Flexible API for IoT Services with Named Data Networking

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***Abstract*—Internet of Things (IoT) is changing our life for the better. IoT covers various heterogeneous devices which are sensing the environment and/or monitoring a special event in the network. These devices are mostly mobile and are wirelessly connected either to each other or to the Internet. Additionally, IoT devices run many different applications and services which provide the consumers with data and information. This paper focuses on the design and implementation of an Application Programming Interface (API) for IoT services using the Named Data Networking (NDN). NDN provides an efficient and intelligent communication paradigm for constrained devices like in IoT and uses named content to transmit data in the network. We extend the IoT-NDN architecture and add a new layer for IoT services which will effectively improve the performance of communication between the heterogeneous devices and the services integrated in IoT-NDN. Furthermore, we show the usage of our API and give a small example of network time synchronisation on IoT devices. This illustrates how flexible and lightweight is our approach for several services implemented on heterogeneous devices in IoT.**

***Index Terms*—Internet of Things, IoT Applications and Services, Named Data Networking.**

I. Introduction

Due to the flexibility design and infrastructure of Internet of Things (IoT), IoT applications and services could be useful in our day-to-day activities. IoT devices will be integrated to the Internet to collect important information or to observe several events around us. However, there are many steps to support the integration of heterogeneous devices and many IoT applications to the Internet. One important step is to define the interface for such applications and Services which are running on IoT heterogeneous devices.

In the past, researchers did not plan use the current Internet structure for everything connected to the Internet. This infrastructure of today's Internet was not intended to be associated with the increasing number of devices connected to the IoT or to the Internet. The first idea of designing the traditional Internet was to send a message between two devices (from device A to device B). However, the Internet today has overstepped this concept and has been used for almost everything in our life activities. Furthermore, this structure does not suit the rapid development of many things which need IP addresses to be connected to the Internet. Additionally, all consumers who use the Internet today require information. Such information could be sensed or collected by any device or sensor integrated to the IoT. Example: in the IoT, such information could be used to improve our life by prompting to an uneventful incident etc.

If we consider applications and services which run in different IoT fields, most of them consider information as main goal. Therefore, the research community is trying to define better networking solutions in IoT to match the use of the future Internet. They want to replace the current communication paradigm from device to device (Host-to-Host) to information centric paradigm [10]. Furthermore, the security of the current internet lets us to think about new communication paradigm which assures us highest level of security of our personal information transmitted in the Internet [10]. The Named Data Networking (NDN) as new approach of Information-Centric Networking (ICN) [1] is the best solution for mentioned problems and it matches the rapid development of future Internet. NDN uses named content to deliver the data. In section II-B1, we introduce the NDN architecture and give an example. To achieve effective IoT system in different application scenarios, we propose an IoT architecture via NDN. In this IoT infrastructure, we have included the important concepts of the NDN system such naming, forwarding etc.

The rest of the paper is categorized into four different sections as follows: Section two describes the IoT system with the Named Data Networking and gives an overview about IoT with NDN structure. Section three discusses our proposed API for IoT services and its integration to the IoT with NDN. The implementation of our proposed architecture and its components are presented in section four. Finally, section 5 concludes the paper and gives us an outlook of future work.

II. IoT with Named Data Networking (NDN)

Recently, many groups have claimed IoT as a revolutionary technology for future Internet in terms of efficient energy consumption, better quality of life etc. The main goal of IoT is to collect and share information/data from several devices connected to the Internet from anywhere around the globe. The consumers use this Information/Data to efficiently improve and control the quality of life. Furthermore, such information could be usable in different application scenarios such as smart cities, smart home etc. to execute rapid decisions e.g. during an emergency situation.

Figure 1 shows the current structure of IoT using NDN communication paradigm, more about NDN see section II-B1. Our developed systems called "IoT-NDN" is presented and discussed in several papers, see section II-B. In the following we will introduce every layer of the maintained architecture and provide a brief description of the same.

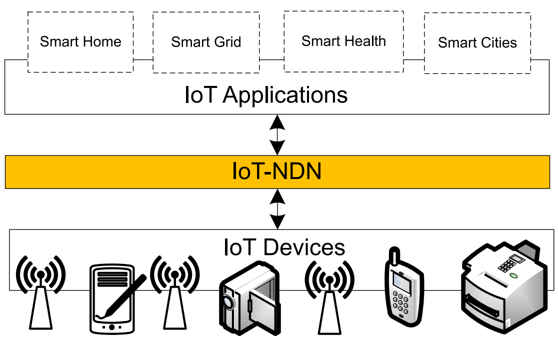

Fig. 1. IoT-Layers with NDN

A. IoT-Application

This paper [2] plots the fundamental of service integration in the Internet of Things and endeavoured to give a few illustrations for the design of integration application or services on IoT devices.

