Information-Centric Networking-Enabled 5G Network Support for IoT-Based Environment

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Abstract- Fifth-generation (5G) technologies are considered as next-generation networks having new features and good quality of services. It also promises higher data rates in comparison with existing 4G technology. As, Internet of Things (IoT) requires heterogeneous networks to process a large amount of data, so researchers may need to address different design requirements and challenging issues related to delay and jitter on the access side by the integration of Information Centric Networking (ICN) with 5G IoT network. In this paper, we present a comprehensive analytical study of ICN based 5G IoT networks to identify the limitations and major research gaps related to energy consumption and best forwarding strategy. Some of the challenging issues related to ICN i.e. security, energy, load balancing, routing protocols overheads, content delay also been discussed. At the end of this paper, a case study has been presented to discuss and evaluate performance of delay and jitter metrices on the access side of ICN based 5G IoT network with the help of different scenarios.

Keywords- Information Centric Networking, 5G based IoT, Case study of ICN, Challenges of ICN

I. INTRODUCTION

Fifth Generation (5G) technology [1] plays a vital role in the upcoming era where the users get their desired data at a higher speed. 5G technology focuses on two concepts. First- Application Centric Networking (ACN): A concept in which an end-to-end path is established to the requested server in an application centric network. Afterward, the data is sent from the server to the intended user who has requested the data. Second- Information Centric Networking (ICN): A concept according to [2], the requested data in ICN is located on the access network. It is done by introducing a cache on the access side of the network instead of on a server to reduce the delay. Thus, ICN provides services without establishing an end-to-end connection to a server. The users get their desired data from the access side of the network with less time and delay. The architecture of 5G based ICN network is presented in Fig 1.

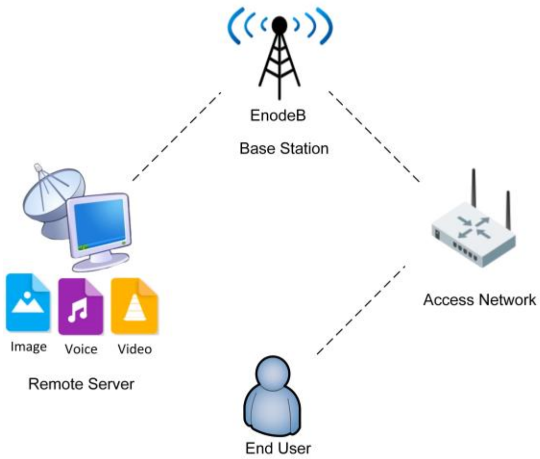

Fig 1: Overview of 5G based ICN network

Modeling a 5G based ICN is very crucial. Generally, three deployments models, presented in [3], have been used for 5G based ICN infrastructure: (a) Overlay Model, (b) Integrated model, and (c) Flat model. Fig 2 illustrates the deployment model of 5G based ICN network. We briefly describe these three models as below:

- In the overlay model, current IP infrastructure is used for efficient utilization of ICN service.
- In an integrated model, tight integration mechanism between the ICN and the core network infrastructure is adapted.
- In the flat model, the ICN and the current network infrastructure is deployed as a separate entity.

The current architecture of 4G LTE [4] did not provide several features such as naming strategy, efficiency, security, contextual communication, and mobility.

The ICN based 5G network eradicates all above mentioned problems in 4G LTE by giving some features[3] that includes naming strategy, end-to-end based slicing, and mobility as a service. All of these features are briefly discussed below.

