XML Systems for Intelligent Management of Pervasive Computing Resources

Dimitris Alexopoulos[1], George Kormentzas[2] and John Soldatos[3]
1 National Technical University of Athens, School of Electrical & Computer Engineering., 9 Heroon Polytechneiou Str., GR-15773 Zografou, Greece, dalexo@telecom.ntua.gr
WWW home page: http://www.telecom.ntua.gr
2 University of the Aegean, Dept. of Information & Communication Systems Engineering, Karlovasi, Samos, 83200, Greece, gkorm@aegean.gr
WWW home page: http://www.samos. aegean.gr
3 Athens Information Technology, 19,5 km Markopoulou Peania, Ave., jsol@ait.edu.gr
WWW home page: http://www.ait.edu.gr

Abstract. XML technologies have been recently extensively used in IP based network management, where they have been proven capable of alleviating the SNMP shortcomings in configuration management. Our XMLNET system described in [1] has demonstrated that XML systems can greatly facilitate the development of network management applications even in complex heterogeneous multi-vendor networks. In this paper, we present extensions to the XMLNET architecture, with a view to managing not only network devices, but also middleware and hardware resources used in the scope of ubiquitous computing. Ubiquitous computing services are supported by a highly distributed and heterogeneous infrastructures comprising a wide range of sensors (e.g., cameras, microphones, motion sensors, temperature sensor), a well as middleware components (e.g., recognition algorithms, perceptual components). The introduced extensions to XMLNET for ubiquitous computing environments, aim at lever-aging the merits of XMLNET for the inherently complex configuration management operations entailed in pervasive and ubiquitous computing applications.

1 Introduction

Recently, we have witnessed the development of a number of network management solutions (see for example [1-8]), based on the Extensible Markup Language (XML). XML is a standardized meta-markup language by W3C, which features several benefits that can facilitate management tasks. In particular:

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- XML is easy to generate, parse and process, which provides flexibility in handing XML representations of management information.
- XML supports sophisticated data structuring, and can therefore handle complex organizations of management information.
- XML DTD (Document Type Definitions) and XML Schemas specify and validate the structure of XML documents, thus alleviating developers from tedious tasks.
- XML comes with numerous W3C technologies (http://www.w3c.org) supporting rapid development of XML based network management applications. Characteristic examples are the Extensible Stylesheet Transformations (XSLT), which transform XML documents to other XML formats and XPath/XQuery discovering XML elements subject to criteria.
- XML operations can be transformed to SOAP operations allowing management functions to be exported as web services. This allows for loose integration of heterogeneous distributed management systems based on the Web Services paradigm. Similarly, integration can be supported with other types of systems (e.g., Operations Sup-port Systems (OSS)).
- XML has high-level semantics, and is therefore appropriate for performing bulk configuration operations.

In the area of IP based network management XML based solutions have been adopted to alleviate the limitations of the Simple Network Management Protocol (SNMP) [9]. This is manifested in research (e.g., [1-8], [10]), standards (e.g., [11]), as well as industrial initiatives (e.g., [12-14]). Configuration management of composite heterogeneous networks is one particular area where XML management technologies add value to conventional network management approaches. This is mainly due to the high-level semantics of XML, and the wide range of technologies and tools that can easily and flexibly process XML documents. The XML high level semantics can be used to express complex high level configuration commands that impact the status of multiple heterogeneous devices. Note that the power of XML based configuration mechanisms can be exploited not only in the area of network management, but possibly in other fields dealing with heterogeneous systems. The latter are likely to rely on complex configuration processes for their operation.

In this paper, we argue that XML based configuration mechanisms are applicable to configuration management processes entailed in the scope of pervasive and ubiquitous computing (Ubicomp) systems and services. Ubicomp systems exploit the full range of sensors, devices and networks available to transparently provide services, regard-less of time and user's location [15]. Ubicomp services are essentially context-aware services that acquire and process information about their surrounding environment. Ubicomp infrastructures typically include [16]:

- A transparent sensing infrastructure, which is as non-intrusive as possible.
- Middleware for controlling sensors and actuating devices.
- Collection of perceptual components gaining elementary context cues from the various sensor streams.
- Information fusion components combining elementary context cues towards deriving more sophisticated context.

