Caching in Named Data Networking

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***Abstract*—*Named Data Networking* (NDN) supports the *Internet of Things* (IoT) with features like named-based routing and in-network caching. Traditional caching algorithms are ill-suited for energy, storage, and processing-limited IoT devices. This paper presents a novel distributed probabilistic caching strategy considering device limitations. We also compare this solution to traditional caching strategies in terms of data retrieval and network energy efficiency.**

I. Introduction

In the Internet of Things (IoT), wireless devices interact with their environment and the Internet to support context-aware services. As IoT data is smaller and more transient compared to internet content, they require new protocols. Recently, Information-Centric Networking (ICN) has been explored for IoT, offering benefits like simplified data retrieval, mobility support, caching, and content-based security [1]–[3]. To address the lack of caching strategies for wireless IoT, we introduce pCASTING, a *probabilistic CAching STrategy for the INternet of thinGs* considering data freshness, energy levels, and storage capabilities for each network node.

II. Caching Strategy

A. Named Data Networking

NDN is a content dissemination architecture with hierarchical URI-like content names in Interest and Data packets. Each NDN Node has three tables: Content Store (CS), Pending Interest Table (PIT), and Forwarding Information Base (FIB) [5]. The node's caching system comprises a caching decision strategy and a replacement policy, determining whether to cache incoming Data packets or which packet to replace in a full Content Store, respectively.

B. pCASTING

In our scenario, a resource-constrained multi-hop wireless network involves N nodes with limited battery energy. Nodes, either fixed (e.g., sensors) or mobile (e.g., smartphones), include a set of consumers $C = \{1, ..., N_c\}$, where $N_c < N$ and a producer P generating IoT contents with specific freshness. The remaining nodes can cache and forward incoming Data packets. When a node receives a Data packet with a matching PIT, the caching decision follows the pCASTING strategy, considering three dynamic attributes related to the device and content to calculate the caching probability.

The device-related attributes are *energy level* (EN) and *cache occupancy* (OC). These values can easily be monitored by the IoT devices. As a content attribute, we consider the Data *residual freshness* (FR). According to NDN, any producer may include in a Data packet a value indicating the freshness f in seconds, and a timestamp t_s identifying the instant when the information is produced.

We assume that the caching probability is directly (inversely) proportional to each of these parameters. So that for each of the mentioned parameters can be normalized as $0 \leq EN \leq 1$, $0 \leq OC \leq 1$ where the values 0 and 1 mean that the cache or the battery is empty or full, respectively. The residual freshness can be normalized as $FR = 1 - \frac{currentTime - t_s}{f}$. Packets with a negative freshness parameter are considered expired and are not cached at all.

To define the caching probability of a Data packet, we consider a *Caching Utility Function* F_u that takes into account all of the normalized parameters above. The function can be written as follows:

$$F_u = \sum_{i=1}^{N_p} w_i g(x_i)$$

where N_p is the number of parameters and the weights w_i assume a value such that $0 \leq w_i \leq 1$ and $\sum_{i=1}^{N_p} w_i = 1$. Therefore the weights express the importance of each parameter in the computing of the utility value.

F_u must assume values in the interval $[0 : 1]$ and gives as a result the node's caching probability.

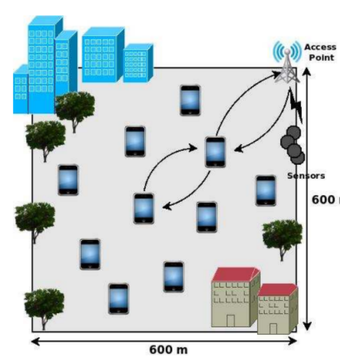

Fig. 1. Simulation scenario.

C. Experiments

To evaluate the performance of the proposed pCASTING solution we consider a smart city scenario in Fig. 1 representing an urban area of size 600m x 600m. A group of

TABLE I
Simulation Settings

Category	Paramter	Value
Application	Data packet size	512 bytes
	Consumer's freshness	rand(1:10)
	Consumer's update period	1 minute
	N_d	5
NDN	CS size	10 packets
	Routing	controlled flooding [4], [7]
	pCASTING	$w_1 = w_2 = w_3 = 1/3$
		n = 1
Access	Technology	IEEE 802.11g
	Rx Sensitivity	-83 dBm
	Propagation	Rayleigh
Scenario	Area Size	600m x 600m
	Number of movile nodes	60
	Mobility Model	pedestrian [8]
	Number of Consumers	1-8

TABLE II
Data dissemination performance metrics

Metric	CE^2	No Caching	P(0.5)	pCASTING
Cache hit ratio	42%	0%	49%	61%
Consumers' received data pkts	206	208	217	239
Data retrieval delay[s]	0.2	0.34	0.18	0.12

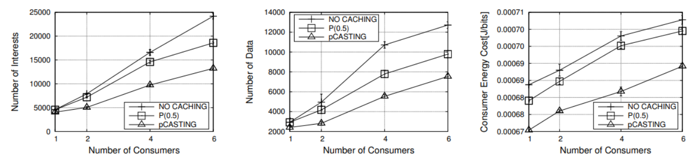

Fig. 3. Metrics for retrieval performance analysis

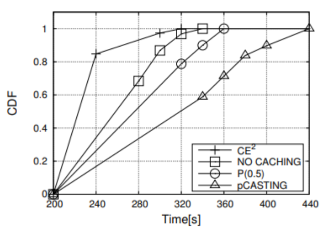

Fig. 2. CDF of the discharge time of the forwarding nodes.

sensors deployed in the city periodically generate data for context-aware services. An Access Point offers these services to interested consumers. Each service consists of N_d Data packets. The described scenario and the pCASTING solution were implemented in the ndnSIM tool [6], the reference simulation platform of the NDN research community deployed in ns-3 [9]. Additional information concerning the simulation settings is listed in Table 1.

In the initial analysis, we aim to assess the energy efficiency of pCASTING while ensuring good performance in terms of retrieval delay and collected Data. Consumer nodes start with high initial energy while forwarding nodes start with low initial energy. The simulation concludes when all forwarding nodes deplete their energy.

As an energy performance metric, we consider the *cumulative distribution function* (CDF) *of the discharge time of the forwarding nodes*. As indicators of the dissemination performance, we consider three values as listed in Table 2.

We evaluate pCASTING by comparing it to three reference schemes: Caching Everything Everywhere (CE^2), a probabilistic scheme denoted as $P(0.5)$, and a *no caching* scheme. Results are calculated over ten independent runs and can be examined in Fig. 2 or Table 2, respectively.

In the second experiment, fully charged nodes are monitored for energy consumption over ten minutes. Assessing the caching strategy's efficiency from the network perspective involves considering the *number of Interests and Data packets* transmitted. From the consumer perspective, efficiency is evaluated by examining *consumer energy costs*, calculated as the average ratio of energy spent to correctly received bits.

We compare pCASTING against the *no caching* and $P(0.5)$ scheme. Results are averaged over ten independent runs and can be examined in Fig. 3.

pCASTING outperforms in all metrics and both experiments, showcasing its energy-aware behavior and probabilistic caching decision-making. This approach maximizes content diversity, leading to overall improved performance.

III. Conclusion

This paper explores in-network caching in named data wireless IoT networks, introducing the distributed caching scheme, pCASTING. This scheme adjusts caching probability based on battery energy level, cache occupancy, and Data packet freshness. Simulation results confirm the solution's effectiveness, reducing node energy consumption and ensuring low content retrieval delays. The simplicity of pCASTING's caching probability computation allows for easy modification by adding additional parameters.

References

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