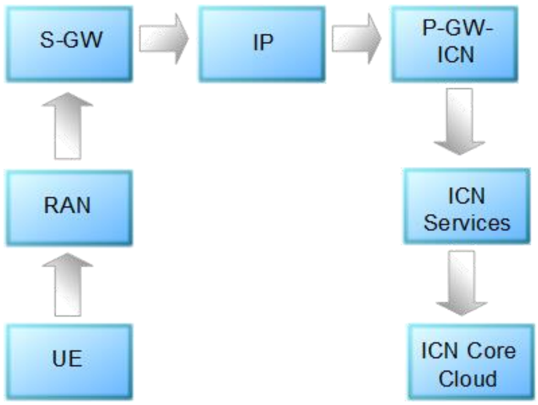

Fig 2: Deployment sequence of 5G based ICN network

By employing the naming-based strategy in ICN, we can eradicate the concept of the conservations of IPs. ICN provides a key role in the upcoming trending technology such as the Internet of Things (IoT) [5]. As, IoT could potentially connects billions of devices to the internet therefore, it is responsible for making heterogeneous networks[16]. The scalability of IoT devices can only be achieved through ICN characteristics that include naming strategy in-network caching and content-based delivery. Efficient performance of ICN can be achieved in Ad Hoc Network. The rudimentary requirements for this purpose include session less and per hop-based name resolution.
The second feature of ICN based 5G network is end-to-end slicing when deployed in 5G architecture. Slicing provides certain services concerning the nature of the applications. The slicing is done between the 5G architecture and the current IP based infrastructure. To do the slicing, a framework is introduced in [3], which bears five different Functional Planes (FPs) namely FP1, FP2, FP3, FP4, and FP5. The functionality of these FPs are given below.

- Service business plane lies in FP1. It primarily provides an interface between software architecture and external 5G clients. Execution of various APIs are also another functionality of the FP1 layer.
- FP2 provides services such as service orchestration and management plane.
- FP3 consists of global orchestration.
- The services such as domain name orchestration and infrastructure plane are considered to be the portions of FP4 and FP5, respectively.

The last features of ICN based 5G network is mobility as service [3] that includes six operations: 1) Network slice bootstrap, 2) Mobility Network Slice bootstrap, 3) Conference slice, 4) User Equipment (UE) bootstrap, 5) Dynamic mobility, and 6) Handling seamless connectivity.
By using the Base Network Slice VNF Orchestrator [3] we can support ICN service virtualization. It is done by enabling the UE first to provide security functions and appropriate gateway. Mobility service is the functionality of Mobility Network Slice bootstrap. Conference slice gathers all the basic requirements and further mapped for load management purposes. Afterward, the UE bootstrap and dynamic handling mobility are being performed. In the last phase, the late binding mechanism is executed that is the functionality of handling seamless connectivity.
In this paper, we present the recent studies related to ICN based 5G IoT networks. We also discussed some challenges and limitations regarding ICN based 5G IoT network. Delay in content and jittering of packets are major problems in 5G based ICN IoT networks. So, a case study has been done along with proposed solution by considering these two performance metrics i.e. delay and jitter. We designed the 5x5 grid based topology for this purpose and simulated different experimental scenarios for our proposed solution. Our results showed less delay in terms of content delivery to consumers.
The rest of the paper is organized as follows: Literature review is presented in section 2. Section 3 describes the research gaps related to ICN. The challenges and their proposed solutions are discussed in section 4. A case study has been presented in section 5. Section 6 concludes the work.

II. LITERATURE REVIEW

Several researchers have targeted different areas of ICN based 5G IoT network. We discussed some of the recent studies related to ICN based 5G IoT networks which are as follows.

a) Latency Aware Cache

The researchers in [6] implemented a policy in Latency Aware Cache. They described that the out-going data must be stored in the cache or discarded from the cache located on the access side of the network. They tested their proposed technique on two different topologies: (a) line-based topology, and (b) tree-based topology. In line topology, three hops exist that are routers. These routers on the access side of the network maintain a cache of almost equal size between the client and the server. Whereas, the tree-based topology comprised of eight hops having fixed cache size between clients and server in top-down approach i.e. keeping the users at the bottom and servers at the top of clients. The LAC methodology experiences better results in terms of content mean delivery time. The key advantage of employing this approach is that the client accesses its data from the server in less time and delay. The important question that arises here is the dynamic caching size. However, considering dynamic caching size, will this technique remain robust? If the co-routers on the access side of the network go down then chances for congestion in the system will occur and packets will drop gradually, therefore requires a robust mechanism in this regard.

