IoT Caching in Information Centric Networks

A Systematic Mapping

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Abstract—**The Internet of Things will connect billions of devices to the Internet. However, our current Internet infrastructure does not support this amount of connected devices and cannot process the amount of data generated by them. In order to improve our Internet, a novel architecture has being proposed, Information Centric Networks. This work has the objective of identify and analyze the current state of the art solutions for Caching Schemes in Information Centric Networks. To achieve that, a mapping of these solutions was conducted. This mapping resulted in the finding of 127 works, of which 20 were identified as primary studies. This mapping shows what is being researched and which directions have been considered for improving Caching in Information Centric Networks.**

Keywords-Information Centric Networks; Caching; In-network Cache; Internet of Things; Systematic Mapping.

I. INTRODUCTION

Everyday, different types of objects are being connected to the Internet. Objects like an irrigation monitor and control systems, thermostats, refrigerators, and door lockers that were not previously connected are now part of a network of things with the purpose of providing data and/or acting on its environment. This trend is called Internet of Things (IoT), and it is a concept that has the potential to change our day to day lives.

The IoT is enabling business models that rely on data from a variety of different physical objects, like health systems that monitor pacemakers. Current forecasts estimate that 28-34 billion devices will be connected by the year 2020, from which 17.5-24 billion will have IoT as their primary purpose [1]–[3]. They also estimated that, by 2020, nearly 6 trillion dollars will be invested in IoT solutions focusing on lowering costs, increasing productivity, expanding business to new markets, and developing new products [2].

This amount of connected devices provides us with a unique opportunity to create solutions capable of interacting with different areas of human knowledge to improve our lives, like Urban Infrastructure, Agriculture, and Manufacturing. Among the currently targeted areas, Health Care is considered as the most promising of those [4]. Digitally delivered services like disease prevention, diagnose, monitoring, and treatment are expected to create a global growth in economy by 2025 of $1.1-2.5 trillion [4].

Even though the predictions for the IoT reveal a promising area, it is not yet a reality. Challenges like interoperability, security and privacy, scalability, performance, availability, and device mobility [5][6] are still being researched before we are able to connect the amount of devices the IoT requires or to process the amount of data that will be produced by these devices.

In order to solve these issues, researchers and companies are working on multiple fronts. For example, the interoperability and scalability issues are being tackled by, among other things, the development of IoT platforms. These platforms enable the connection and communication of devices under a single protocol, like KNoT [7], Xively [8], and Amazon IoT [9]. Regarding the performance issue in IoT, a novel solution has emerged. It is called Information Centric Networks (ICN).

ICN is a novel network architecture that aims to replace TCP/IP as the default protocol of the Internet. The ICN architecture proposes a shift in paradigm, from a host-centric network to a data-centric network. In ICN, the focus is on the data the user is trying to retrieve instead of from where the data is coming. Focusing on the data means that the data the user is looking for can come from anywhere in the network. That encourages the use of in-network caching [10][11], allowing popular data to be stored near the users that request them the most.

In this paper we will map the state of the art of Caching approaches in ICN. We will use a process defined by [12] in order to minimize any possible bias during the analysis of papers. This work aims to be a concise overview of the research being made in this field.

This paper is organized as follow: Section II briefly explains ICN's protocol, how it works and what is still being researched. Section III will describe the methods, processes, and protocols that were used in this mapping. In Section IV, we will present the analysis made in the primary studies found during the process described in Section III. Finally, in Section V, we will depict the results found in our mapping.

II. INFORMATION CENTRIC NETWORKS

ICN is a novel approach to network architecture that changes the paradigm from a host-centric Internet to a data-centric Internet. In order to achieve that, content is promoted to a first class citizen in ICN. That means that instead of requesting data to an Internet Service Provider (ISP)

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through TCP/IP and URL, in ICN the user requests the data through an Unified Content Name. This approach decouples data from its host and allows it to be stored anywhere in the network [10].