IoT has been disseminated as revolutionary technology in diverse applications area like smart Cities, smart Homes, healthcare, smart Grid and many another research fields. Many of the mentioned applications have been become an integral part of the future internet research, in terms to provide us with superior control and quality of life. Because of the flexibility and the low cost of IoT systems and its communication, the research community is considering the IoT as the best technology for changing people's lives for the better [3].

Recently, IoT applications are added as a part of every smart device and are incorporated in all smart application fields. The authors in [4] describe the concepts of IoT and show how IoT devices interact with each other to build new systems with smart applications and services.

IoT applications operate on the top of the IoT structure and have the role to make the information reachable and usable from any device connected to the Internet. IoT applications are expanding and are popular in every area related to our life. This revolution of IoT involves many fields in our routine life from the smart home to the private information in healthcare industry. Such applications provide us security, energy saving and notification, e.g. about health state which could be important for saving people's life.

Additionally, IoT has been considered in smart factories, enterprise and industry [5]. Most organisations and governments try to use the connectivity of Internet (from medical devices to smart home applications and sensing everything) to build an efficient, secure and low cost system. The work in [6] addresses the challenges of integration of IoT in the IT system and shows how useful is the usage of IoT infrastructure and how easy is it to integrate the IoT entities into SOA.

In fact, IoT is the next stage in the revolution of information. Internet/Cloud of Things and its embedded services and wearable devices have a bright future in the field of Internet and IoT. The papers [7] and [8] discuss the IoT applications and its information/data in the cloud. The authors in [7] depict the complexity of handling produced data from the sensors in IoT and its interaction with each other to other domains, like the Internet cloud. They present a data-centric framework to develop IoT applications considering the clouds for data handling (filtering, access, sharing etc.). The work in [9] uses a name centric service for the cyber physical system. The authors consider the CCNx for their architecture and define a Service Bus to register a service in the CPS.

B. IoT-NDN

The current Internet structure was typically designed for small tasks like sending a small message between two computers. We now notice that the use of Internet has come a long way from this concept. Users and companies use the Internet to exchange multimedia files and big data. The need of change in today's Internet structure is very important to satisfy users requirements. Therefore, the research community developed a newer design of Networking protocol called NDN.

1) Named Data Networking (NDN): NDN is a future network architecture which has achieved a significant interest within the research community. NDN replaces the host-to-host communication paradigm of traditional TCP/IP protocol to Naming Data communication. With NDN, the communication between devices is based on the name of data. More information about NDN architecture can be found in [1].

NDN uses hierarchically structured names to deliver content. The names are carried in so-called Interest and

Data Packets. All nodes which run NDN maintains three tables:

i) Content Store (CS): CS caches all in-coming data.
ii) Pending Interest Table (PIT): PIT keeps track of the forwarding including the faces ID which the Interest coming from.
iii) Forwarding Information Base (FIB): FIB is as a routing table, it routes and forwards the content based on content names.

For requesting data from producer or any node in the network, the consumer sends an Interest which carriers the content/data name. If the producer receives the Interest, it first looks in the CS; if a match is found, then the node sends the data back. Otherwise, if there is a matching entry in the PIT, the Interest is discarded because a similar request has already been forwarded. Otherwise, a new PIT entry is created and the Interest is forwarded to the matched interface stored in FIB. The Data packet follows the chain of PIT entries back to the consumer and intermediate nodes cache a copy of the delivered content in its CS which reduces and limits the massive data access to the same producer. Further information about NDN can be found in the NDN project [10] and [1].

2) NDN for IoT Systems (IoT-NDN): In fact, NDN has been designed for multimedia contents such as Youtube videos or audios and similarly sized contents. These contents are frequently requested by several users in the Internet and are usually connected with fixed and/or wired content routers [11]. Such schemes with high performance links usually increase the overhead and the complexity of the systems [12]. This approach is unsuitable for resource constrained (mobile) devices.