b) Caching Sharing strategy

In another study, the authors in [7] worked on a caching sharing strategy for IoT based 5G systems. They employed this strategy on BS, neighboring smart devices, and in-network routers. Energy efficiency is a main issue in wireless-based systems. The wireless-based routers consume much more energy once the computing and caching capability is performed on the access side of the network. So, the router's energy will be depleted rapidly. The authors in [7] evaluated the performance of Energy Efficiency in a scenario based study. They carried out experiments by opting for three different strategies for EE purposes: (a) the Multiple-Input and Multiple-Output (MIMO) based antenna with long distances evaluation, (b) short distances based, and (c) core network. The authors formulate the set of equations for EE. To evaluate the energy efficiency, they opted following parameters for performing experiments:

- A carrier frequency of 20 MHz is used, and
- MIMO based antenna.

MIMO based antenna accepts multiple inputs from the environment and sent out multiple outputs. Multiple inputs and multiple output operation have been carried in the form of RF electromagnetic beam. However, the authors didn’t conduct the experiments by changing the carrier frequency to evaluate the EE performance.

c) Coupling of ICN and Network Function Virtualization

The authors in [8] proposed a combination of two well-known technologies: (a) ICN, and (b) network function virtualization (NFV). They merged both technologies and introduced a new architecture. They considered three performance metrics for the results: (a) Efficiency, (b) Utility Function, and (c) end-to-end performance of the 5G wireless network. The authors also worked on the caching problem that arises in backhaul alleviation. They considered heterogeneous networks comprise of macro cells and 12 small cells having in-network caching capability for evaluating the virtual resource allocation and in-network caching strategies. Their experimental scenario comprises of two Radio Access Networks Infrastructure Providers (RAN InPs), two backhaul Infrastructure Providers (InPs), one Mobile Virtual Network Operator (MVNO), and three Service Providers (SPs). The RAN InP1 has one macro Base Station (BS) and six small BS whereas RAN InP2 consists of six small BS only. During their experiments, the location of macro BS is fixed which was in the center and other small 12 BS are uniformly distributed.

The results are better when the author integrates both technologies: ICN and NFV. Their results showed better performance concerning the backhaul alleviation. However, the authors did not consider the microcell strategy while conducting their experiments.

d) ICN network Virtualization with virtualized Information Centric Network

The authors in [9] presented a virtualized Information Centric Network (vICN) platform that helps simplify the management and deployment of the ICN network. Virtualized Ethernet interfaces are used to integrate CICN suit and Linux containers. The pictorial representation of ICN network virtualization with vICN is shown in Fig 3 [9].

Some of the key features of vICN are as follows. ICN network deployment became easy and quick due to vICN. It provides the best platform to conduct experiments and testing before implementing it on the operational network. Network performance is analyzed based on statistics generated by the live monitoring facility of vICN. Live topology changing feature of vICN is critical, especially in situations such as the deployment of IoT infrastructure.

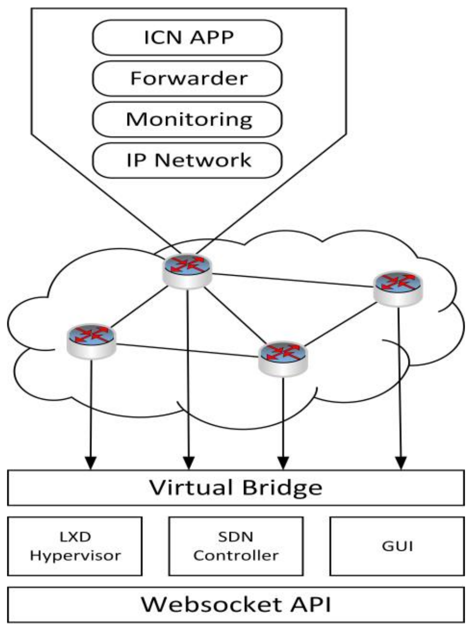

Fig 3: ICN network virtualization with VICN [9]

