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Caching and forwarding mechanism for smart grid communications networks

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ABSTRACT

A smart grid aims to integrate alternative and renewable energy sources. NDN has the advantage of being better than IP networks and can optimize the delivery of information. The concept of Named Data Networking (NDN) is designed for smart grid systems. This study aims to implement the NDN concept on a smart grid system and analyze forwarding and caching strategies. The implementation of the system strategy is supported using the NDN network topology, which is based on IEEE 39. The author evaluates network performance by paying attention to parameters such as delay, and cache hit ratio. From the data the author obtained, it can be concluded that the best route-LRU and client control-LRU systems are better choices to be implemented in a smart grid communication system than the best route-FIFO and client control-FIFO systems. In other words, the LRU caching override method is superior to the FIFO caching override method. Meanwhile, the forwarding method does not show significant graphical results. This happens because the forwarding method that the authors use has the same route determination. Something that differentiates between the best route and client control is only the control of selecting the path. The best route is controlled by the producer, and client control is controlled by the consumer.

NOMENCLATURE

Term	**Meaning**
NDN	Named Data Networking
IP	Internet Protocol
LRU	Least Recently Used
FIFO	First In First Out
CS	Content Store
FIB	Forwarding Information Base
PIT	Pending Interest Table
PMU	Phasor Measurement Unit
WAC	Wide Area Control

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1. INTRODUCTION

The smart grid is a modern network infrastructure that aims to improve efficiency, reliability, and security by seamlessly integrating alternative and renewable energy sources through automatic control and modern communication transmission technologies [1]. The smart grid is expected to be able to integrate all aspects of electric power [2]. Currently, power grids in the smart grid field are usually built using private networks, but for cost control, they use dedicated and often not very large bandwidth. In addition, with the increase in the number of nodes monitoring large areas, the existing energy information network is gradually becoming unable to meet the needs of the system. At the same time, the pressure on bandwidth due to large data volumes also has an impact on increasing latency [3]. The biggest cog in the smart grid endeavor is the network and communication architecture, which will facilitate the envisioned flow of information. Therefore, a scalable architecture that meets smart grid communication requirements such as high-volume network traffic, low latency data delivery, and interoperability in heterogeneous networks is essential [4]. The smart grid is expected to integrate individual consumers into the energy market, enabling them to make smart energy transaction decisions. A two-way flow of information capable of seamless, real-time response to requests, monitoring, and maintenance is also required. Named Data Networking (NDN) is a special implementation of information center networking that replaces the use of traditional IP addresses with the use of information content names. NDN also adopts a name-based route and transmission approach and utilizes registration, publication, and communication mechanisms by sending the desired packets and receiving data packets without the need to look up specific host addresses [3]. The concept of NDN is based on identifying data by name, not source and destination addresses as used in Internet Protocol (IP) networks. This is a weakness of IP in terms of flexibility and scalability in the smart grid system [5]. Moreover, this new network architecture uses two types of packets. Interest packets are used to request specific content, while data packets are used to deliver content [2]. NDN has a network caching feature that allows for the storage of packet responses. With this feature, if a user accesses the same data repeatedly, the data can be retrieved from a nearby cache without needing to access the original source. This helps reduce network traffic and the risk of network congestion [3]. According to Gelli Ravikumar [6], NDN is more suitable for smart grid network communication because the NDN architecture on network routers simultaneously forwards the same packet on multiple interfaces to take advantage of available network paths, offering higher reliability and lower latency than IP in terms of package delivery. NDN brings many advantages, especially efficient in-network caching and a content-centric rather than host-centric paradigm [7].

2. THE COMPREHENSIVE THEORETICAL BASIS

2.1 Topology

Basically, the Smart grid network topology in a Wide Area Network (WAN) is mostly described using a tree topology because the parent node is usually connected to many children [8]. In a Wide Area Network (WAN), networks in this area can cover an area of ± 10–100 km with data rates reaching 10 Mbps–1 Gbps [9]. So that it can be categorized by the main or largest components first, such as generators, providers, and substations. The author's research uses the IEEE 39-Bus System topology as a simulation and analysis [10]. This topology originates from the power system network in the New England area of the United States. Based on the IEEE-39 Bus System, an NDN network topology is designed by providing NDN nodes or routers in several areas for data communication processes. In addition, for measuring electrical parameters, which are then processed and transmitted by the router, PMU and WAC devices are provided.