In our previous papers we interceded our lightweight design and extension of the NDN for IoT system and its constrained devices [13], thereafter this would be named as ”IoT-NDN”. The research community shows how IoT systems and its integration with NDN could build an efficient and optimal system which would be user friendly to people’s requirements. Many papers have been suggested NDN for IoT. The authors in [6] introduce the first study of NDN with experiments in a life-size IoT deployment. The resource-constrained node has a small cache size at most in the order of 1KB. That is a big reason why we need a communication paradigm such NDN to process and manage the caching system of IoT devices efficiently.

The IoT devices produce permanent information which would be stored for a while in the cache and from time to time updated or removed (information is ephemeral). Caching the information in small devices increases content availability and decreases the number of lossy multi-hop wireless paths towards the producer. That is beneficial for devices which are limited with energy. The IoT content’s size is usually small and could be also stored in the small cache size of IoT devices. Therefore, several IoT packets can be stored in a single cache.

We as well as several papers [14] and [15], have considered a multi-hop wireless network system for IoT. This system composes a lightweight IoT-NDN approach for (mobile) resource-constrained nodes. The IoT-NDN systems deal with all application scenarios related to IoT.

C. IoT-Devices

By 2010, it was estimated that approximately 50 billion heterogeneous devices would be connected to the internet [3], [4]. Most of them are connected wirelessly to the IoT.

However, due to the resource limitation of these devices, the NDN is considered as an efficient communication paradigm in terms of energy consumption. Future IoT with NDN will insure more secure and trust data transmission for small devices. The integration and development of IoT with NDN will be successfully designed using the architecture proposed in this paper. Such devices are integrated in every sector and field in our life.

III. API FOR IOT SERVICES

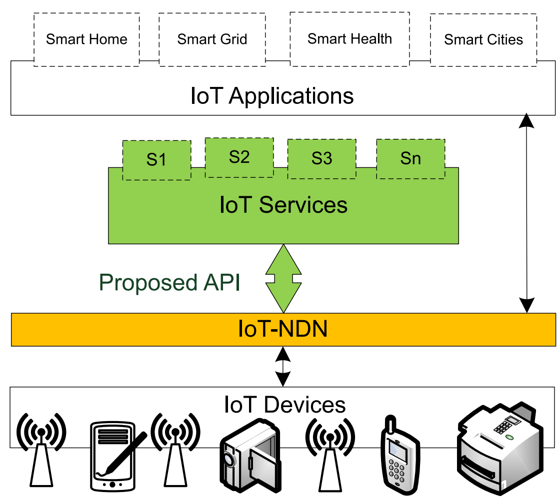

Fig. 2. The proposed API for IoT-Services using IoT-NDN

In this section, we introduce a general API for IoT services and protocols used by different IoT scenarios.

Services are a fundamental of most of today’s and future software and systems in Internet. They are small entity to run a defined task and to deliver specific information for the consumers, for example the service for network time synchronisation can synchronize the physical clock of Microcontroller of every device run in the network. Another service can be defined as a location service to detect current location of devices e.g. mobile devices.

The definition of services is discussed by the research community, but till now no definition has been accepted [6]. Services should be considered as a single device that enables other applications or users to gain access to its resources in order to deliver specific information for consumers or organisations.

However, the IoT services provide us different information from the sensors equipped on the devices or any information about network environment. This information could be used for evaluation or for taking decisions e.g. about particulate healthcare situation. Therefore, IoT services could be vital to provide us with precise statement regarding the future.

The proposed API in this paper is flexible to integrate any service to the IoT-NDN system. Using our API, the users or any organisation can simplify share and get the information from any services integrated on the IoT device. Figure 2 shows the overview of our API for IoT-Services in the IoT-NDN system. Smart cities, healthcare industries and many different fields using IoT can benefit from the low cost and flexibility of our API architecture. Using different flexible and extendible interfaces between layers makes IoT system as a reliable and an efficient communication system.

Some papers discuss and explain the advantage of using services in IoT and physical systems [16] [17]. In term to simplify building a complex application on IoT devices a simple service-oriented integration is presented in this paper. Recently, these services have played a major role for the IoT and could be programmed as a small module of the system. Since IoT devices are resources-constrained, the services layer which is proposed here is suitable to integrate any service to the IoT system. For example, a service which is developed by a person or enterprise can run on IoT device with the application to find the number of neighbouring nodes.

Furthermore, in our architecture we can flexibly integrate several IoT protocol or services such as real time protocol or smart parking etc. In comparison to the traditional internet structure and depends on the layer related to the defined protocol we can flexible extend our design in order to outline a new layer for various another tasks.