Per packet load balancing is another key feature of vICN. vICN platform integrates features of simulators and testbeds to conduct the experiments. Although it provides nearly a perfect platform, yet it inherits the weaknesses of simulators to a very small extent while designing a network and predicting system behaviors. It can be employed for small-scale experimentation with the limited number of nodes only due to its limitation of managing large-scale network. These are some of the shortcomings of vICN. No ICN technologies can be gathered under its umbrella due to its limited diversity.

e) Deploying ICN islands over IP

Content distribution via caching is among the salient features of ICN. IP protocol may be employed for this purpose. However, due to its host-to-host communication nature, content sharing using an IP network is a complicated task. In this study [10], the researchers introduced a business model by deploying ICN islands on the edges of the IP network similar to IP based business model where a customer is charged for data usage and capacity of the link. The deployment of ICN islands over IP is presented in Fig 4 [10]. Their proposed models have some benefits, which are discussed further. Caching deployment is the operator's concern and customers are unaware of it. Like IP business model, in the ICN business model a customer is charged for the amount of data used and link capacity. It is not necessary to implement the business model locally because content sharing can be done using routing protocols. A customer can access the contents of ISN Island using a proxy on the internet. A large ICN island can be formed by merging multiple local islands. The shortcomings of the ICN business model are as follows. The Core network of ICN islands is IP-based; making it complicated to decide how to charge the customer for content sharing becasue IP lacks the facility of content sharing. For ICN connectivity, routers are yet to be developed for interdomain routing.

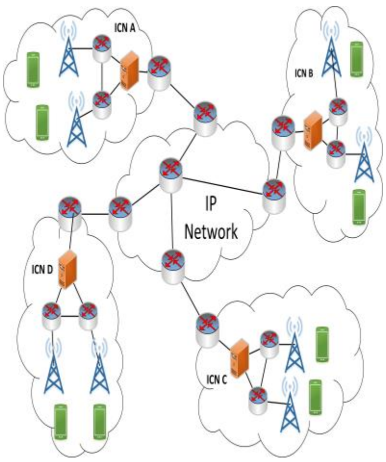

Fig 4: Deploying ICN islands over IP [10]

f) Forwarding strategies in ICN networking

The researchers in [11], proposed three forwarding strategies for 5G ICN networking applications such as smart grid, etc. They evaluated these strategies using ndnSIM simulator and measures the performance of the network in regard to latency and throughput. The forwarding strategy for 5G ICN networking is shown in Fig 5 [11]. These strategies are briefly described in subsequent sections.

i) Multicast

In this methodology, a data packet received at one interface of the router is forwarded to all interfaces except the downstream interface. The working principle of this strategy is: as a packet takes multiple paths to reach the same destination, therefore, significantly increases the probability of packet delivery. If a link is down or congested, then the packet will be forwarded to other routes to reach the destination, hence in this way link redundancy is increased. On the other hand, it has few shortcomings: (a) wastage of bandwidth due to the abundance of traffic on links. (b) Since a single packet is needed at the receiver, discarding the rest of the copies, after the packet is delivered, requires extra processing.

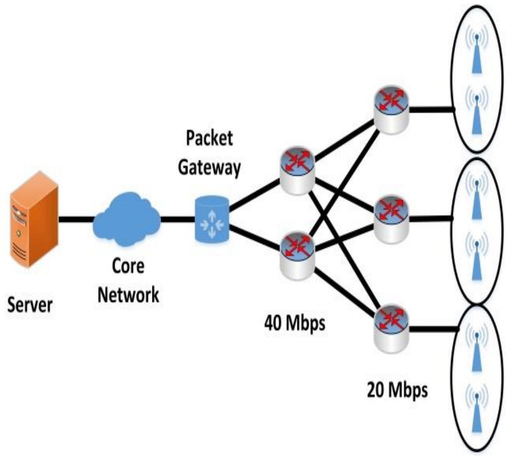

FIG. 5: Forwarding Strategies in ICN [11]