It is therefore evident that Ubicomp infrastructures comprise numerous hardware, software and middleware components, which make them extremely diverse and heterogeneous. Configuring a Ubicomp infrastructure entails therefore several

operations on a variety of components and devices. Given the complexity of the associated management operations, we suggest the use of XML based management mechanisms to-wards flexibly configuring the wide range of components comprising a ubiquitous computing environment. In this paper we extend our XMLNET architecture for net-work management [1], to account for ubiquitous computing devices and components. XMLNET extensions are required towards dealing with an augmenting set of devices comprising not only network elements, but also sensors, actuating devices, middle-ware components and services. Moreover, XMLNET has to be augmented to handle not only network related information (e.g., Element level Management Information Bases (MIB)), but also information relating to sensors, actuators and middleware elements such as perceptual components. The paper describes these extensions and outlines applications that manifest the benefits of the XML based approach.

The rest of this paper is structured as follows: Section 2 provides a brief yet comprehensive description of the XMLNET architecture, to allow readers understand its key functionalities. Section 3 discusses extensions to XMLNET towards managing resource and services within an heterogeneous pervasive computing environment. Section 4 describes potential applications of the proposed XML based architecture for managing pervasive computing resource. Finally, Section 5 concludes the paper.

2 Overview of the XMLNET architecture

The XMLNET architecture [1] provides the means for structuring complex management operations (at the Element Management Layer (EML) and at the Network Management Layer (NML)) as XML documents. EML composite operations consist of several atomic management operations each one affecting or querying a single MIB object. NML composite operations are structured as a set of composite EML operations. Authoring specifications (XML schemas) guide the development of XML documents, according to a composition language. This composition language reflects the core programmability of the system, since it makes provisions for aggregating primitive SNMP (get / set operations) into higher level operations. Moreover, the composition language supports additional features such as allowing for repeatedly executing operations (i.e. looping), processing information elements and enforcing actions when particular conditions are met. Based on the XML schemas specifying this composition language, network managers define composite management operations as XML based APIs at both the EML and the NML levels. XML management applications are authored through assembling API operations and defining parameter values. Note that the composition language is a key element of the architecture, since it specifies how atomic operations are combined into composite ones, as well as how composite ELM operations are combined to composite NML operations. The composition language realizes the programmability of the architecture, since it transforms XML documents to simple network management programs that can be parsed and executed by the run-time

environment. The XML schemas defining the structure of application and API documents reflect the constructs and capabilities of the composition language.

The architecture specifies also a runtime environment that parses and executes XML based applications. This environment renders application development a matter of XML authoring. This approach results in cost effective application development, while increasing authoring flexibility and boosting the programmability of management operations. Also, a potential standardization of APIs can allow third parties (e.g., vendors, NMS providers) to produce network management applications. Based on this architecture we have implemented a network management system enabling authoring and execution of XML management documents comprising EML and NML management applications. This system [17] makes use of a rich set of XML technologies and XML based programming techniques.

As far as the presentation and visualization of the network management applications is concerned, a rendering subsystem presents XML results to a console. This subsystem fulfills visualization requirements relating to the application and/or user preferences. XML technologies (e.g., XSL) can be exploited towards developing presentation mechanisms. XSL can be used to filter XML documents returned by XML applications. Thus, XSL presentation templates are required, along with (EML or NML) XML application documents. XSL templates can be stored in a repository and retrieved based on application requirements. Overall, the major benefit of this architecture is that application development becomes a matter of XML authoring, which is more cost effective than conventional SNMP programming or scripts (e.g., in Perl, Tcl) authoring [18]. Moreover, the XML APIs constitute XML protocols allowing execution of NML and EML operations. These protocols expose an interface to potential management applications. A standardization of this interface can make network management operations open and programmable. Openness hinges on that third party vendors and/or network managers can use the APIs to develop applications. Programmability allows different network management applications to be authored through writing and assembling XML documents. Note that the XML based interfaces (i.e. APIs) to the XMLNET system are accessible in a distributed fashion through conventional distributed programming mechanisms (e.g., XML-RPC, RMI (Remote Method Invocation), Simple Object Access Protocol).