Normally, the services are the main components to build a software system [6] but the integration of these services to the IoT devices is challenging implementing the current structure.

IoT-NDN is running on every device to serve several applications and services. Services are instances of small software to sense and prepare new data produced by sensors. After registering the service by the IoT-NDN through our API, the service is able to send these data to the consumer and receive new update from the device using special functions programmed by the API, e.g. update the network time automatically.

With a small change, our API could be used for protocols implemented in the highest level of device which could be used for the communication between application and hardware device.

IV. Implementation

A. *Naming Concept for IoT-Services*

Requesting data in NDN is more flexible than in traditional Internet structure. The NDN uses a hierarchically structured name which is used to request data. The names contain human friendly components and are location independent unlike IP approach. NDN's name structure allows applications and services to control the data transmission between two devices in the network more flexible. However, the same generated data from one device could be interesting for more than one device at the same time. Therefore, NDN enables that intermediate nodes can save a copy of transmitted data. Now, devices are able to retrieve the generated data from any another device in the network which has a copy of them. This device does not need to forward the Interest to the device which produced the data (sink device). IoT systems benefits from such mechanism because of reducing the traffic load in the network

Mostly in IoT systems, the names describe a specific task, event or application scenarios. If we consider the naming concept in IoT-NDN system or this paper, e.g. an Interest name to request information about network time sensor located on patient could look like in Figure 3, where "/" indicates the components and does not indicate to the names request. The name here contains different components as shown in Figure 3 and described in table I. Using the proposed name structure, the IoT-NDN applications can easily understand the request and it's answer to facilitate data transmission [15]. NDN

TABLE I
DESCRIPTION OF SOME COMMANDS IN NAMING CONCEPT OF THE PROPOSED ARCHITECTURE

Command	\%CCOMMAND	Description
Reset	**RESET_**	Reset any device in the network
Update	**UPDAT**	Update time or data of any selected device
SetConfig	**SCONFI**	Set the configuration of a service or Interest like scope and etc.
Help	**HELP__**	To get general information about a integrated service and its functionality

concept and its name structure match the principle of IoT communication. Since the IoT system requests data using human-friendly names (clear names), this concept is beneficial for the IoT system but has some security gaps [15].

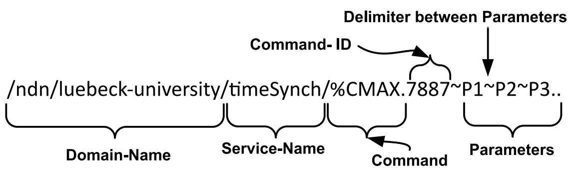

Fig. 3. Name Structure for IoT services including commands and their parameters

*1) **Command Concept in the Service Name:*** Table I shows some commands which could be defined in a service of IoT.

The commands contain three parts:

i) COMMAND: It consist of six letters (A-Z, a-z). It serves to handle some specific tasks already included in the service or will be added in the future. The command is encoded in the Type-Length-Value (TLV) format like another component in the name, for more information about NDN Type-Length-Value (TLV) Encoding see [10].

ii) COMMAND ID: It operates the identification of the message or command send from the service on the device.

iii) COMMAND PARAMETERS: Parameters to process the command in the services on the sink device or intermediate nodes. It could be useful to transmit information about e.g. specific status.

The last component of the name service which includes the command part could be flexible extended to send and receive as well as to transmit another piece of information. Furthermore, the consumer who is interested to use any service run on the IoT device can get the general info about the services with the help command.

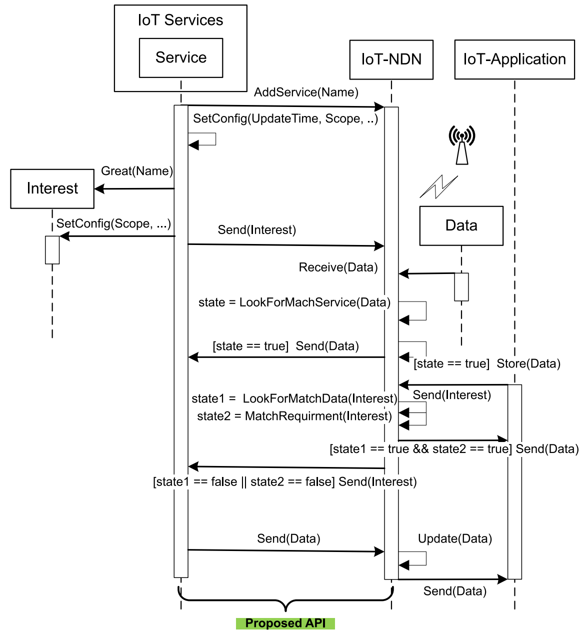

Fig. 4. Example of Service Integration and Exchange of Interest and Data Packets in IoT-NDN with our API