ii) Best routing

In this case, the all costs of all links to the destination are calculated, and the packet is forwarded to a link with the lowest cost. If the packet is lost on the path, then the packet is retransmitted via a link having cost higher than the previous link. One of the main advantages related to the best routing strategy is the lowest link. It has low latency so performance in terms of latency improved. This strategy has shortcomings too. Every time a packet arrived on the router interface requires recalculation of all links cost to determine an interface with minimum cost. It requires extra computing and eventually caused extra overhead on the links. It might be possible that a link with minimum cost is not suitable for several reasons such as congestion. Under stress, the traffic delay varies significantly, so it is not recommended for delay-sensitive applications.

iii) Content Centric Networking

The Content Centric Networking is also known as NCC. In this methodology, delay for all paths is calculated. The packet is then forwarded to an interface with the lowest delay and waited for 8 to 12 milliseconds to get acknowledgment. If the acknowledgment is received within the stipulated time, the waiting time is reduced by 1/128 for the next packet but increased by 1/8 times otherwise. We will now explain some of its advantages such as low performance in terms of latency, data transmission is steady and jitter. The main limitation of this strategy is delay estimation. For delay estimation of all routes, a complete picture of the network is needed.

g) IoT Edge Network

In this study, the authors in [12] proposed a service slice for IoT devices. IoT devices connected with actuators and sensors are used for designing a network comprising of lightweight ICN stacks that provides facility to users to implement their policies using their mobile devices. Fig 6 [12] depicts the ICN slicing framework to build the IoT Edge Network.

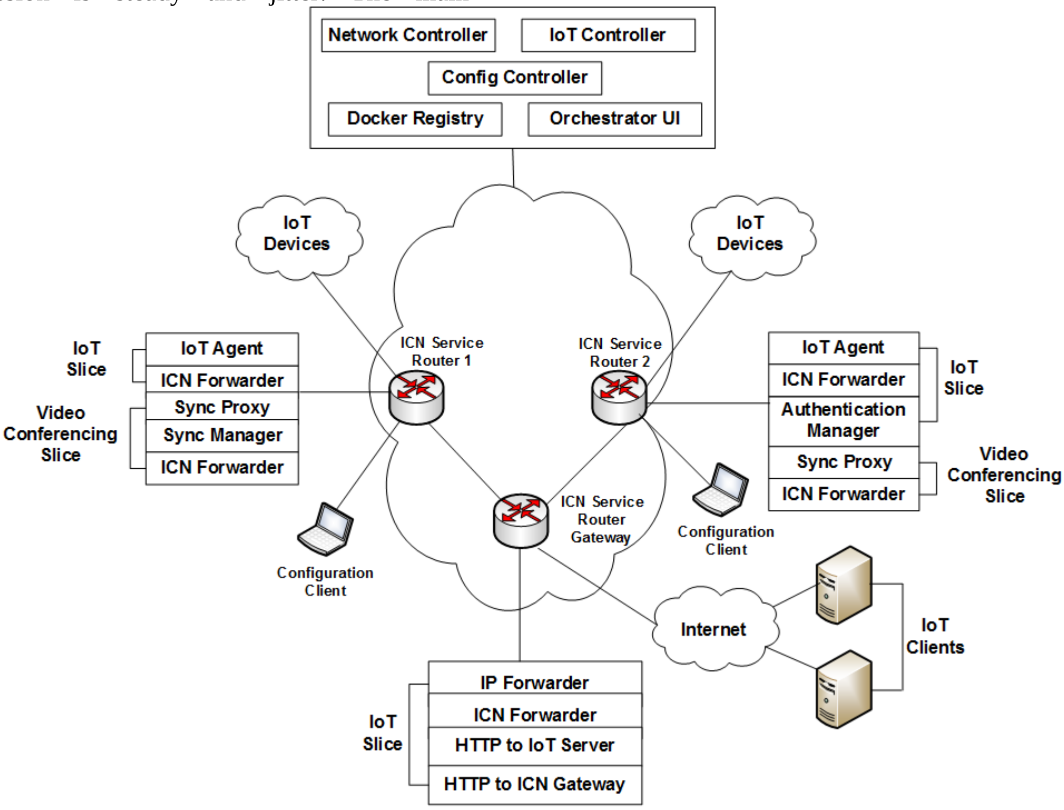

Fig 6: ICN slicing framework to build an IOT edge network [12]