3 XMLNET for Intelligent Management of Ubicomp Resources

Following paragraphs list the extensions required to exploit the XMLNET architecture for managing pervasive & ubiquitous computing resources. Moreover, they describe the required modifications to existing XMLNET sub-systems.

Adapters

XMLNET relies on the low element level network management protocols with a view to interfacing to network elements. Pervasive computing environments comprise however a much richer collection of sensors, actuators, devices, as well as middleware components (e.g., perceptual components). Towards conveying

management commands to these components, implementation of device specific adapters is required. These adapters transform commands expressed in XML protocols (e.g., SOAP, XML-RPC) to the devices based on protocols that can access the proprietary low-level capabilities of each device. In the case of Firewire cameras for example, an adapter constitutes a bridge from XML to IEEE1394 commands. Similarly, a perceptual component (e.g., tracker) maps XML commands to the proprietary API provided by the component developer. Figure 1, depicts an enhanced version of the XMLNET architecture, including the additional element level adapters and parsing engines.

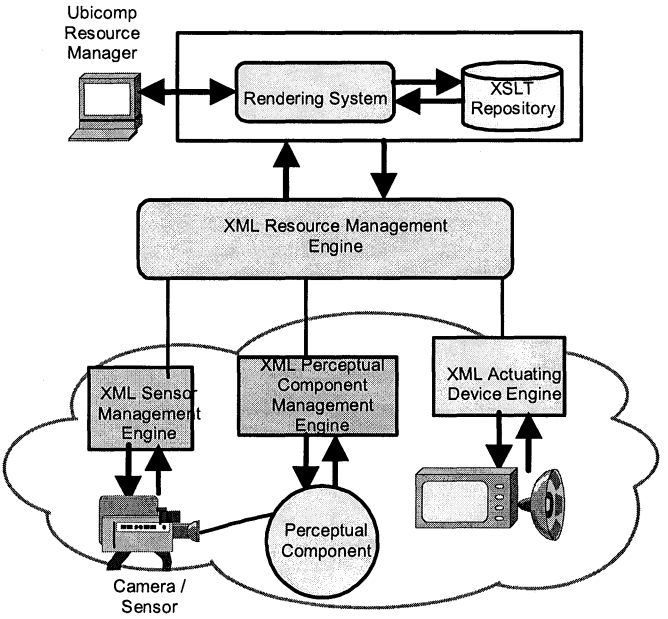

Fig. 1. Overview of the XMLNET architecture for managing Ubicomp Resources

XML Information Bases

XMLNET leverages XML representations of network management information. Towards targeting a wider pervasive computing, there is a need to represent in an XML format. Formatting information about pervasive computing devices and components as XML documents has the distinct advantage of facilitating access to this information from the wide range of heterogeneous components of a ubiquitous computing environment. These components are likely to run on different platforms and/or to be written in a variety of different languages. Thus, a neutral format (such as XML) eases information fusion and exchange in a pervasive environment. Moreover, it can ease the portability of components across different pervasive environments (e.g., different smart spaces). Indeed, installing a middleware component for pervasive computing in a different operational environment demands a clear specification of input, output and configuration parameters.

Element Level Managers

XMLNET incorporates special ELM parsers that process XML commands targeting network elements. In a pervasive computing environment, additional parsers need to be implemented for all sensors, devices and other components comprising a pervasive computing environment. These parsers along with the corresponding adapters can be classified as Element Level Managers including:

- An XML based interface for accessing the element, device or component.
- An interface to the XML representation of the information pertaining to the element.
- The adapter enabling access to the low-level capabilities of the element.

Figure 2 depicts an Element Level Manager for an engine pertaining to a sensor (specifically a digital Firewire (i.e. IEEE.1394 camera).