Topology Figure 1 refers to the electric power system standard or represents the IEEE-39 standard. In the network topology, the system uses an NDN router of 28 nodes, which represent the bus system node on the IEEE-39 bus system network and each generator or generator. The router also functions as a producer on the NDN network, while the generator is provided with tools, PMU and WAC, which function as consumers who will receive data according to the desired prefix or interest.

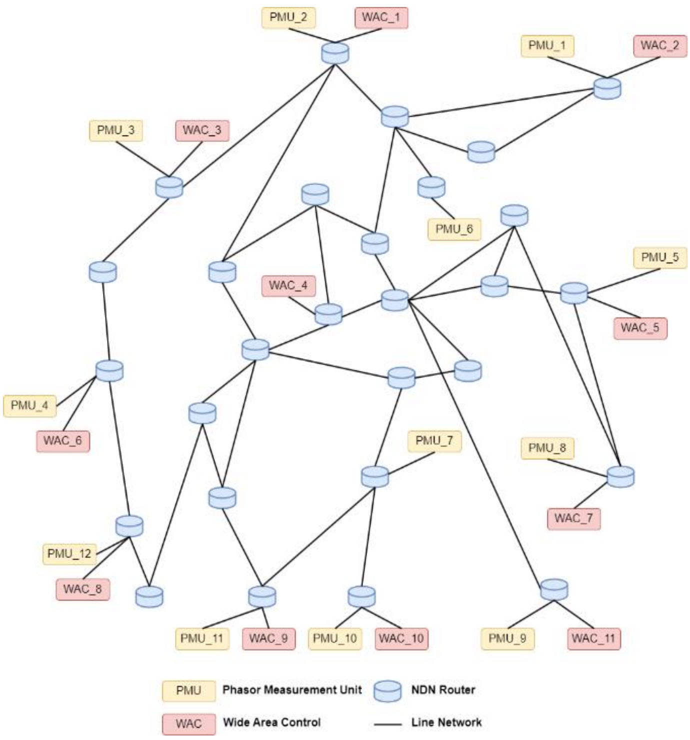

Figure 1. NDN Smart Grid Topology

2.2 Caching

Caching in the network context is a fundamental component of NDN, which aims to store content at various locations on the network without requiring decisions from a particular application layer [11]. The working mechanism of cache processing can be divided into two processes: the process of selecting data to be stored in cache (decision strategy) and the process of selecting data to be deleted from cache when the memory is fully loaded (replacement strategy). When starting the cache system for the first time, the cache memory is still empty. All data sent to the cache node goes through an initial process that determines whether the data is cached or not. When the memory used to store data in the cache is full, the cache cannot store new data. The replacement method is used to delete data that is in full cache and replace it with new data. The author distinguishes two aspects of caching [12]: Selection of Cache Sites: This aspect involves decisions about where the content will be placed in the cache or whether the content needs to be cached at the node level or not. The most common strategies used in NDN are: Leave Copy Everywhere (LCE), Leave Copy Down (LCD), Edge Caching (EC), and Consumer Cache (CC) [13]. LCE places content at every node in the communication path between consumers and producers, which increases content availability but also creates a lot of duplication. LCD stores content at only one node after the producer. EC places the content in the consumer edge node, whereas CC stores the content in the cache directly connected to the consumer. Cache Replacement Selection: This aspect determines which content will be removed from the cache to make room for new content if the cache is full. Some policies commonly used in NDN are: Least Recently Used (LRU), Least Frequently Used (LFU), First-In-First-Out (FIFO), Random Replacement (RR), and Time-to-Live (TTL) [14]. LRU strips out the rarely requested content and selects the most cached content. The LFU outputs the content with the lowest frequency of use and selects the content with the highest usage frequency to be cached. FIFO replaces content that has been in the cache the longest with content that has just arrived. RR randomly deletes content from the cache and replaces it with new content. Finally, the TTL sets a time limit for each cached item, and when the item reaches that limit, it is removed from the cache. In this study, the authors studied two caching strategies, namely Least Recently Used (LRU) and First-In-First-Out (FIFO).