One of the main advantages of IoT edge network is that it provides data processing capability on the access network rather than on the core network. Through this processing capability on the edge network, we are able to spare the extra traffic loads on the backbone links as well. By employing IoT, the latency among edge routers and IoT devices has been improved. With the help of IoT edge network, the scalability and reliability are also increased because of the lower data traffic on the edge routers of IoT edge network. This lower data traffic is achieved due to the processing capability on the edge network. The limitations of the IoT Edge network is that we are unable to get a perfect realistic environment

h) Disaster Information Sharing System

The researchers in [13] tested the ICN in a disaster management scenario. The main idea behind this approach is that the delivery of particular data from the access side of the network router by employing ICN in the case of disaster scenarios. They introduced a methodology known as the Disaster Information Sharing System. This technique uses the coordinates for delivering disaster information to the client. The name prefixes are embedded with a coordinate for content delivery to a particular user. For the first time, the client statically fills out the forms having information in respect of name, address, and coordinates of the location. This information is stored on the access side of the network router in the cache. They conducted experiments based on simulations and achieved better results concerning the content delivery to particular persons to its coordinates. However, the dynamic versions can integrate at the client side for carrying out the information from the client rather than the static version. From all of the above literature review we find out the limitations in those studies and those are mentioned in Table 1.

TABLE 1: Critical Analysis of ICN-based Studies

Findings	**Techniques**	**Limitations**
Latency Aware Cache [6]	Proposed a method for Improvement in content mean delivery time	Dynamic caching size Co routers go down
Caching sharing strategy Energy Efficiency [7]	Derive the sets of equations for energy efficiency. Author purposes EE improvement with MIMIO based antenna.	Carrier frequency not changed for evaluation of the EE performance.
Coupling of ICN and network function virtualization [8]	Backhaul alleviation technique proposed.	Microcell stagey
Virtualized ICN platform [9]	ICN network deployment became easy and quick due to vICN approach. The proposed approach is very close to the real environment	Weaknesses of simulators to a very small extent Employed for small-scale experimentation with the limited number of nodes.
ICN business model by deploying ICN islands on the edges of the IP network [10]	A framework for Caching deployment is the operator's concern. ICN business model a customer will be charged for the amount of data used and link capacity.	Core networks become complicated to decide about charges of content sharing from the customer. Inter-domain ICN routing connectivity.
Forwarding strategies for 5G ICN networking [11] Multicast: Best Routing: NCC:	Using the multicasting approach the probability of packet delivery has increased significantly. Latency improved. Low delay, performance in terms of latency improved.	Wastage of bandwidth increased The minimum cost link is not suitable For delay estimation of all routes, a complete picture of the network is needed.
Service slice for IoT devices [12]	A service slice mechanism introduced to enhanced the Scalability and reliability.	A simulator-based environment cannot simulate perfectly a realistic environment. Services run over IP network
Disaster Information Sharing System [13]	Content delivery sharing system for persons with respect to its coordinates	Dynamic versions at the client side for carrying out the information

