IPv6-Based Test Beds Integration Across Europe and China

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Abstract. The present article exposes a new approach in multiple test beds integration by using the IPv6 properties. It demonstrates the potential of such approach combined with 6LoWPAN and RESTful protocols, such as CoAP. It presents the results of an initial pilot between Mandat International (MI) and Beijing University of Post and Telecommunication (BUPT). Both partners have interconnected their respective test beds, respectively located in Geneva and Beijing. The article presents applied the conceptual model and its implementation. The article provides an overview of IPv6 impact and relevance for the Internet of Things, as well as future envisaged developments.

Keywords: Test bed · IPv6 · CoAP · 6LoWPAN · Internet of Things · IoT6 · ECIAO · Europe · China

1 Introduction

Over the last decades, the Internet has had a profound effect on the way we live and conduct business. The original ARPANET was conceived as a simple and reliable network of interconnected servers but the standardization of TCP/IP between 1974 and 1982 [1] has unexpectedly paved the way to the largest single market of human history. Since then, the Web has emerged and encompassed a huge numbers of connected applications and services. As more and more systems and actors were connected to the Web, the emergence of digital and social platforms was still a rather natural development, using the very same Internet architecture.

We are now facing a disruptive changes impacting the structure and scope of the Internet itself with the extension of the Internet to the Internet of Things and the transition towards the Internet Protocol version 6 (IPv6).

This paper explores the potential of these disruptions and demonstrates how IPv6 can ease the integration of distributed test beds located in different parts of the world to support experiments on the Internet of Things. We start by briefly introducing this evolution. We then present briefly the two research projects that have paved the way to this article: IoT6 [2] and ECIAO [3]. The rest of this paper then goes on to present

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a model of IPv6 and CoAP based integration of test beds. We illustrates the relevance and consistency of our approach through the concrete fulfillment of a pilot for an integrated test bed involving sensors distributed between Geneva in Europe and Beijing in China.

2 IoT and IPv6 Convergence

For years, there was an implicit expectation that the growth of the Internet would be limited in a way which correlates to the World population. This expectation was continually strained as the number of websites and users connected to the Internet continued to grow and is not valid anymore, as we have entered a new era: the era of the Internet of Things. We are moving beyond a point of no return, with more devices connected to the Internet than human beings. While varying – attempts to estimate the number of connected devices in 2020 place the number as high as 50 Billion [4]. Each day our devices are becoming smaller, more pervasive and more mobile. The Internet is already used as a vehicle for many M2M connections, as it is used for Voice over IP and EPC tags management. We are increasingly seeing the Internet as a broad platform for the connectivity of many kinds of entities. We are rapidly moving towards a network in which machine-to-machine and machine-to-human communications will become more numerous than human initiated activities.

Since 1982, the Internet has benefited from the stable and well-designed Internet Protocol version 4 (IPv4). Unfortunately, however, IPv4 only has a capacity of about 4 billion theoretical public addresses (and fewer in practice). This corresponds to less than one public IP address per living adult on Earth – a number that was believed to be sufficient to address current and future needs at the time of its creation. Progressively, however, the growing allocation of public Internet addresses started to cause concerns, leading to restricted public allocation policies and the introduction of Network Address Translation (NAT) mechanisms to provide end-users with private (and sometimes volatile) addresses. Most users effectively became "Internet homeless", unaware that they were sharing potentially volatile public Internet addresses with others.

This continuous growth of the Internet convinced the IETF to deliver a new protocol with a larger addressing scheme, standardized in 1998 as the Internet Protocol version 6 (IPv6). [5] IPv6 is based on an addressing scheme of 2^{128} bits, split in two parts: 2^{64} bits for the network address and 2^{64} bits for the host ID. IPv6 is now globally deployed and a growing number of Internet Service Providers (ISP) are offering IPv6 connectivity.

The extended scheme offered by IPv6 enables an almost unlimited number of addresses, overcoming the scarcity issues of IPv4 and creating the necessary infrastructure for the exploding needs of the Internet of Things. The addressing scheme now available provides the possibility to allocate unique public Internet addresses to as many devices as needed, making each and every smart object Internet accessible through a unique, public and permanent address.

IPv6 is emerging as the natural answer to the emerging Internet of Things requirements. It provides a highly scalable addressing scheme [14, 15] as well as many useful features, such as stateless configuration mechanisms [6], as well as a native integration to the future Internet.