In ICN, users do not connect directly with a host in order to access their data. Instead, they send an Interest Packet to all nodes in its Forwarding Information Base (FIB). Upon receiving an Interest Packet, the node looks for the data in its Content Store. If it is present, then the node consumes the Interest Packet and answers the message with the desired Data Packet [13]. In case the data is not present, the Interest Packet is queued in the Pending Interest Table (PIT) and the node forwards the Interest Packet to all nodes in its FIB. Once the Packet reaches a node that has the desired data – be it an ISP or another node in the network – it answers the message with a Data Packet. The Data Packet then follows the trail of breadcrumb left by the Interest Packet in the PIT of each node in the network until it reaches the original requester [13]. While following the breadcrumb, the Data Packet meets nodes that implement and nodes that do not implement cache policies. The ones that implement cache policies will evaluate the Data Packet to decide if it is worth caching or not, depending on the criteria configured for that node. This characteristic of ICN allows Data Packets to be spread in the network, making it easier to be accessed.

Because of the protocol described in the previous paragraph, cache has gained primary importance in ICN. Through in-network caching, data can be retrieved from neighbor nodes in the network, instead of the ISP, decreasing the delay of data retrieval.

The default implementation of the caching protocol in ICN is called Cache All [13]. However, this protocol imposes a high storage cost to all nodes in the network. Moreover, duplicating all data in all nodes can lead to duplication where the data is not necessary. In order to make ICN viable for day to day use, ICN's Caching Scheme needs to be improved. Several research are being made with this goal in mind. This work will map some of these research.

III. APPLIED PROTOCOL

The objective of this mapping is to identify the state of the art solutions for Caching in ICN. In order to identify the studies related to this topic, the following question was thought:

- How the Internet of Things will affect the performance of the Internet?

From this question, secondary questions were developed in order to help the comprehension of the solutions:

- How is Information Centric Networks handling information cache?
- In what ways can we use cache to improve the data availability in the Information Centric Networks?
- What are the main challenges in using cache in Information Centric Networks?

The protocol used in this study is based on the protocol used in [12], which is based on the guidelines of Kitchenham [14] and the analysis of [15]. This review process is composed of the following five stages: (1) identification of inclusion and exclusion criteria, (2) search for relevant studies, (3) critical assessment, (4) extraction of data, and (5) synthesis. Each of these stages is elaborated in the next sections.

A. *Inclusion and Exclusion Criteria*

For this review, we focused on studies that present novel caching solutions for ICN. These solutions ranged from novel forwarding algorithms to monetized caching policies. Since the focus was to analyze the state of the art considering Caching for ICN, the studies were excluded in case they did not fit at least one of the following criteria:

- Published after 2015.
- Published in English.
- Studies that were not available online.
- Call for works, prefaces, conference annals, handouts, summaries, panels, interviews, and news report.

B. *Search Strategies*

The studies gathered for this review were found in the databases below:

- IEEE Xplore.
- ACM Digital Library.
- SpringerLink.

Keywords were identified and combinations of those were used to make sure relevant content were not missed. The queries below were the result of these combinations:

- ICN AND cache
- ICN AND caching
- "information centric network" AND cache
- "information centric network" AND caching

These queries were combined into one query and used in order to search the databases. The searches were performed in March 2017. The results of each search were grouped and were later examined in order to remove duplications. Table I shows the amount of studies found on each database.

TABLE I. AMOUNT OF STUDIES FOUND ON EACH DATABASE

Database	***Number of Studies***
IEEE Xplore	24
ACM Digital Library	47
SpringerLink	57

C. *Studies Selection Process*

This section describes the Selection Process from search in the databases engines all the way through the identification of the primary studies.

In the first stage, the studies gathered in the databases through the queries were grouped in a spreadsheet for further analysis. This search returned 127 non-duplicated studies.