2.3 Forwarding

Forwarding is the process of handing over packages (Interest, data, and Nack) between interfaces. Forwarding strategy involves making decisions to carry out package forwarding, including systematic package delivery destinations and delivery times. The Forwarding Information Base (FIB) has an important role in providing forwarding strategies and determining the next step in the routing process. The Forwarding

Information Base (FIB) consists of a prefix name with the name prefix/electricity/prices/8pm/provx and the outgoing packet interface destination. In NDN, there are two main user roles: data producers and data consumers. As a data producer, the user will send the initial data to the network, and the nodes along the route will receive the data and form a Forwarding Information Base (FIB) table [3]. To retrieve data, the consumer enters the desired data name into the Interest packet and sends it to the network [15]. When a router receives an interesting packet, its first step is to check if there is appropriate data in the content store cache. If the data is available, the packet will be forwarded according to the desired packet request. However, if the data is not in cache, the router will check the PIT table. If a specific package name is contained in the PIT table, this indicates that the data packet requesting the same index has been stored and will be forwarded. Next, the router will add a new input interface to the PIT table. If there is no appropriate record in the PIT table, the interest packet information will be added to that table and forwarded to the Forwarding Information Base (FIB) table for the next step. However, if there is no matching interest packet information in the FIB table, the packet will be rejected. When a node receives a data packet, it checks the PIT table to perform a similar process [3]. If the table contains matched packet records, the data packets are cached and passed accordingly, otherwise, they are discarded. This paper conducts research on two forwarding strategies, namely client control and the best route. In general, the client control strategy gives clients greater flexibility to control routing, while the best route strategy delegates routing decisions to network routers. The choice between these two strategies depends on the needs and wants of the applications using NDN.

3. METHOD

The system to be developed for the smart grid communication system uses Named Data Networking (NDN). This NDN has better advantages than IP, namely the presence of forwarding, which has a fast name search function, intelligent forwarding strategies, and an effective caching policy. In addition to forwarding, NDN also has caching, which can streamline and stabilize the delivery time of information packets compared to unstable IP networks. Before creating an NDN forwarding scenario.

In the early stages of designing a topology using NDNSim tools, a network simulator is used to test Named Data Networking (NDN) network protocols. After designing the topology using NDNSim, the next step is to create forwarding and caching scenarios using the topology that was built in NDNSim.

3.1 IEEE-39 Bus System Topology Design

The topology design can be compiled into a.txt file format, which can be created using text editing software. This topology can be used in NDN scenarios by using a topology reader or connecting nodes directly.

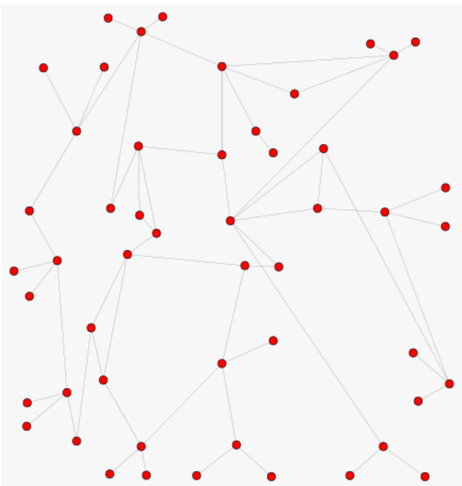

Figure 2. NDN topology on NDNSim

The IEEE-39 Bus topology applied to the smart grid consists of 28 router nodes, 12 Phasor Measurement Unit (PMU) nodes, and 11 Wide Area Control (WAC) nodes [10].

3.2 Implementation of Forwarding and Caching

On NDN (Named Data Networking) forwarding and caching in the context of smart grid, pseudocode allows us to describe the logical steps required to set up an NDN stack, set a caching strategy, configure routing, and install and run consumer and producer applications. Thus, the pseudocode below becomes a powerful tool for visualizing and planning the implementation of NDN forwarding and caching on smart grids.

```
Include necessary libraries

Define the namespace ns3

Define the main function with command line arguments (argc and argv)

  Parse the command line arguments

  Create an AnnotatedTopologyReader object and set the topology file name

  Read the topology file

  Install the NDN stack on all nodes

  Set the Caching strategy and Cache size for the NDN stack

  Choose the Forwarding strategy for the nodes

  Install the global routing interface on all nodes

  Define an array of consumer nodes and a producer node

  For each consumer node in the array:
    - Create an NDN consumer application
    - Set the frequency of Interests
    - Set the prefix for the consumer
    - Install the consumer on the node
    - Start the consumer application at a specific time

  Create an NDN producer application
  Set the payload size for the producer

  Register the producer prefix with the global routing controller
  Install the producer on the producer node

  Calculate and install the Forwarding Information bases (FIBs)

  Install tracers for Delay, L2 and L3 rates, and Content Store

  Set up the animation interface

  Stop the simulator at a specific time

  Install tracers for Content Store

  Run the simulator

  Destroy the simulator

Return 0

End of the namespace ns3

Define the main function outside the namespace and call ns3::main
```