In parallel to IPv6, several IPv6-related standards have emerged, including among others: 6LoWPAN [7] providing a lighter version of IPv6 for constrained nodes and networks; CoAP [8] providing a light substitute to HTTP, RPL [9] providing a routing protocol for lossy networks; Mobility enablers, such as NEMO [10]; and new emerging standards such as 6TISCH [11].

3 Participating Projects

3.1 IoT6

In 2011, the IoT6 European research project [2] was initiated and designed by the coordinator of the UDG project[12]. It was started to further research the potential of IPv6 for heterogeneous integration and gathered together several academic and industrial research partners, including Mandat International and the University of Luxembourg. The objectives of IoT6 were to:

- Research the potential of IPv6 and related standards to support the future Internet of Things and to overcome its current fragmentation and lack of interoperability;
- To develop a highly scalable IPv6-based Service-Oriented Architecture to achieve interoperability, mobility, cloud computing integration and intelligence distribution among heterogeneous smart things components, applications and services; and
- To explore innovative forms of interactions with multi-protocol integration, mobile and cellular networks, cloud computing services (SaaS)[16], RFID [17] and Smart Things Information Service, information and intelligence distribution.

In other words, IoT6 explores the potential of IPv6 for horizontal integration (across various domains of the IoT) and vertical integration between the IoT and the Cloud. The main outcomes of the IoT6 project are recommendations on IPv6 features that can accelerate the Internet of Things coupled with an open and well-defined IPv6-based Service-Oriented Architecture that facilitates its exploitation.

3.2 ECIAO

The EU-China-FIRE Project is a 2 years (Aug. 2013 – Aug. 2015) EU-funded project, facilitating coordination and support to EU-China cooperation on Future Internet Experimental Research (FIRE) [18] and IPv6. China is a very large country pursuing its ICT[19] infrastructure development which could lead to pioneer the implementation of Future Internet advanced technologies as well as being a force to promote large scale IPv6 deployment more critically than EU due to lack of IPv4 resources. Since Europe is investing substantially in Future Internet Research and Experiment (FIRE) and could benefit from exchange and experience from large scale deployment requirements in China, the EU-China FIRE project is exploring mutual benefit cooperation activities. In addition to an interactive web portal, two large conferences and workshops will be organised and many public reports will help to increase awareness of benefits of cooperation between EU and China in the area of Future Internet research and experiments.

The EU-China FIRE project aims in particular to explore EU-China mutual benefit cooperation activities in:

- Strengthening EU-China joint research efforts on the Future Internet by developing interoperable solutions and common standards. Federation of test beds will be explored and interoperability initiatives will be undertaken.
- Reinforcing academic and industrial cooperation on Future Internet experimental research, through a better networking between European and Chinese actors. The EU-China FIRE web portal, linked also to leading social networks and with dedicated helpdesk services, will offer an efficient exchange platform stimulating cooperation between EU and China researchers. A minimum of five common research areas will be identified and documented.
- Exchanging good practices for IPv6 deployment and support the creation of interconnected IPv6 pilot(s) between Europe and China.

4 Initial Test Beds Overview

4.1 Mandat International Test Bed

Mandat International has built up a distributed test bed gathering heterogeneous sensors and actuators in two main locations:

- A smart office test bed in Geneva with end-users. This environment enables experimentations in real conditions, addressing the multidimensional nature of the Internet of Things.
- A university lab in Geneva with more technically focused experimentations.

The test bed has been used in several European research projects, addressing research topics such as energy efficiency, safety, smart buildings, WSN deployments and comfort. It intends to gather all kinds of devices, reflecting the inherent heterogeneity of the Internet of things. The deployed sensors and actuators are heterogeneous and can be split in three main categories:

- IP/6LoWPAN and CoAP based devices;
- IP but non-CoAP based devices;
- Non-IP devices.

The non-IP sensors and actuators are integrated to the IPv6 environment through the UDG technology [12] enabling multiprotocol interoperability and legacy protocol integration into IPv6.

The described pilot was focused on a subset of CoAP and 6LoWPAN sensors, accessible through global public IPv6 addresses.

4.2 BUPT Test Bed

BUPT has built up one 6lowpan based monitoring system, which is already deployed in the BUPT campus. Moreover, CoAP based platform is developing to support IoT application development and resource management.

As illustrated in Figure 1, the system is composed of three main parts: wireless sensor network (WSN) management system, WSN gateway (router) and wireless sensor nodes. The system can be used for collecting information, sending the alarm information and sharing data to the 3rd party. Figure 2 shows the software stack of the sensor network.