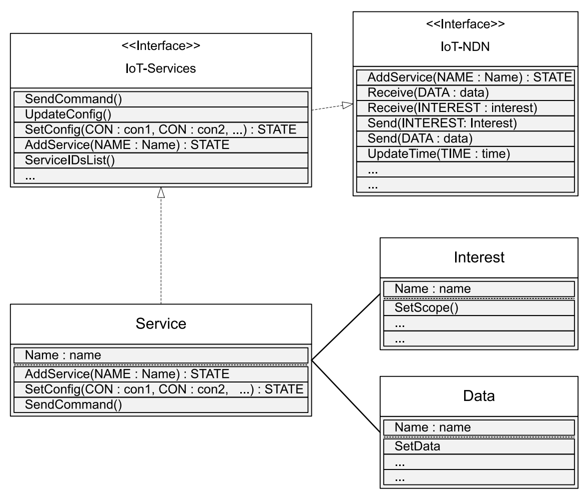

Fig. 5. Class Diagram with IoT-NDN and IoT-Services Components

B. Deployment of IoT Services

The service could be considered as a small software which senses or monitors a specific event in the network and delivers a specific knowledge about things in IoT. This increases the efficiency for taking decision in IoT system which is interesting for another services, application or users in the network. We extended our work in [14], [18], [19], [20], and defined new interface to simplify the integration of services using this API.

Figures 4 and 5 present the architecture of our API and its simple functions to register a new service. An example to integrate a service in IoT-Services is illustrated in Figure 4. It shows the simple exchange of some Interest/Data packets between IoT-Services and IoT-NDN layers. The service is registered by the IoT-NDN with the name structure explained in section IV-A. After registering and setting the configuration of the service, IoT-NDN system starts to look for matching Data in the CS. Otherwise the Interest will be forwarded based on the NDN concept explained in section II. Based on the service settings, another application or service can use the same information produced from the service or are transmitted or cached on the devices in the network.

1) Example of Service Registration: In this example we consider the network time synchronisation on devices connected to the Internet. The name is defined as {/ndn/luebeck-university/NetworkTimeSynch/%SCONFI.1˜5s}. After the integration of the service, based on the set configuration of service, the IoT-NDN sends an Interest to the neighbour nodes to set or get important update from them if present. The above name contains the setConfig command with the message ID "1" and parameter set of 5 seconds "5s". It serves to update the network time every 5 seconds. Figure 6 shows a small overview of the steps to develop and integrate a service in IoT-NDN.

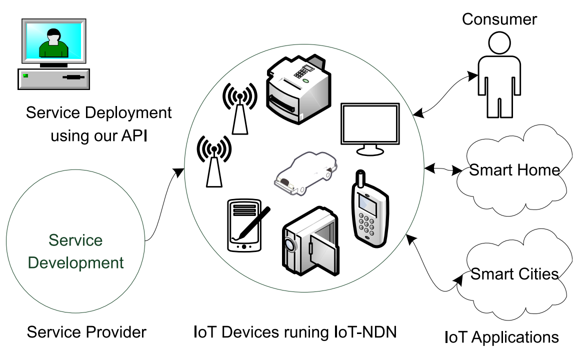

Fig. 6. Overview of Service Registration in the IoT-NDN System

V. Conclusion and Future Work

In this work, we presented an Application Programming Interface (API) for IoT services with the new communication paradigm Named Data Networking (NDN). This API provides the developer a simple and flexible way to integrate different services Associated with heterogeneous devices in IoT.

In this paper, we proposed that NDN approach is an efficient and intelligent communication paradigm and have also summarized IoT-NDN system and its advantage in brief. We have extended the naming concept of NDN with additional command system to provide an effective service control through the proposed API. A network time synchronisation service was demonstrated to check the flexibility and the advantage to integrate services with our API.

In the future, we plan to test the API with more services integrated to the IoT devices and parallel extend our implementation to improve and simplify the use of it.

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