3.3 Test Scheme

In this study, there are testing parameters, namely the change scheme for the size of the content store, replacement caching, interest frequency, and forwarding strategy. When the test parameters are run by the router node as a producer and the WAC and PMU nodes as consumers, more details are in Table 1.

Table 1. Test scheme

System	Content Store Size Changes
Best Route-LRU	20,40,60 (Frequency Interest 100 int/s)
Best Route-FIFO	20,40,60 (Frequency Interest 100 int/s)
Client Control-LRU	20,40,60 (Frequency Interest 100 int/s)
Client Control-FIFO	20,40,60 (Frequency Interest 100 int/s)

According to Table 1, the information provided relates to system performance metrics for various scenarios involving changes in content storage size and various routing algorithms. The size of the change in content storage refers to the size change that has been mentioned, namely 20, 40, and 60. In the best route-LRU scenario, the best route routing algorithm is used with the LRU replacement method. The interest frequency that occurs is 100 interests per second. The best route-FIFO scenario involves using the best route routing algorithm with the FIFO replacement method. The interest frequency that occurs is 100 interests per second. In the client control-LRU scenario, forwarding client control is involved with the LRU replacement method. The interest frequency that occurs is 100 interests per second. The client control-FIFO scenario involves forwarding client control with the FIFO replacement method. The interest frequency that occurs is 100 interests per second.

4. RESULTS AND DISCUSSION

The simulation results using NDNSim 2.9 with the test scheme for changing the size of the content store, packet interest frequency, replacement caching method, and forwarding strategy will be displayed in graphical form.

4.1 Content Store Size Changes

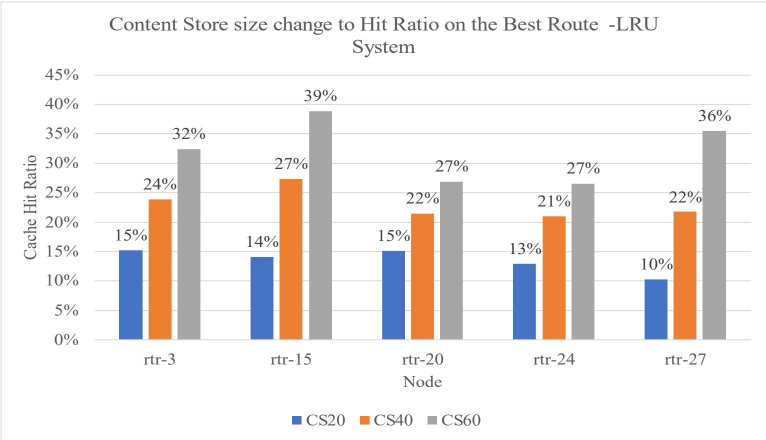

Figure 3. Graph of changes in the size of the Content Store to the Hit Ratio on the Best Route-LRU system

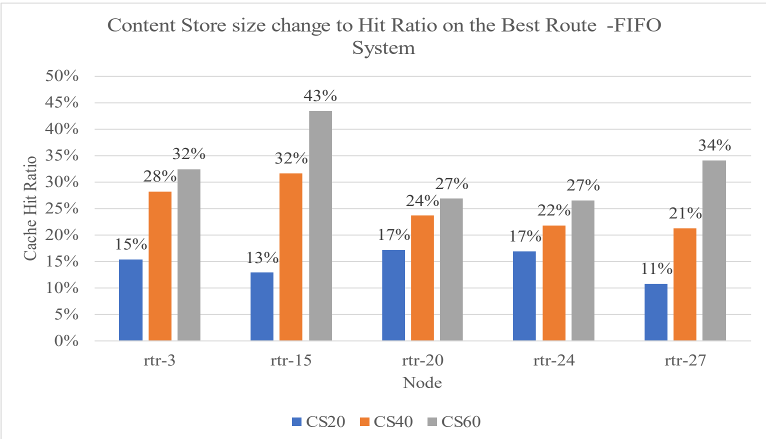

Figure 4. Graph of changes in the size of the Content Store to the Hit Ratio on the Best Route-FIFO system

