Interconnecting smart objects through an overlay networking architecture

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ABSTRACT

Network characteristics in the Internet of Things (large scale networks, more dynamic and more heterogeneous) increase the complexity in the design and provision of advanced services, making the traditional approaches inefficient or even inappropriate. This paper focuses on the design of a novel and open overlay network architecture for the end-to-end interconnection of networked (physical or virtual) objects, the support of distributed information fusion and the provision of advanced services in challenging (e.g. large scale, heterogeneous, resource constrained, etc.) environments. The proposed architecture follows a layered-approach and aims at the provision of a generic framework that will facilitate the design and development of autonomic and decentralized services in Internet of Things deployments.

I. INTRODUCTION

The vision of Future Internet based on standard communication protocols considers the merging of computer networks, Internet of Media (IoM), Internet of Services (IoS), and Internet of Things (IoT) into a common global IT platform of seamless networks and networked “objects” [1]. A dynamic network of billions or trillions of wireless identifiable “objects” will be created, communicating with one another and integrating the developments from concepts like Pervasive Computing, Ubiquitous Computing and Ambient Intelligence [1].

With the trend to interconnect all kinds of “objects” via the Internet or at least using Internet technology, the need to support previously unconnected “objects” and to provide new services arises. All the interconnected “objects” will vary largely in terms of computing power, available memory, and communication bandwidth. In such a networking environment, mainly three phenomena should be taken into account: the increase of the heterogeneity of the end systems and objects connected to the network (e.g., laptop, smart phones, sensor nodes, etc.), the diversification of the type of communication paradigms (e.g., content distribution, content-based networking, event-based, proximity-based group, etc.), and the change of the security needs, which currently go beyond what was envisioned at the time of the Internet’s design [2].

Furthermore, the trend in the Future Internet is the transition to networks that provide highly distributed, pervasive and communication-intensive services. These services pose new requirements on the underlying network infrastructure [3] [4] that derive from the need to operate on top of dynamic, heterogeneous and complex networks. In order to cope with these requirements, such services will be expected to (i) be aware of the context and the environment in which they operate, (ii) self-configure and self-adapt according to the network conditions that they sense and (iii) require minimum feedback from the end-user avoiding any explicit human intervention.

Taking into account the existing projects and the already proposed approaches, it could be argued that there is clear a need for integrating two research “worlds”: (i) research over the design and specification of the Internet of Things and (ii) research over the development of autonomic mechanisms and techniques for the self-managing Future Internet. Internet of Things evolution has to take in account the need for (i) interconnection of networks and objects belonging to different administrative domains, (ii) reduction of the administration overhead and deployment of self-management mechanisms in the network, and (iii) creation and maintenance of service oriented virtual overlay communities.

Based on these open research challenges, our approach is focusing on building upon the existing protocols in the Internet and proposing a generic architecture for autonomic service provision in dynamic and heterogeneous networks. The proposed architecture will be applicable to diverse networking technologies and abstract the physical network entities and resources from the application and management layer. Common interfaces, that hide the physical network heterogeneity and dynamicity, will be provided to application developers and network administrators. In order to do so, the integration of existing IP and overlay protocols, as well as their adaptation and extension according to the supported functionalities in the network, is considered necessary.

II. PROPOSED APPROACH

A layered-approach is described in this section aiming at the provision of a generic framework that will facilitate the design and development of autonomic and decentralized services in the IoT. The proposed architecture tackle issues related with the efficient utilization of the available network resources in a dynamic environment, independent services provision from the underlying network topology, services reliability reassurance in case of network topology changes, reduction of the network management complexity and increase of flexibility to application developers.

A. *The Approach and Key Technological Concepts*

The proposed approach [5] is based on the creation and maintenance of an overlay topology that logically interconnects all the participating nodes/objects in the physical network (Fig.1). Any node that connects to the physical network has to join to the virtual infrastructure. In the virtual infrastructure, multiple overlay networks may be created with all or a subset of the network nodes.