III. RESEARCH GAPS

5G based ICN is designed for heterogeneous networks for accessing the required data from the access side with less time. This method has certain limitations such as energy consumption, content mean delivery time with respect to variable cache size, and dynamic naming strategy. Although numerous research work has already been done to identify the best forwarding strategy for 5G ICN. However, the optimized performance is big challenge yet because each strategy has its pros and cons. Furthermore, 5G applications have different requirements of latency and peak data throughput. Therefore, an optimum-forwarding scheme is the need of time. Due to the unavailability of real-time environment of 5G, testing and opting for an optimum scheme is still a challenging task. ICN has adopted caching with computing towards 5G based IoT devices which consumes tremendous amount of energy [14] that causes energy issues in those areas where the electricity is not widespread. Therefore, Energy consumption is a major problem regarding ICN deployment in such areas where electricity infrastructure is unavailable. To cope with this problem, as discussed earlier, we need to employ some sort of energy transfer technique. The EnB consist of various antennas, which emits electromagnetic radiation. So, every EnB receives and transmits an EM pattern, and can convert a electromagnetic radiation into electrical energy to attain and balance the energy requirements. It introduced some sort of thresholds levels to reduce overcharging effects. With 5G, IoT based devices having omnidirectional and unidirectional antennas are the best choices.

IV. CHALLENGES

Although 5G based IoT ICN network is better in terms of computing and caching facility that is provided on the access side of the network. However, there are some versatile challenges related to 5G-based IoT ICN networks which are discussed separately in the following section.

a) Security

In the 5G-based IoT ICN network, the data is cached on the access network. Mobile payments and digital wallet applications are widely used for this purpose [15]. With these applications, an intruder may breach the network and stole data; thus, security is compromised. Once the intruder has access to the data, he may deploy false data or information. To avoid this, a secure mechanism of encryption and decryption should be introduced for the security of data cached on the access network.

b) Energy

In the 5G-based IoT ICN network, caching is implemented on the access side of the network; results in the consumption of immense amount of energy [14]. An efficient energy approach is needed to reduce the energy consumption and at the same time the ICN network should not be down due to the depletion of energy.

c) Load Balancing

As every request of the user is resolved on the access side of the 5G based IoT ICN network and path is established from the user to the access network where the cache is deployed. So, the access network must be prepared to handle the huge load in case of disaster. An efficient scheduling mechanism must be employed to resolve load balancing.

d) Overhead of routing protocols

The 5G based IoT ICN network is capable to communicate with heterogeneous technologies[17]. In such an environment every communication technology designs its routing protocol to communicate with another network which increases the overall overhead of the routing protocol itself. So, a need arises to design a common routing protocol which will be used in the heterogeneous networks. By employing an efficient common routing between heterogeneous networks, we can overcome the routing protocol overhead. The findings indicate here [18] there is a diverse situation with a large dependence on deployment. Multitype protocols are more adaptable, while ICN protocols are tough in heterogenous environments. The claim resources competitively on congested links, while CoAP politely coexists on the price of its performance.

e) Content Delay

As the cache is on the access side of the 5G based IoT ICN network and delay is an important factor in it. If the delay is higher, the user gets their desired content in high time which are not good in real-time applications. So a case study should be needed to design such a topology that minimizes the delay factor.

The paper [19] discusses the use of network slicing and Multiple-Access Edge Computing in 5G networks to facilitate the deployment of Information-Centric Networking (ICN) for low-latency data services. ICN provides multifeatured such as cashing with limited latency in data communication. However, most existing approached do not include caching resource allocation in the dynamic and hierarchical environment, which can impact user-requested latency and the operator's revenue.

The study [20] proposes a new scheme that combines Edge Computing with ICN for smart cities in IoT-based environment to manage multimedia traffic. It supports content caching and decision making using various parameters. However, elaboration of each step regarding edge computing in 5G networks may require.

From all of the above research gaps and challenges, as discussed in section 3, and section 4, we are going to address the delay in content problem and jittering of packets. The case study for this is discussed in section 5.

V. CASE STUDY

For ICN-based 5G network we proposed a case study to evaluate the delay of contents to consumers located on the access sides cache of ICN and the jittering effect of packets.

To evaluate the delay and jittering effect of packets, a scenario has been designed for this purpose in which total of 25 consumers were arranged in the form of (5 x 5) based grid topology. The consumers in that topology tried to get their contents from the cache located on the access node of the network.