Figure 3 represents a sample of NDN routers that occur in content store size changes of 20, 40, and 60 against hit ratio using the forwarding best route and the replacement LRU method. Meanwhile, in the graph of Figure 4., using the forwarding best route and replacement FIFO methods on the graph, the percentage of hit ratio or the amount of data that has been successfully fulfilled by the cache can be seen. The average percentage with the highest hit ratio is owned by the best route-LRU system on content store size changes. In Figure 5, there is a graph of the change in size of the content store to the hit ratio using the client control system with the LRU replacement method.

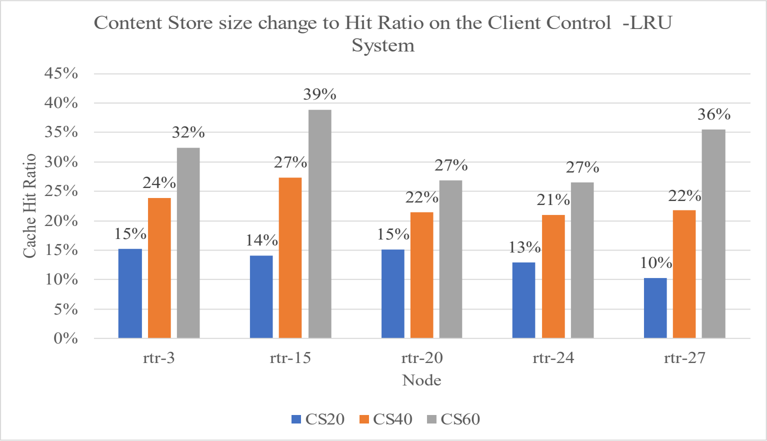

Figure 5. Graph of changes in the size of the Content Store to the Hit Ratio on the Client Control-LRU system.

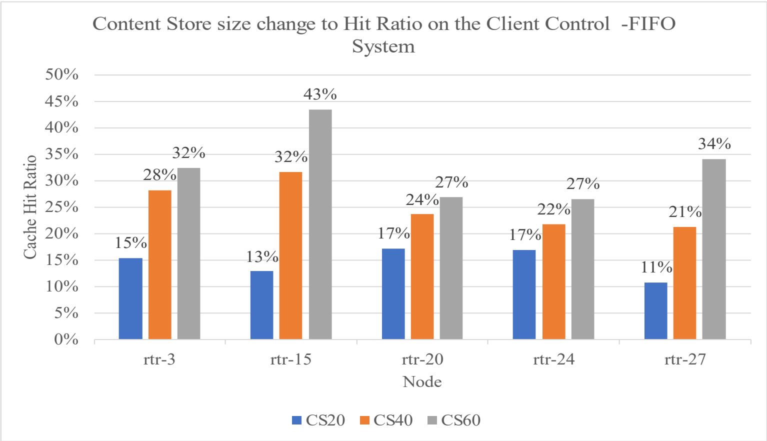

Figure 6. Graph of changes in the size of the Content Store to the Hit Ratio on the Client Control-FIFO system

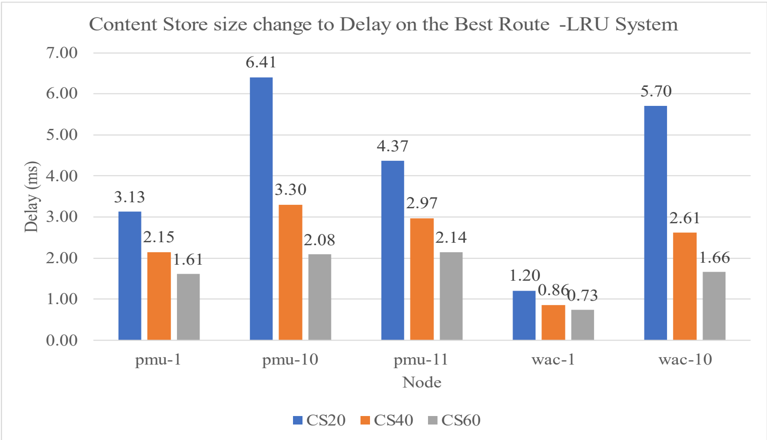

Figure 7. Graph of Content Store size change to Delay on the Best Route-LRU system.