During the bootstrapping of the physical network, the connected devices have to be able to identify each other. Upon establishment of connectivity and multi-hop communication capability among the participant nodes, overlay networks have to be formulated. Overlay networks can abstract the physical network topology and hide any details of the underlying physical infrastructure, e.g. link establishment or torn down, node failures, node mobility, etc. Given the existence of an overlay network, participating nodes must store and retrieve data using a p2p protocol. Information retrieval can be achieved with the storage and retrieval of key-value pairs. Every node that wishes to store a key-value pair, or query a value based on a key, can achieve it by using a DHT that operates on-top of the overlay topology. In a similar way, several applications can be built taking under consideration the existence of a high level Generic Application Programming Interface (API) that will provide them access to distributed (or centralized) repositories of data. Specific functions, such as *put(key,value)* and *get(key)*, can be exposed in order permit interaction with a DHT protocol that operates on-top of a non-reliable IoT environment.

Taking into account the operation of a stable distributed data repository and the description of a Generic API, advanced services can be designed based on the collaboration and dissemination of information among the participating nodes. These services can be fully decentralized as data and functionality is allocated in different nodes at the overlay network. Some functions may be delegated to more than one node for higher reliability. In case of changes or failures, roles may be re-assigned autonomously and performance guarantees may be assured for the services provision.

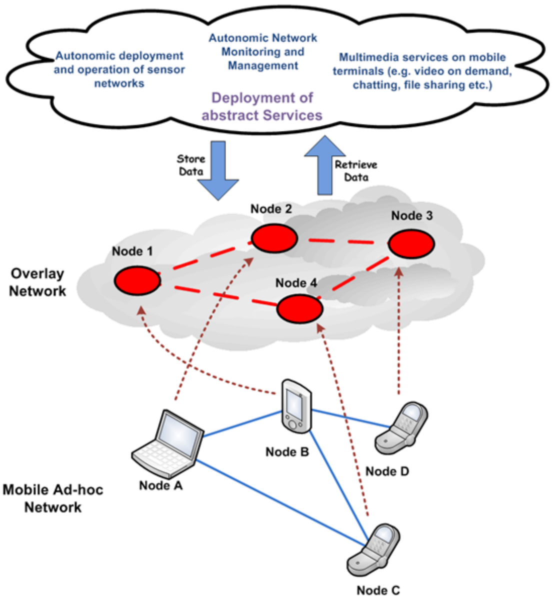

Fig. 1. Proposed approach for autonomic and decentralized services in the IoT

B. *Generic Architecture*

The proposed generic architecture is based on a five-layered scheme driven by the functionality requirements imposed by the provided services and the underlying physical networking environment. As shown in Figure 3, the following five layers are defined; i) *Medium-Level-Connectivity layer*, ii) *Routing layer*, iii) *Topology Maintenance layer*, iv) *DHT layer* and v) *Autonomic Application layer*. Each layer has a discrete role and implements different mechanisms. The proposed layered approach is independent from the selection of p2p protocols and topology formulation mechanisms. Therefore, any combination of different protocols may be selected and proper adaptations may be proposed.

The *Medium-Level-Connectivity layer* is responsible for delivering an upper-layer frame from one neighbor to another neighbor. Also, this layer is responsible for maintaining (i.e. initializing and keeping up-to-date) the routing cache of the Routing layer since when neighbor-to-neighbor links are created or destroyed the related routing information has to be updated. On the other hand, the *Routing layer* is responsible for delivering an upper-layer frame from one node to another node, assuming that these two nodes do not have medium-level connectivity. This layer relies on the routing protocol for frame forwarding across the network. The selection of the appropriate protocol, e.g. an IPv6-enabled routing protocol, is based on the physical infrastructure characteristics.

The *Topology Maintenance layer* is responsible for formulating an overlay topology of the participating nodes. Consequently, this layer undertakes the task of identifying the relative position of each node in the overlay topology without being based in centralized or semi-centralized techniques.

The *Distributed Hash Table layer* is responsible for maintaining a DHT that is bootstrapped over the stabilized overlay topology. For this purpose any existing p2p protocol may be used. These protocols are (semi or fully) decentralized and -in addition to storage and retrieval functionality- may succeed load balancing, reduce bandwidth consumption and improve data reliability across the network.