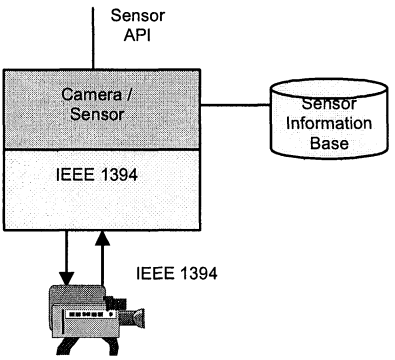

Fig. 2. XML based Sensor Manager

XML Resource Managers - Pervasive Environment Managers

The core intelligence of the XMLNET enhanced architecture for pervasive computing resources management lies in the higher level XML resource management engine, depicted in Figure 1. This component parses higher-level XML document comprising a variety of element-level operations pertaining however to the whole range of elements available in a pervasive environment. Towards combining these element-level XML operations a composition language is required, driving the combination of element-level operations towards intelligent added-value operation. Note that the scope of such a composition language is unlimited; however the XML based composition language of XMLNET [1] can serve as a starting point. This language supports:

- Serial combination of element-level operations, which is particularly useful for composing complex configuration operations impacting several elements and components.
- Automatic extraction of derivatives on quantities relating to the operation of the components (e.g., actual frame-rates for a camera, recognition accuracy for recognition/identification algorithms etc.).
- Event triggering upon occurrence of specific conditions (e.g., when some threshold is exceeded).

- Looping, allowing for repeatedly executing the same operation or batch of operations.

Note however that the composition language of the pervasive environment manager can be significantly extended to include information about component combinations such as combination of perceptive components according to particular situation models [19]. In such a case, a situation modeling component can dynamically define the perceptual components that support it and reflect this combination in a certain composition construct.

4 Prototype Applications

Having a number of element level interfaces at hand, along with a composition language to combine them, we may build a large number of innovative applications, utilities and services. Characteristic examples include:

- A Smart Space Resource Manager (SSRM), as a utility enabling monitoring and control of perceptual components, sensors and actuating services available in a smart space (e.g., smart room). Administrators of a smart space may use the SSRM utility to manage a variety of heterogeneous distributed entities from a single entry point. Such a resource manager has been already built [20], [21], based however only on element level operations. The combination of element level operations ac-cording to the XMLNET composition language can allow for the automation of more complex operations in the scope of a smart space. Such complex operation may for example include the automatic configuration of all sensors and perceptual components of a smart space for a particular application.
- Service development and deployment utilities, that automatically start, configure the components entailed within a service, while also auditing their interrelation-ships and interoperation. For example, a utility may audit the integrity of a situation modeling component (e.g., a situation recognition engine) by setting appropriate thresholds relating to the operation of all the components supporting the situation model. Accordingly, the administrator of the pervasive environment or service will get notifications on the appropriate operation of the situation model as a whole.

5 Conclusions

Configuring Ubicomp services is a particularly tedious task, given the numerous hardware, software and middleware components comprising a Ubicomp service. XML based protocols feature high-level semantics and come with a large number of ready-to-use tools for parsing and processing meta-data. Therefore, XML base architectures are appropriate to automating configuration management tasks in the scope of large scale, diverse and heterogeneous pervasive computing environments. The XMLNET system (originally designed for network management) provides a conceptual architecture that can be applied in ubiquitous computing management. This architecture needs however to be augmented with:

• Interfaces to the low-level capabilities of the whole range of elements and devices entailed in ubiquitous computing. While XMLNET relies on SNMP based interfaces to network elements, the augmented system should also offer interfaces to sensors, actuators and middleware components.
• Element level XML Parsers, processing high-level management commands and translating them into element level operations on sensors, devices and perceptual components.
• A Pervasive Resource Manager, combining element level operations into higher level added value operations for the pervasive environment at hand. Key to this combination is a composition language specifying how to compose added value operation based on the API interfaces provided by the element level components.

The augmented architecture can serve as a basis for a number of useful tools and applications, facilitating management of pervasive computing infrastructures, as well as development, deployment and integration of ubiquitous computing services.

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