Tolerant Networks (DTNs), Opportunistic Networks (OppNets), and Vehicular Networks. These networks introduce unique challenges such as intermittent connectivity, which could benefit from CCN's caching and forwarding strategies.
- **Advanced Caching Mechanisms:** Developing advanced cache replacement policies and placement strategies to enhance efficiency in resource-constrained networks.

Techniques such as edge-assisted caching or machine learning-based popularity prediction could optimize content placement.
- **Integration with Emerging Technologies:** CCN could be integrated into 5G and beyond networks, leveraging their low-latency and high-bandwidth capabilities. Additionally, exploring its role in IoT (Internet of Things) environments, where devices operate under limited resources, could unlock new use cases.
- **Scalability Enhancements:** Simulating large-scale deployments with diverse topologies to assess scalability. The addition of hierarchical caching strategies and multi-tier architectures could improve CCN's adaptability to global-scale networks.
- **Security Extensions:** While CCN includes inherent security features, such as cryptographic hashes in names, future work could explore enhancements like quantum-resistant cryptography or distributed trust models to further bolster its resilience.

By addressing these areas, CCN can evolve into a highly adaptable and efficient networking paradigm suitable for the demands of next-generation applications.

V. Conclusion

CCN redefines networking by emphasizing data rather than location. The evaluation presented in this paper underscores its potential as a robust and scalable solution for content-driven applications. By demonstrating the relationship between content diversity, caching strategies, and network performance, this work highlights the practical implications of deploying CCN in diverse environments. Low diversity scenarios maximize caching efficiency, while high diversity challenges demand innovative caching and forwarding mechanisms.

The findings also provide a foundation for designing next-generation ICN networks that optimize resource usage while ensuring high reliability and low latency. Future advancements in CCN tools and real-world implementations could address the limitations observed in dynamic and resource-constrained environments. Moreover, CCN's inherent flexibility and adaptability make it a prime candidate for integration with evolving technologies like IoT and 5G, further expanding its applicability.

As CCN research progresses, the lessons learned from this study pave the way for enhanced protocols and architectures that meet the needs of modern communication systems. The potential to provide a seamless, content-oriented networking experience across diverse applications is a testament to the value and relevance of CCN in shaping the future of network communications.

VI. Acknowledgments

We acknowledge the contributions of the CCN research community and the guidance of RFC 8569 in shaping the concepts discussed in this paper.

VII.
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