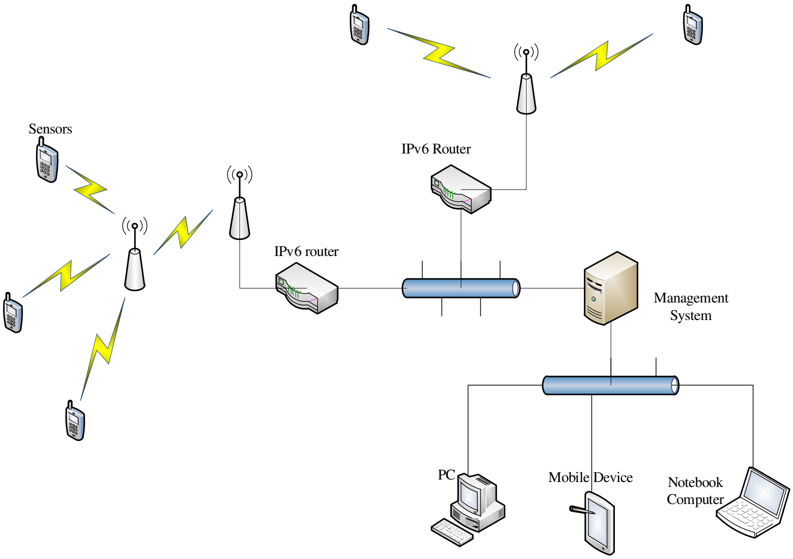
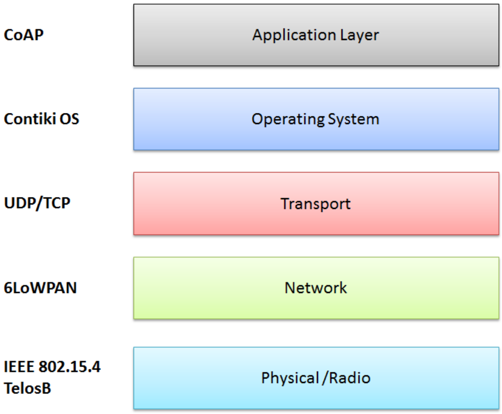


Fig. 1. WSN management system network structure



CoAP	Application Layer
Contiki OS	Operating System
UDP/TCP	Transport
6LoWPAN	Network
IEEE 802.15.4 TelosB	Physical /Radio

Fig. 2. Software stack

Since BUPT IoT platform is a dual-way system both for collecting measurement data and sending control commands, it is possible to do both remote and wireless monitoring and control in real time. Figure 3 shows a screen shot of the result of real-time measurement inside the campus.

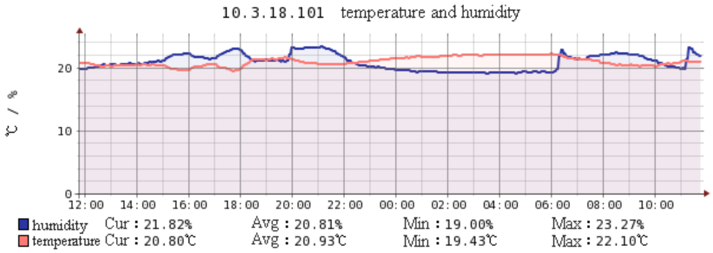


Fig. 3. Result of measurement

The test bed is implemented based on restful architecture approach [20]. The data that is collected by wireless sensors can be easily shared with 3rd party with restful architecture interface. Meanwhile, this platform also provides secured mechanism to protect the private data which users do not shared. All the data in the test bed will be presented by XML format and JSON format.

5 Test Beds Integration

5.1 Integration Model

The main objective was to test and validate the possibility to enable a test bed of sensors and actuators distributed across Europe and China. The experimentation should be able to access the various sensors regardless of their effective location. The first step of the joint pilot intends to demonstrate direct end-to-end access to distributed sensors located in Beijing and Geneva through IPv6.

The integration concept relies on a triple levels integration effort:

- At the sensor level, we have adopted a common interface and environment, by using 6LowPAN and CoAP. This enables the sensors to provide a RESTful interface, with a large scale capacity potential.
- At the network level, we have decided to use direct and secured IPv6 connection between both test beds. IPv6 provides a flexible and highly scalable network environment. A major concern was to enable a transparent interconnection from the sensor to the application wherever each one was located.
- At the application level, applications have been developed to interact with the CoAP enabled sensors. In order to demonstrate the integration, two websites are being implemented in each site with direct on-line access to sensors from both sides.

