The Networked Physical World: An Automated Identification Architecture

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Abstract

We have developed an open and scalable network-oriented architecture that integrates the physical world with the virtual world and admits the efficient storage and retrieval of data and information. The architecture works with existing and future network and Automated Identification (Auto-ID) technologies and requires the use of Globally Unique IDentifiers (GUIDes). An Auto-ID tag affixed to a physical object stores the GUIDe for that object. Networked tag readers wirelessly communicate with the Auto-ID tags, thereby connecting the physical objects to the network. An object’s GUIDe acts as a pointer to storage locations for data and information about that object, operating in a similar manner to pointers in programming languages. Given a GUIDe, the Object Name Service (ONS), a facility similar to the Domain Name Service (DNS), is queried to identify these storage locations on the local network and over the Internet. Storing an object’s data and information in a standardized XML-based language such as PML allows the use of Internet friendly query languages such as XQL and Quilt and enables the automated storage and retrieval of data and information at remote locations. Our architecture efficiently networks the physical world, allowing effective and truly automated information search, information retrieval, and functionality.

1 Introduction

The Auto-ID Center is an industry sponsored research center charged with investigating automated identification technologies and their use with disparate technologies such as the Internet. Guiding this research is our vision of a world in which every object is tagged with information about that object. In conjunction with these ubiquitous tagged objects there must be ubiquitous networked tag readers. Having ubiquitous networked tag readers allows communication with all object tags at all times, thereby seamlessly connecting the physical world to the virtual networked world. This vision is complementary to that of ubiquitous or pervasive computing [5] since the ubiquitous tags and tag readers enable locally controlled applications and thing-to-thing communications. The realization of our vision will result in a networked physical world, enabling diverse ubiquitous automated applications including automated inventory control, automated supply chain management, improved security and theft prevention, automated recycling, and improved human-computer interfaces [4].

2 System Overview

We have designed and implemented a network-oriented architecture that allows the realization of our vision of a networked physical world. The fundamental design decision for our architecture involved determining what information to store in the physical object tags. It is economically infeasible to store all possible information about an object in the tag affixed to that object. Doing so would require affixing large capacity storage devices to every object in the world. Therefore, instead of storing the object information in the tag affixed to an object, we take advantage of the networked tag readers and store the object information in networked object information servers called PML Servers. (PML, the Physical Markup Language, is a standard language developed to describe physical objects [2].) A Globally Unique IDentifier (GUIDe) that acts as a pointer to the appropriate object information servers is the only data stored in the object tag. An identifier resolver, the Object Name Service (ONS), is used to locate the desired PML Server given a GUIDe. The structure of the GUIDe enables ONS to be hierarchical and distributed.

The components of our system work together in a similar manner to the way that the various components of the World Wide Web work together. GUIDes are analogous to URLs (the Uniform Resource Locators). PML Servers are analogous to Web Servers. PML is analogous to HTML (the Hyper Text Markup Language). And, ONS is analogous.
to DNS (the Domain Name Service). There is no analogous component to object tags in the World Wide Web. The key difference between the workings of our system and the World Wide Web is that multiple PML Servers may store data and information about an object, and, using ONS, the GUIDe associated with that object must act as a pointer to all of these PML Servers. This is in contrast to the World Wide Web where a single URL acts as a pointer to a single Web page on a single Web Server.

3 Globally Unique IDentifiers (GUIDes)

The Globally Unique IDentifier (GUIDe) associated with an object uniquely identifies that object and, with a well structured GUIDe, enables a hierarchical identifier resolver. Furthermore, a globally unique identifier enables a plethora of applications, including item tracking, access control, and counterfeit protection, that are impractical when non-unique identification schemes are used.

The Internet Protocol (IP) addressing scheme is an example of a well structured GUIDe. Another example is the electronic Product Code (ePC) identification scheme [1] that we have proposed to identify physical objects. The standard ePC format subsumes the Universal Product Code (UPC), or bar code, formats commonly used to identify commercial items today. The basic ePC format consists of 96 bits divided into four partitions: version (8 bits), manufacturer (28 bits), product (24 bits), and serial number (36 bits).

4 Physical Markup Language (PML)

A standard language for describing objects is required for automated applications. To this end, we are developing the Physical Markup Language (PML) to describe the data and information associated with physical objects. PML is an XML-based language that provides a standardized set of document tags to describe objects and data. PML allows for the specification of passive data, i.e., data that does not change, and active data, i.e., data that changes over time. Passive data, such as the product expiration date and cooking instructions, provides factual information about an object that may be replicated and stored in multiple devices. Active data allows current telemetry information, such as the current location of an object, to be stored within an PML file. Active data is more difficult to manage than passive data; however, active data enables various applications such as product tracking and inventory control.

5 Object Name Service (ONS)

The Object Name Service (ONS) [3] is an identifier resolver that maintains the mapping from an GUIDe, such as the ePC, to the PML Servers storing information on the associated object. Due to the extremely large number of unique object identifiers (more than $2^{96}$ possible ePC codes), the ONS service must be scalable. Furthermore, to be useful, it must be fast.

ONS leverages the success of DNS by being structured in the same manner. However, instead of mapping a machine name to its IP address, the ONS maps an GUIDe to the IP address(es) of the PML Servers containing data and information on the corresponding object. The ONS mapping is facilitated by the partitioned structure of the GUIDe.

6 Looking Forward

Tremendous benefits may be had by integrating the physical world with the virtual world. Initial, limited, attempts at this integration have supported this theory and reinforced the benefit claims. Therefore, it is only a matter of time before all of the physical world is properly integrated with the virtual world.

Our system architecture provides a pathway for this integration. By networking the physical world, uniquely identifying physical objects with an GUIDe, and locating an object’s information over the network, the physical world is easily integrated with the virtual world. Prototype implementations of our architecture have proven its design and applicability. A full scale real-world test of our architecture is being driven by our corporate sponsors and commences in the Fall of 2001. As the system is refined and the implementation ameliorated, the benefits of ubiquitously networking the physical world will prove out. This, in turn, will further drive ubiquitous applications and the integration of all of the physical world with the virtual world.

References