In Figure 6. is a graph of the change in size of the content store to the hit ratio using the client control system with the FIFO replacement method. The average comparison with the highest hit ratio is in the client control-LRU system. On the graph of Figure 3, Figure 4, Figure 5, and Figure 6., it can be concluded that the method with the highest hit ratio is obtained from the system with the LRU replacement method, because the hit ratio can be said to be directly related to the replacement method used. Delay is an important parameter in the network; if a network has a high delay, it can be said that the network is not feasible to use.

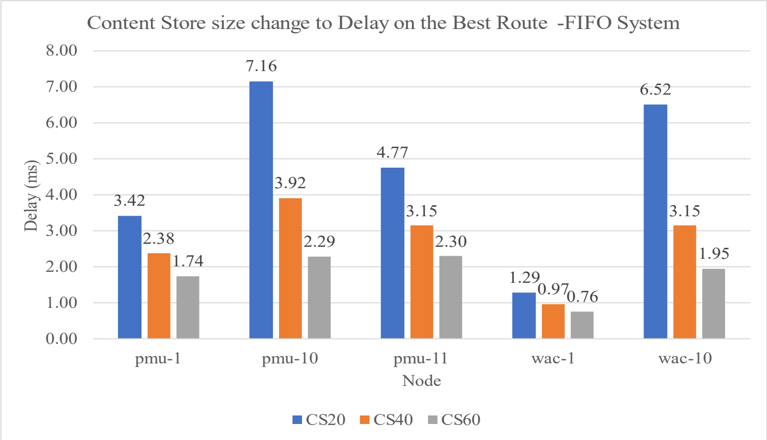

Figure 8. Graph of Content Store size change to Delay on the Best Route-FIFO system.

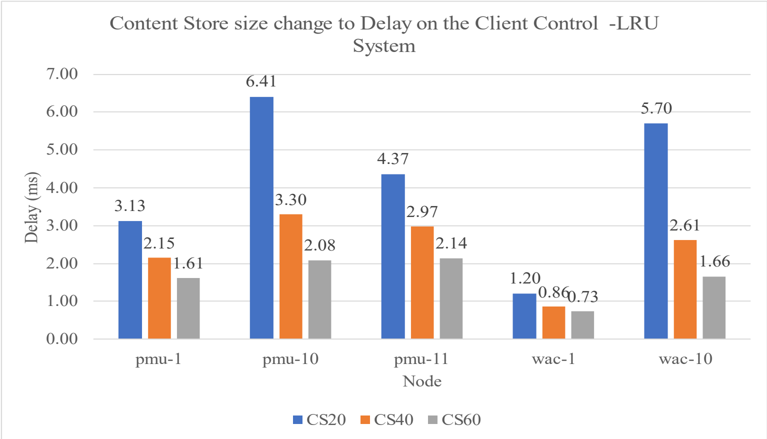

Figure 9. Graph of changes in the size of the Content Store to the Delay of the Client Control-LRU system

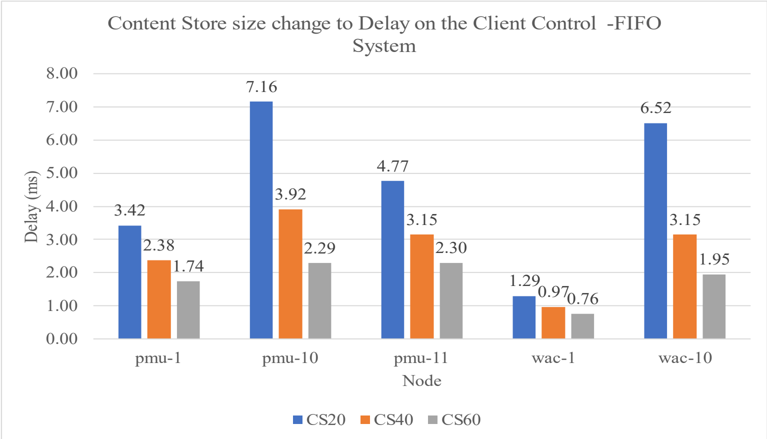

Figure 10. Graph of Content Store size change to Delay on the Client Control-FIFO system

Graph in Figure 7 and Figure 8 represents a sample of consumer devices on content store size changes to network delay or the time that these devices can find the content they are looking for in the NDN network. Based on the graph of Figure 7 and Figure 8, the lowest average delay is found in the best route system with the LRU replacement method. In Figure 9 and Figure 10. displays the effect of changing the size of the content store on delay is displayed with each replacement method and forwarding strategy according to the previously determined subsystem.

