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Q1 # On the application of contextual IoT service discovery in Information Centric Networks

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ABSTRACT

The continuous flow of technological developments in communications and electronic industries has led to the growing expansion of the Internet of Things (IoT). By leveraging the capabilities of smart networked devices and integrating them into existing industrial, leisure and communication applications, the IoT is expected to positively impact both economy and society, reducing the gap between the physical and digital worlds. Therefore, several efforts have been dedicated to the development of networking solutions addressing the diversity of challenges associated with such a vision. In this context, the integration of Information Centric Networking (ICN) concepts into the core of IoT is a research area gaining momentum and involving both research and industry actors. The massive amount of heterogeneous devices, as well as the data they produce, is a significant challenge for a wide-scale adoption of the IoT. In this paper we propose a service discovery mechanism, based on Named Data Networking (NDN), that leverages the use of a semantic matching mechanism for achieving a flexible discovery process. The development of appropriate service discovery mechanisms enriched with semantic capabilities for understanding and processing context information is a key feature for turning raw data into useful knowledge and ensuring the interoperability among different devices and applications. We assessed the performance of our solution through the implementation and deployment of a proof-of-concept prototype. Obtained results illustrate the potential of integrating semantic and ICN mechanisms to enable a flexible service discovery in IoT scenarios.

1. Introduction

In the last few years, the coupling of networking communication capabilities and devices with disparate characteristics and capabilities (e.g., sensors, actuators) has prompted different actors (ranging from academia, to service providers, manufacturers and operators) into the development of solutions towards an Internet of Things (IoT). These solutions are able to remotely exploit the sensing and actuating capabilities of such devices and convey them into communicating and processing platforms, empowering different kinds of "smart" scenarios [1,2]. The added value generated by bridging the physical and digital worlds has contributed to a continuously increasing massification of connected devices and generated information exchanges ([3] indicates 7.3 billion Machine-to-Machine (M2M) networked devices by 2018, globally), raising connectivity provisioning and operation concerns at all levels. The stringent new requirements placed over the underlying networking fabric to support this connectivity explosion have prompted the need for ground-breaking ideas and solutions, able not only to support these challenges, but also to confer the capability and flexibility to better face future challenges and requirements.

Information Centric Networking (ICN) [4,5] is an emerging networking paradigm that has content at the centre of the networking functions, shifting from the current host-centric approach of the Internet. Moreover, unlike the current underlying architecture of the Internet, this new approach intrinsically couples its networking procedures with important supportive mechanisms, such as security, mobility support and efficient caching. These capabilities, along with the possibility of expanding its range of scenario applications at the design stage [6], have naturally brought the ICN and IoT concepts closer [7,8], allowing the pursuit of ICN as an IoT-capable platform, while exposing it to new scenarios and contributing to its own development. Moreover, this approach can actually provide new solutions for open issues that plague current Internet mechanisms.

In the IoT, different devices/manufacturers specify their own structure for sharing information leading to information silos [9].

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This has hindered the interoperability between different applications and the realization of more complex IoT scenarios. Moreover, efficient device and service discovery has proven to be a complex and dynamic aspect of IoT scenarios [10]. Therefore, in order to make information useful and to ensure interoperability among different applications, it is necessary to provide data with adequate and standardized formats, models and semantic description of their content (metadata), using well-defined languages and formats [1]. However, the lack of standards and the heterogeneity of formats for describing IoT content has triggered research on techniques to deal with unstructured information, where particular emphasis has been given to semantic similarity. The goal behinds its application is to enable the adoption of the IoT on a wide scale by allowing the proper identification of information with similar context, regardless of the vocabulary used therein [11].

The aim of this paper is thus to contribute to the deployment and usability of ICN protocols by extending existing solutions with semantic discovery capabilities. Consequently, we integrate and evaluate the unsupervised semantic similarity solution proposed in [12] with an ICN-based discovery mechanism developed on top of the Named Data Networking (NDN) architecture [13]. In doing so, some of the core concepts of [12] had to be further evolved and a novel service-query matchmaking interface was developed.

The remainder of this paper is organised as follows: Section 2 briefly introduces ICN concepts, contextualize its usage in IoT environments and provides an overview of previous work on service discovery and semantic matching techniques. Section 3 defines the problem statement. Section 4 details the proposed solution and Section 5 discusses experimental results. Finally conclusions are provided in Section 6.

