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ID-based service-oriented communications for unified access to IoT☆

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ABSTRACT

The dynamic development of technologies for smart devices and the increasing availability of sensors and actuators facilitate significantly the implementation of the Internet of Things (IoT) solutions. The massive use of the IoT depends on the simplification of the set-up and management of the systems, which makes the service creation and composition easier. This paper discusses a prototyped implementation of IDSECOM (ID-based SErvice-oriented COMmunications for unified access in IoT): an innovative hierarchical network infrastructure for connecting IoT objects and services in an easy-to-manage and flexible way. This solution is appropriate when the location of the nodes is closely related to the structure of the environment as it occurs in intelligent buildings/enterprises.

1. Introduction

The growing popularity of the Intelligent Building (IB) concept has its roots in the rapid development of consumer electronics and software created for this purpose. Currently, many off-the-shelf solutions dedicated for IB are available on the market. Among them, one can observe two areas where the networked IoT objects are successfully used: energy saving and security. Both require sensors (*i.e.*, passive infra-red, fume detectors, etc.) and actuators (*i.e.* light switches, window actuators, etc.) located in selected areas of a building. Their location is strictly dependent on the structure of the building and on the connections between them, which create a hierarchical network that can be modelled as a tree topology. The logical topology of sensors/actuators is used in the IDentifier layer (ID layer) for the ontological description of the composed services. Nonetheless, programming of such composed services is more complex due to the existing duality between the ID and network layers and because the object name described in the logical topology must be mapped to the network address.

This article presents an ID-based SErvice-oriented COMmunications system for unified access in IoT, called IDSECOM system, which proposes to integrate the ID and network layers. In IDSECOM, the routing/forwarding functionality of the ID layer node and the network addressing are performed by the use of IDentifiers related to the physical location of the

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sensors/actuators creating, in this way, a location-oriented network topology. This paper discusses architectural and implementation details together with test results of the hierarchical network we have developed to connect IoT objects where node location may be defined by the same environment structure, which is typical in intelligent buildings/enterprises. This article extends the early stage specification and implementation presented in [1]. Consequently, we have also taken into consideration results from our basic experiments, presented in [2], which encouraged us to go further in our research efforts. One of the objectives we have set ourselves while implementing the IDSECOM system was to implement the assumed functionality in all network nodes to make them operable in a real network. The network node discussed here has mostly been developed in a Linux kernel module; it extends the solution proposed in the Flexible Packet Forwarding (FPF) method [3].

In this paper we describe a prototyped implementation of the IDSECOM platform that supports packet processing based in parallel on identifiers and IP addresses. Moreover, it offers a functionality specific for IoT traffic (*i.e.*, registration, resolution and publication) and its features go beyond the State of the Art on forwarding mechanisms, as shown in Section 2. Besides the specification of the architecture and the functionality it offers (Section 3), the main research effort was directed toward prototype development (Section 4) and experiments demonstrating that the IDSECOM node is not worse (in sense of performance) than for instance the Linux implementation of a software IP router (Section 5).

2. Context

Over time, popular solutions of sensor networks have become factory standards widely used in industry control [4,5] (*e.g.* Controller Area Network). Generally, the sensors used in industry are equipped with standard wired or wireless Ethernet interfaces [6], they may thus share the same network infrastructure as other applications. Another approach assumes focusing on power consumption minimization while preserving the flexibility that comes from radio communication. This approach is represented by solutions based on popular communication standards *e.g.* Z-Wave, ZigBee or Bluetooth Low Energy (BLE). The use of solutions based on radio transmission gives wide possibilities to make changes in the number and distribution of smart objects in the building. However, it is sometimes more convenient to use wired connection, *e.g.* for power supplying or for maintaining continuous control over the smart object. In such cases it is desirable to implement the objects using a layer-2 network that is backwards compatible with Ethernet.

In order to develop the location-oriented network topology, the key idea is to embed the physical network connectivity structure into a (logical) topological space (*e.g.* introducing a metric or Euclidean space). This approach was presented among others in VIRO (Virtual Id ROuting) [7] to illustrate how the novel topological perspective enables the development of scalable resilient network routing algorithms. Another example of this approach is SEATTLE [8], which introduces an OSPF-style shortest routing in layer 2 for interconnecting objects and Ethernet switches. Such solutions are aimed at reducing network-wide flooding—often typical for Ethernet switches needed to forward packets whose locations are not yet known. This applies mainly to wide L2 networks, which include small LAN networks.

Other approaches aim at replacing the existing global IP address space by flat identifiers/names. They exploit several methods of hashed ID assignment (mostly based on a Distributed hash table, DHT), which produces an id-space completely independent of the underlying network topology. As a result, these methods perform routing based on logical distance to the ID of the destination. The above mentioned methods have been adopted by Virtual Ring Routing (VRR) [9], Unmanaged Internet Protocol (UIP) [10] and Routing on Flat Labels (ROFL) [11].

The requirements and limitations imposed by the attached smart objects need to be taken into account when selecting the most suitable network architecture for the IoT applications. Moreover, the need for a fast response time and predictability when taking into consideration the Home Building/Office Automation systems should be emphasized. This leads these networks to solutions applied in Real-Time Control Systems (RTCSs).

Typically, RTCSs involve not only topological addressing, but also transmission parameters such as packet delay and predictability of the response time. In such systems, the transmission is moderated by a controller/supervisor, which grants permissions to specific devices (*i.e.* sensors/actuators) by sending appropriate tokens. This topology, defined in IEEE 802.4 [12], assumes that the order of polling is fixed according to the address table (with flat structure) stored in the controller and may have nothing to do with the physical placement of devices. The device with the next highest address is the logical neighbour, even when they can be located at the extreme ends of a physical network. Example solutions include, among others, Profibus [13] and DeviceNet [14].

The aforementioned solutions unify network addresses and identifiers of devices (usually these identifiers are related to the physical location). The solution that we propose in IDSECOM includes these properties and makes the implementation (or composition) of new IoT services easier, since the addressing of IoT services (as well as registration and discovery) follows the same scheme as the objects. Therefore, the service implementation is not bound up with specific scenarios (*i.e.*, specific intelligent building/enterprise) but it is valid for any scenario following the same addressing scheme.

Thanks to that, IDSECOM solutions may incorporate mechanisms specific of Information-Centric Networking (ICN) to the IoT environment. Due to ICN features such as name-based routing, in-network caching, native support for multi-/anycast communication and mobility, the ICN paradigm, and especially the ICN architecture proposed by the Named Data Networking (NDN) [15] project, has been recently incorporated into IoT. In [16–18], the authors compare conventional 6LoWPAN with NDN-based IoT development and show the advantages of the latter in terms of control plane overhead, service access latency and energy consumption. Amadeo et al. present an NDN-based architecture optimized to the IoT requirements (low