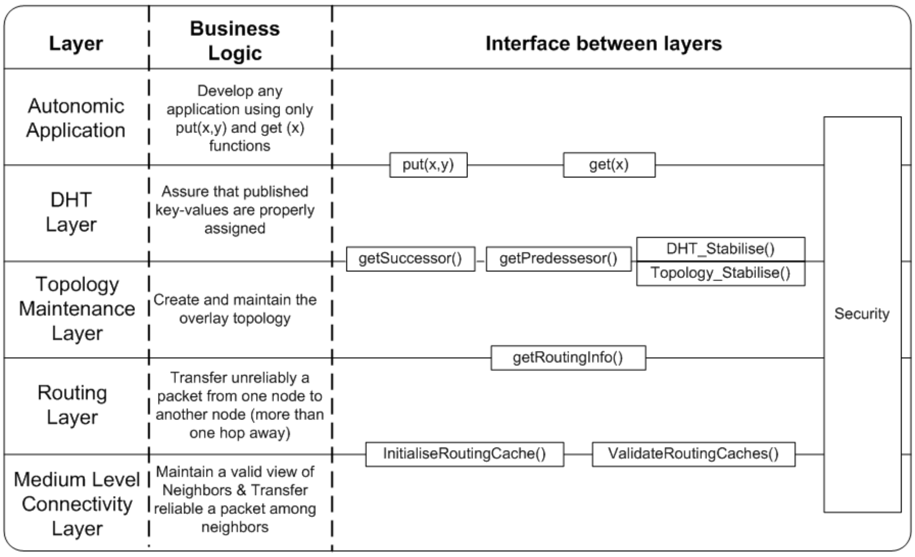

Fig. 2. The Four-Layer Approach

As a result of the concrete layering, specific operations will be exposed from one layer to the other. DHT layer will expose to the application developer the ability to store and retrieve key-value entries, while the Topology maintenance and the DHT layer will exchange notifications regarding their stabilization procedures. Finally, the Routing layer contains interfaces with the Medium-Level connectivity layer since every time a new neighbor joins or leaves the IoT ecosystem, the routing cache -maintained in each node based on the applied routing protocol- has to be re-validated.

On top of the layering scheme, the *Autonomic Application layer* exists. In this layer, services may be designed, composed and provided based on information that is available in the overlay network. Any node in the overlay network can store (i.e. *put(key, value)*) and retrieve (i.e. *get[key]*) a set of values. We refer to set of values since multiple values may be associated with a single key. A decentralized repository is maintained in this manner where data can be consistently stored and successfully retrieved by any node in the network without broadcasts at the application layer.

Each node may undertake the role of the service provider, access the necessary data and provide a service. The design of the services can be realized independently from the underlying physical network while specific functions can be provided to application developers for deploying useful applications.

III. CONCLUSIONS

A novel architecture for the interconnection of numerous intelligent devices and the provision of advanced services has been presented in this paper. The proposed architecture is based on five distinct layers, each of them addressing specific technical challenges. In the lower layers, existing protocols may be exploited in order to establish and maintain multiple overlay networks. Further enhancements and adaptation to existing protocols may be required so as to improve performance guarantees and enhance their scalability. In addition, the upper layers aim to simplify service development, provision and maintenance over the virtual infrastructure. A generic application programming interface will provide access to data repositories and, thus, will reduce the complexity in developing new applications.

REFERENCES

[1] H. Sundmaeker et al., "Vision and Challenges for Realising the Internet of Things", European Commission, Brussels, March 2010, ISBN 978-92-79-15088-3

[2] Wolf,T. "In-Network Services for Customization in Next-Generation Networks", IEEE Network, July/August 2010, pp. 6-12

[3] Bless, R., Hiibsch, C., Mies, S., Waldhorst, O.P. 2008. The Underlay Abstraction in the Spontaneous Virtual Networks (SpoVNet) Architecture, Next Generation Internet Networks, NGI 2008, pp.115-122, 28-30 April, 2008.

[4] A. Galis et al., "Management and Service-aware Networking Architectures (MANA) for Future Internet," *Communications and Networking in China (ChinaCOM)*, pp.1-13, 26-28 Aug. 2009.

[5] P. Gouvas et al., "Integrating Overlay Protocols for Providing Autonomic Services in Mobile Ad-hoc Networks," *IEICE Communications*, Special Issue on Implementation, Experiments, and Practice for Ad Hoc and Mesh Networks, vol. 93-B, 2010, pp. 2022-2034.