2. Background and related work

In this section, we present the fundamental aspects related to the ICN concepts, with emphasis on Interest-based ICNs, along with the application of those concepts for service discovery and in IoT environments. Additionally the section presents some background on the main methods used for evaluating the semantic distance between two words, and concludes with some remarks regarding recent efforts to support Service Discovery in IoT environments.

2.1. Information-Centric Networking

Although existing ICN solutions share the core concepts of this novel paradigm (e.g., information oriented communication, content based security, in-network caching), different implementations follow different design choices (e.g., communication model, naming principles, routing and forwarding). In this work we will focus on Interest-based ICN solutions. Interest-based ICNs (e.g., Named Data Networking (NDN) [13], Content Centric Networking (CCN) [14]) propose a communication model driven by the information consumers and based on the exchange of two packet types, i.e., Interest and Data. A name, contained in both types of packets, is used to identify the content being addressed. Requests (Interests) for a given piece of information are forwarded towards the producer(s) of the content according to the information stored in the Forwarding Information Base (FIB) and following a configured Forwarding Strategy. Nodes maintain a Pending Interest Table (PIT) for outgoing forwarded requests and map them to the network interface from where the corresponding requests have been received. Data is then routed back using the reverse request path based on the state information stored in the PIT. Upon the forwarding of a Data packet, the Interest is considered as satisfied and the corresponding PIT entry is removed (i.e., Data consumes Interest). The nodes involved in the communication can cache both requests (through aggregation in the PIT) and content objects (in the Content Store (CS)). Content objects are signed by the producers, ensuring both integrity and authenticity of the content.

2.1.1. Information-Centric Networking for the Internet of Things

In the recent years, the research community has been witnessing an increasing interest on the application of the ICN concepts in addressing IoT scenarios. The Information-Centric Networking Research Group (ICNRG)[1] of the Internet Research Task Force (IRTF) has identified IoT as a baseline scenario where the use of ICN, as underlying communication paradigm, could bring significant advantages compared to existing Internet protocols [6]. Some relevant works have provided a detailed analysis on addressing IoT scenarios from an ICN perspective, identifying the main benefits and challenges, along with some design choices aiming at an efficient and scalable realization of such technology integration [7,8,15].

Different research works have tackled particular challenges of enabling an ICN-based IoT. For example, enabling push-like communications through long lasting Interests [16]; lightweight alternatives to meet the memory and computational constraints of some IoT devices [17]; authenticated interest and encryption based access control for secure actuation [18] and sensing [19] in IoT-like environments; enabling data retrieval from multiple sources [20]; management aspects of IoT deployments over ICN [21], impact of caching in energy and bandwidth efficiency [22], information freshness [23].

Authors in [24], go one step further and provide an experimental analysis of the shortcomings of ICN applied to IoT. Their work showcase the feasibility of using ICN in constrained devices and show that it can bring advantages over approaches based on 6LoWPAN/IPv6/RPL in terms of energy consumption, as well as in terms of RAM and ROM footprint.

2.1.2. Service discovery in ICN

PARC[2] included a description of a Simple Service Discovery Protocol [25] within the specifications of their latest release of CCNx[3] (version 1.0). The proposed scheme is based on the existence of a Service Discovery Broker responsible for managing the services within a Service Discovery Name Space. Services must be registered in the Service Discovery Broker and can be later discovered by Clients. Replies to Service Discovery queries contain the names and additional metadata for the services that have been admitted to the Service Discovery Name Space.

In [26], authors propose a CCNx prototype of an infrastructure-less service discovery mechanism. The proposal included two different protocols, a Neighbour Discovery Protocol (NDP) and a Service Publish and Discovery Protocol (SPDP). The NDP allows CCNx nodes to collect information about their locally reachable neighbour nodes, while the SPDP is responsible for receiving service registrations via an API and for querying other SPDPs about available services. The querying process is based on a recursive hop-by-hop propagation of an Interest from one SPDP instance to another and also hop-by-hop aggregation of the response(s).

2.2. Semantic distance estimation

Semantic distance is a measure of proximity between two units of language, in terms of their meaning. For example, the nouns *"temperature"* and *"heat"* are closer in meaning than the nouns *"temperature"* and *"acceleration"*. In this context, semantic distance

[1] https://irtf.org/icnrg
[2] www.parc.com
[3] www.ccnx.org

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