The second stage consists of the analysis of the titles of all the resulting studies to determine its relevance for this mapping. At this point, many works that were not related to caching in ICN were discarded. From the original 127 works, 40 remained after selecting them by titles. Among the works left, some were put aside to be analyzed in the next stage due to ambiguous titles.

After analyzing the titles, the abstracts of the remaining studies were analyzed in the third stage. In this stage several other studies were discarded since many did not match our expectations of presenting solutions for caching in ICN. After this stage another 18 works were discarded, leaving 22 to be analyzed.

Table II summarizes the amount of studies left after each stage of the Selection Process.

TABLE II. AMOUNT OF STUDIES LEFT AFTER EACH STAGE OF THE SELECTION PROCESS

Phase of Selection Process	*Number of Studies*
1. Database Search	127
2. Title Analysis	40
3. Abstract Analysis	22

D. Quality Assessment

In this stage, the remaining works went through a careful analysis. This analysis took into account not only the title and abstracts, but the whole content of the study. During this analysis, 2 (two) studies were considered uninteresting for this mapping so they were discarded.

In this analysis, relevance grades were used to classify each of the studies according to five questions. These questions helped in the identification of studies related to our mapping of caching solutions in ICN. From these five questions, the first two were crucial to the process of assessing the study contribution for this mapping. The remaining questions were used to assess the quality of the studies. The questions were:

- Does the study propose a solution to improve the performance of Information Centric Networks?
- Does the study adequately describe the proposed solution?
- Was the solution adequately tested? e.g., did it use an ICN Simulator?
- Were the conditions of the test adequately described?
- Were the results adequately compared with other solutions?

Of the remaining 22 works, 20 were selected as primary studies. These studies then went to the Data Extraction and Synthesis stage. The quality assessment process will be explained in more details in the Results section, along with an assessment of the 20 studies.

IV. RESULTS

As stated before, 20 works were selected as primary studies [15]–[35] after the Selection Process. These studies approached the caching issue in ICN in a variety of ways. Some proposed novel Replication and Content Eviction algorithms [17][18]. Some proposed Collaborative Caching polices among routers [23]. And some worked on the possibility of using monetization to incentive popular content caching throughout the network [27][28].

The following sections will dive deeper into the qualitative and quantitative analysis of the selected studies.

A. Quantitative Analysis

This section brings a quantitative analysis of the selected studies. This analysis intends to show who is studying Caching in ICN, where they are, and which keywords to use in order to find these studies.

The 20 selected studies were written by 66 authors affiliated to institutions in 12 countries. These studies were published between January 2015 and March 2017. In total, the studies used 63 different keywords.

The most common keywords used in these studies were: information centric network (13), caching (6), ICN (6), ccn (3), content centric networking (3), in-network caching (3), cache (2), content delivery networks (ccn) (2), game theory (2), named data networking (2), and network pricing (2). All the other keywords appeared only once. It is worth noticing that the first seven keywords are directly related to the theme of this mapping.

An analysis of these keywords can show how the primary studies are subdivided. The most frequent keywords represent the common theme among the studies, keywords like caching, networking, and information centric are present in all studies. Moving past these keywords, we can see keywords that state some of the concerns of these studies, like performance and bandwidth. One step further revels keywords that represent the strategies used by the researchers, like forwarding, replication, and popularity based algorithms. At last, the least common keywords are the names of the proposed solutions. Fast-Start [24], CLCE [17], LFRU [17], and RB-CCC [32] are a few of them.

Regarding the country of origin, China had the most published studies (4.07). United States came in second place with 4 publications, Japan in third with 3 studies, India and France with 1.66 each. Brazil, Canada, Greece, United Kingdom, and South Korea came in fifth place, all with 1 publication, Germany in sixth with 0.33, and Sweden in seventh with 0.25.

B. Qualitative Analysis

As described before, each of the selected primary studies have been assessed according to five quality criteria related to their relevance. When considered, these five criteria can provide a clear view of how much each of the primary studies is relevant to this work. Each study has been classified for each of the criteria using a positive or negative answer.