In this experiment, the forwarding method did not show significant graphical results. This happens because the forwarding method that the author uses has the same route determination. Something that differentiates between best route and client control is only in the path selection control. Therefore, the caching method will play a role in delaying according to the NDN concept. It can be seen that the caching method that gets a fairly low delay rate is the Least Recently Used (LRU) method compared to the First In First Out (FIFO) method. It can also be seen in the graph that the larger the content store, the smaller the delay it has. That's because more and more content can be stored in the cache with a larger content store. So, consumers can easily find the content they are looking for.

Table 2. Final Result

Content Size Change Scheme						
System	Delay			Hit Ratio		
	CS 20	CS 40	CS 60	CS 20	CS 40	CS 60
Best Route-LRU	3.70 ms	2.13 ms	1.47 ms	7%	12%	17%
Best Route-FIFO	4.05 ms	2.36 ms	1.61 ms	7%	12%	16%
Client Control-LRU	3.70 ms	2.13 ms	1.47 ms	7%	12%	17%
Client Control-FIFO	4.05 ms	2.36 ms	1.61 ms	7%	12%	16%

Table 2 is the result of testing the performance of the forwarding and caching systems against changes in the size of the content store. The performance of the system is measured using the delay parameter, which shows the time it takes to send data from the consumer back to the consumer, and the hit ratio parameter, which shows the ratio in percentage, which represents requests served by the local cache without retrieving data from the source (producer).

Based on the delay measurements in Table 2, the system scheme with the LRU caching method, namely Best Route-LRU and Client Control-LRU, obtains the smallest average delay with values of 3.70 ms, 2.13 ms, and 1.47 ms for each change in content store size. This shows that this network system has a higher speed for sending and receiving data. Whereas in the measurement of the hit ratio, each system does not have a significant difference, and a difference of about 1% is obtained in the Best Route and Client Control forwarding systems that use the LRU caching method for content store changes of 60 with a percentage of 17%. Therefore, it can be concluded that the Best Route-LRU and Client Control-LRU system schemes provide lower delays and higher hit ratios than the other schemes.

5. CONCLUSION

In this paper, the authors model the NDN network to be applied to the smart grid using ndnSIM 2.9. The author tested various schemes, which included Content Store resizing, Replacement cache methods, and Forwarding strategies. The author uses the IEEE-39 Bus topology for this experiment. Furthermore, the authors evaluate network performance by paying attention to parameters such as delay, and cache hit ratio. Based on the graphical results obtained from each model, changes in cache size: Best Route-LRU and Client Control-LRU systems have the same delay time for each change in content store size, namely 3.70 ms, 2.13 ms, and 1.47 ms. Meanwhile, the Best Route-FIFO and Client Control-FIFO systems have slightly higher delays, namely 4.05 ms, 2.36 ms, and 1.61 ms. For Hit ratio, the Best Route-LRU and Client Control-LRU systems have the same hit ratio at each change in content store size, namely 7%, 12%, and 17%. Meanwhile, the Best Route-FIFO and Client Control-FIFO systems have the same hit ratio for each content store size change, namely 7%, 12%, and 16%. From the data the author has obtained, it can be concluded that the Best Route-LRU and Client Control-LRU systems are a better choice to be implemented in a Smart Grid communication system than the Best Route-FIFO and Client Control-FIFO systems. In other words, the LRU cache override method is superior to the FIFO cache override method. Meanwhile, the Forwarding method does not show significant graphical results. This happens because the Forwarding method that the author uses has the same route determination. Something that makes the difference between Best Route and Client

Control is only in the control of selecting the path; Best Route is controlled by the producer, and Client Control is controlled by the consumer.

This research can be used as evaluation material and input for other parties in reducing delay and increasing the hit ratio in a smart grid network system. For further research, the caching and forwarding methods used need to develop more system variables, for example, for multicast and NCC forwarding. Then for caching, for example, Least Frequently Used (LFU) and Random Replacement (RR), as well as involving more varied test scenarios in conducting tests that can show changes in delay and hit ratio.

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