First, an experiment is conducted with five consumers requesting 100 bytes, 500 bytes, 1000 bytes, and 1500 bytes of data. A delay has been calculated across each number of bytes of data for five consumers. Then the number of consumers increased to 10 and repeated the same scenario experiment.

Further, separate experiments with 15, 20, and 25 consumers are conducted. TCP Reno is used as a traffic agent type in the experiments. We evaluated the delay and jitter on the access side of ICN 5G based IoT.

Fig 7 depicts the delay across consumers requesting different bytes of contents from the ICN access network. The delay is increased initially while 5 consumers requesting 100 bytes of data but with time, the delay is decreased eventually with the increase in the number of consumers requesting more bytes of data. The overall minimum delay of 85.5 milliseconds (ms) is observed with 25 consumers requesting 1500 bytes of data.

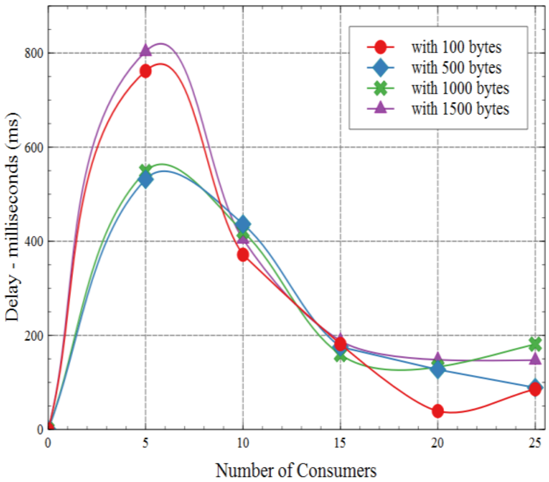

Fig 7: Delay across consumers requesting different bytes of packets

Fig 8 illustrates the jittering of packets across consumers requesting different bytes of contents/ data. It is shown from Fig 8 that initially the jittering of packets is increased with 5 consumers requesting different bytes of data. With the increase in the number of consumers, the packets jitter is decreased. The minimum packets jitter is observed with 25 consumers, requesting 100 bytes of data and 500 bytes of data is 4.9 ms and 5.2 ms, respectively.

If the delay is low, then consumer gets their data from the cache located on the ICN access network in less time. The same is the case with the jitter. In our proposed grid topology scenarios, we achieved minimum delay as well as jitter.

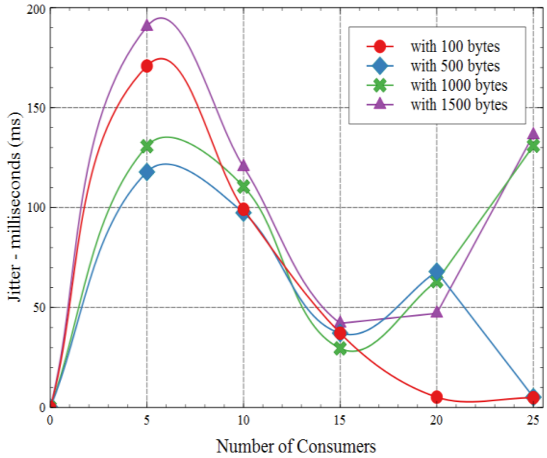

Fig 8: Jitter across consumers requesting different bytes of packets.

VI. Conclusion

ICN based 5G IoT network plays a significant role in computing and caching. By deploying ICN a path is established by the user to access the network where the cache is deployed. So, the user gets their desired data in less amount of time. This paper provides a comprehensive review of different studies related to ICN based 5G IoT networks. We also discussed some research gaps and pointed out some limitations of the present studies which should be resolved in the future. We presented some challenges with their proposed solutions. Future work will be done based on these challenges and research gaps to improve the performance of ICN based 5G IoT network. In the end, a case study along with an experimental scenario is designed to evaluate the delay and jittering effect of packets on the access side of ICN based 5G IoT network. In future work will perform experiments in heterogenous 5G-based environment to analyze the quality of experience.

VII. Acknowlegement

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