Table III presents the result of this analysis. Each row represents a study and the columns 'Q1' to 'Q2' represent each of the defined quality criteria: Solution Proposal and Description, Validation, and Comparison with other solutions. For each criteria, '1' is used to represent a positive answer and '0' is used to represent a negative one.

All but [19][27][28] had positive answers for 'Q1' and 'Q2'. As stated before, these questions were used as a way of measuring the contribution each study could have to this

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mapping. However, even though these studies did not proposed any novel approaches to ICN caching, they were included in the study since they either evaluated [19] an approach that was not present in the database search or proposed improvements in an already existing approach [27][28]. Including these studies allows us to have a bigger picture of the research in ICN caching.

TABLE III. QUALITY ANALYSIS OF PRIMARY STUDIES

Study	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Total*
[17]	1	1	1	1	1	5
[18]	1	1	1	1	1	5
[19]	0	0	1	1	1	3
[20]	1	1	1	1	1	5
[21]	1	1	1	1	1	5
[22]	1	1	1	1	1	5
[23]	1	1	1	1	1	5
[24]	1	1	1	1	1	5
[25]	1	1	1	1	1	5
[26]	1	1	1	1	1	5
[27]	0	0	0	1	0	1
[28]	0	0	0	1	0	1
[29]	1	1	1	1	1	5
[30]	1	1	1	1	1	5
[31]	1	1	1	1	1	5
[32]	1	1	1	1	1	5
[33]	1	1	1	1	1	5
[34]	1	1	1	1	1	5
[35]	1	1	0	0	0	2
Total	17	17	17	19	17	

Other than the studies discussed above, [35] was the only other study that did not met all the expected criteria. It does describe a new approach to ICN caching, but the validation is not properly described nor it is compared to other approaches.

V. DISCUSSION

After the analysis and data extraction phases, it was possible to notice some aspects of the research that have been made regarding ICN caching. Firstly, almost all of the studies analyzed proposed a novel approach to ICN caching. This shows that there is currently no agreement on which solution should be considered standard. Secondly, a great variety of solutions have been proposed. From simply replacing the Storage [17] or Forwarding [20] algorithms, to solutions involving monetization in order to incentive other routers to cache data relevant to the payer router [27][28]. Finally, although most of the research have been made for caching in applications of general use, some research have also been made for niche-specific applications, like video streaming [24].

The next sections will discuss the questions that guided this mapping, and a important aspect of the performance evaluations made in the studies.

A. How is Information Centric Networks handling information cache?

The analysis of the primary studies reviewed several different approaches to in-network caching. The first (and most common) approach was to replace the algorithms used in the Content Store. According to [17], the Content Storage of a network is composed by two elements – the Replication Algorithm and the Eviction Algorithm. The Replication Algorithm defines the policy used to spread the content throughout the network. Examples of Replication Algorithms are Leave Copy Everywhere (LCE) [13][37] and Leave Copy Down (LCD) [38][39]. The Eviction Algorithm defines the rules used to decide whether an arriving content should replace an existing one. An example of Eviction Algorithm is the LRU (Least Recently Used) [40].

Here are a few examples of the proposed algorithms:

- Conditional Leave Copy Everywhere (CLCE) and Least Frequent Recently Use (LFRU), by [17].
- Progressive and Fast Progressive, by [31].
- Object-Oriented Packet Caching, by [29].

These algorithms were built using different assumptions and techniques. Some do popularity-based decisions [31], others use assumptions regarding user behavior as input for its algorithm [35], and some try to fix issues in previously proposed approaches [17].

One of the studies leverages the use of monetization in order to incentive nodes of the network to store data in their caches. The studies [27][28] try to improve the original approach by improving the algorithm used to determine the price. Another study proposes a fixed network layout in order to achieve optimal result with video streaming [24]. At last, one study proposes a change in the Routing Algorithm [20] to improve the changes of finding the data that the user is looking for in neighbor nodes, different than the usual Routing Algorithm that creates a tree-like structure.