Figure 4 illustrates the integration model applied to both test beds.

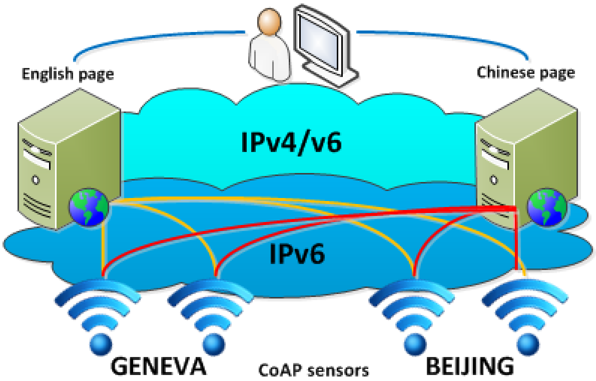


Fig. 4. Mutliple test bed integration model

5.2 REST Full Architecture Approach

RESTful architecture [20] approach is designed for Web applications, whose purpose is to reduce the complexity of the development and improve the scalability of the system. The RESTful architecture interfaces are designed according to the following principles:

1. All the things on the Internet can be abstracted as resources.
2. Each resource is corresponding to a unique resource identifier.
3. Resources can be operated through generic connector interface.
4. Various operations for resource will not change resource identifier.
5. All operations are stateless.

The test bed of BUPT has implemented restful architecture approach. The data which is collected by wireless sensors can be accessed by restful architecture interface. However, the private data which users do not want to make public will be protected by the WSN management system. Data in the test bed is abstracted as resources which users can call through IPv6/IPv4. No matter what kind of system environment or the development environment that users use, they can easily access to these resources. Data in the test bed will be presented with XML format and JSON format.

According to data of the test bed, resources can be divided into 4 different types:

1. A list of gateways.
2. Lists of sensors which are managed by gateways.
3. Real time data which is collected by sensors.
4. History data of sensors which is stored in the database of WSN management system.

According to the types of resources, the interfaces are designed into 4 types. The following chart shows restful interfaces which are used to share with the 3rd party:

URL	/interface/gatewaylist.json(xml)	
Method	Get	
Function	To get a list of gateways.	
Output	Entity	A list of gateways.
Status	Success	
	Failure	
URL	/interface/{gateway name}/sensorlist.json(xml)	
Method	Get	
Function	To get a list of nodes which are managed by gateway named {gateway name}.	
Output	Entity	A list of nodes which are managed by gateway named {gateway name}
Status	Success	
	Failure	
URL	/interface/{sensor name}/realtime.json(xml)	
Method	Get	
Function	To get real time data which is collected by node named {sensor name}.	
Output	Entity	Real time data which is collected by node named {sensor name}
Status	Success	
	Failure	
URL	/interface/{sensor name}/{from time}/{to time}/history.json(xml)	
Method	Get	
Function	To get history data of the node named {sensor name} between {from time} and {to time}.	
Output	Entity	History data of the node named {sensor name} between {from time} and {to time}
Status	Success	
	Failure	

Form 1. The RESTful Interfaces of the Test beds

5.3 Initial Tests and Validation

A first step has been to deploy a joint IPv6 network between Beijing and Geneva. The IPv6 network has been tested and validated and can now provide direct and transparent interconnections. The connections can use SSL[21] and can be tunneled and secured with IPSec [22] if needed.

A first set of sensors have been connected on each site. They are remotely accessible and enable distant interactions from each site. On Geneva site for instance, wireless senor motes, including temperature and humidity sensor, as well as some actuators, including a heating valve and a light switch, are permanently deployed and accessible to the Chinese partners through their IPv6 address and CoAP interface.

6 Conclusions and Future Work

A first set of sensors and actuators have been successfully integrated into a common network enabling European and Chinese researchers to use them. They are remotely accessible and are paving the way to larger scale integration efforts. This initial pilot demonstrates the potential of IPv6 and CoAP for such integrations.

The current effort is oriented in three main directions:

- The extension of the test bed with additional sensors and actuators;
- The integration of other academic and industrial partners in view of addressing scalability requirements;
- The development of two web applications: one in China and one in Europe, providing and demonstrating simultaneous access to sensors deployed in both locations (Geneva and Beijing).

The authors will welcome and duly consider proposals from interested third parties to join the initial platform.

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