This variety of approaches shows that there are many aspects that can be tackled when improving Cache in ICN, not only the most common one: improving the heuristic behind the Eviction and Replication algorithms.

B. In what ways can we use cache to improve the data availability in the Information Centric Networks?

An analysis of the primary studies shows that, although, most of the proposed solutions are not domain specific, some have very specific niches. At one hand, general-application solutions have the advantage of being able to deal with a broader set of situations. These solutions can handle applications like web searching, file downloads, and so forth. On the other hand, however, these solutions have the disadvantage of not being fully optimized for demanding niches, like video streaming.

According to a forecast by Cisco [36], by 2020 82% of Internet traffic will be video stream; against 70% in 2015. This shows a significant growth in video consumption.

In order to minimize network traffic, ICN can be used as a way to cache video content near the consumers. Requiring less hops to find the desired content and creating less overhead in the network nodes. However, it can also be used to store other types of streaming, like music, for example, as well as for general web applications like news feed and data access when the main ISP is offline.

ICN's distributed cache nature allows us to improve the Quality of Service in several different application domains, as well as decrease the load in data centers and Internet Providers, by increasing data availability.

C. *What are the main challenges in using cache in Information Centric Networks?*

Even though caching can be used to improve the performance of many different application domains, not all domains have the same requirements and not all protocols work the same way. Because of this, caching schemes that deliver great performance for video streaming may not work so well when caching data in for autonomous vehicles. Moreover, these protocols are not always compatible among each other.

In order to ICN to become commercially viable, the authors identified three requirements:

- The network nodes should be able to cache relevant amount of data. Consider as "relevant amount of data", data quantities appropriate to the context. Hub nodes should be able to store more data than the local nodes the users will have at his/hers home.
- These nodes should be widely spread in order to ICN to truly show its potential.
- The caching scheme should either be universal, i.e. caching regardless to the protocol, or multiple protocols that are compatible and can work together to complement each other. However, it is necessary to point out that caching protocols should be fast in order to deliver the requested packets as fast as possible. And that this limitation should be in mind when designing a caching scheme for ICN.

D. *Performance evaluation*

As shown in Section IV, most of the primary studies evaluated their solutions and compared to others. After analyzing the experiments performed, some trends were noticed.

Firstly, the majority of studies used a Zipf distribution [41] to generate the randomness in the network traffic. It is based on the the fact that many types of studied data have a similar distribution. This uniformity in input ensures the comparisons are unbiased, distribution-wise.

In order to implement and test the proposed solutions, most of the primary studies used network simulators. Here are a few simulators related to ICN:

- NS-3 network simulator [42]
- ccnSIM [43]
- ndnSIM [44]
- Icarus [45]

These aspects should be followed in order to lessen the bias and create a more uniform approach to evaluate the performance of ICN caching schemes.

VI. CONCLUSION

The objective of this mapping was to identify and analyze studies that contributed to the state of the art of Caching Schemes in ICN. In the search phase, 127 works were found. From which 20 were considered as primary studies, after the phase of quality assessment. These studies were then classified regarding the aspects of the solution proposed.

The analysis of these studies showed that there is the need of a standardization of the Caching Scheme in ICN. Several different approaches were mapped, but none have been particularly successful in establishing itself as a standard. Most of the proposed approaches were only compared to simpler solutions, other than the most sophisticated ones. Leaving a gap of how these solutions compare to each, performance-wise.

This mapping shows how ICN can improve the Quality of Service in many areas. It also lists the approaches used by the studies to try and improve the Caching performance in ICN. And which techniques are being used in order to validate new Caching solutions.

Regarding future works, we propose a comparison between the mapped solutions in order to point the direction to be followed by future researchers of ICN.

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