Web Services and Data Integration in Distributed Automation and Information Systems in Internet Environment

Nikolay Kakanakov [1], Mitko Shopov [2], Ivan Stankov [3], and Grisha Spasov [4]

Abstract – *In this paper an abstract model for adaptation of enterprise technologies in heterogeneous networks of small devices is proposed. The model is based on hierarchical multi-tier approach for better manageability and administration. Its structure allows not only separation between business and presentation logic, but also separation of enterprise and automation functions. Thus, changes in business and automation logics do not affect the user. The actual distribution of functions appears on the service and automation tiers. The level of abstraction of the model allows its usage in various environments – home and office automation, industry, medicine, agriculture. In the paper an experimental application of the presented model for an effective management of HVAC (heating, ventilation and air conditioning) systems in buildings is discussed.*

Keywords: *N-tier model, distributed computing, embedded systems, Industrial Ethernet, HVAC.*

I. Introduction

The globalization of the market and the growth of Internet have brought the business out to a new frontier. Enterprises more and more frequently have several plants spread over different countries and even over different continents. In this situation, the enterprise software systems face new challenges. Among these challenges are: communication between branches spread over large geographical areas; interoperation between loosely-coupled distributed plants and offices; uniform administration and management; linking the enterprise system with different customers, vendors, partners; integration of Enterprise Resource Planning (ERP) system with the enterprise information system and specific production level software subsystems (e.g. manufacturing, logistics, human resources). Most of these challenges have specific solutions but the computer engineers and science are working to find an integrated, composite solution that would satisfy enterprises in all new needs.

Modern business software has sufficient features enabling inter- and intra-enterprise integration of components. On the other side, manufacturing and automation networks often rely on custom, vendor-specific protocols and software systems. This leads to difficulties in interoperation and integration of such subsystems.

The key goal of the work, presented in the paper, is the analysis of the latest off-the-shelf technologies in business information systems and their possible adaptation in distributed automation, based on controllers with embedded communication facilities. For this purpose, a model of information flow and representation in distributed automation systems is developed, employing the standards of e-business, working on the web. An experimental application of the presented model for an effective management of Heating, Ventilation, and Air-Conditioning (HVAC) systems in residential buildings is proposed. The limited resources of the embedded devices as well as the dynamic nature of building's automation networks are impending factors for the adaptation of web services into the systems.

The rest of the paper is organized as follows:

Section II.1 presents prerequisites and background technologies used for engaged in the designed model and Section II.2 discusses the related work on the problem; Section III describes the presented abstract model for integration, including model's overview (III.1) and in-depth description of the model's tiers (III.2); In Section IV possible areas of application of the model are proposed. Section IV.1 presents a hypothetical application - effective management of a HVAC system in residential building; Section IV.2 presents some results and discussions on the hypothetical application; Section V includes the conclusions about the model and gives directions for the possible future work and research.

Background and Related Work

This section gives arguments for making some reasonable solutions and describes the prerequisites on

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which the model is built. It summarizes relevant background technologies and related work on the problem.

I.1. Background

As far as the discussed model faces both enterprise and automation challenges, it relies on well-proven technologies from both areas. The key enabling technique for the vertical integration in the model is derived from multi-tier business information model. The automation part is based on a simple perceive-reason-act model. And, the interconnection is based on web services and TCP/IP as a standard for Internet communication.

Multi-tier business information model proved itself as a standard for building enterprise information systems. Its tiered organization provides functional separation of data storage, business and presentation logic. The applications built upon this model are recognized with their increased security and availability and facilitated administration and management [1].

As building complex models, embracing different hardware and software components, the key for interoperation is using the appropriate middleware technology. Choosing the middleware is based on understanding the needs of the particular application environment. The web services are the state-of-the-art middleware technology for building enterprise systems, in need of inter- and intra-enterprise interaction. Done properly, Web service frameworks add value to existing infrastructure and applications by allowing them to be integrated at a level of abstraction that was previously impractical because of competing, divided standards and non-interoperable proprietary approaches [2], [3], [4].

Internet ubiquity and XML widespread adoption have led to proposals of many communication models for achieving high level of platform independences and interoperability of entire system. All of this produces very high level of abstraction inside the system. The key enabler for WS technology is XML, and the initiatives that form its foundations are simple object access protocol (SOAP), web services description language (WSDL), and universal description discovery and integration (UDDI) [2], [5].

The simple automation model (SAM) consists of a number of sensors and actuators for interacting with environment and a controller that monitors certain output variables and adjusts other input variables to achieve the desired operation. As automation science evolves, an infinite number of approaches and paradigms appear, that can be applied to explore smart environments. The basic Perceive-Reason-Act approach seems to be the most popular one. Applied to automation this model includes: sensors through which the model perceives; a controller with software to reason; and an actuator that affect environments i.e. act [6].

Most commonly in the sphere of automation Profibus, Fieldbus, CanBus, Modbus/IDA and other standards are closely related. In this paper, an automation model embracing embedded systems is discussed. Most of the wide spread embedded systems and controllers have support for TCP/IP communication. This feature of the embedded systems is crucial for further discussed implementation. A trend of shifting form aforementioned standards to Ethernet is observed over the recent years. Ethernet as medium for transmission is very reliable with low level of BER. These prerequisites give a new direction for developing of technologies as well as standards in automation systems.

I.2. Related Work

Nowadays unification of standards and technologies is very significant for future development. An enterprise process comprises a number of structured operations associated with data exchange and function calls among applications or systems residing in the different enterprise tiers Fensel et al. [7] present the web service modeling framework (WSMF), introducing a conceptual model for using WSs for the integration of distributed systems, opening each application’s processes to easily accessible WSs, described through ontology.

D. Lioupis and M. Stefanidakis in [8] presented a model for distributed computation, utilizing the processing power of non-busy embedded nodes. This model do not provide a base for building distributed automation systems but rather provide a methodology for effective utilization of the processing power of the ubiquitous embedded devices. It can be applied to the model presented in the paper as an upgrade for distribution of time-consuming calculations on the non-busy controllers that are not involved in execution of crucial functions.

Kalogeras et al. [5] present a methodology for building enterprise industrial systems utilizing web services. The ontology and workflow representation are crucial for presented methodology. The presented work gives good direction for enterprise interrelation, but do not clearly describe the interaction with the factory level issues and technologies. This approach can be used for systems with clearly defined business components and processes, but do not address the restrictions of the factory environment.

Topp and Mueller in [9] discuss all the needs for particular automation system, depending on the cost, manageability, flexibility and availability, but not affecting the functionality. Using Ethernet, any model can be structured and organized in particular hierarchy for achieving high level of accuracy and performance. The authors consider the importance of interoperability over large distances upon heterogeneous platforms for most of the problems that a model has to solve. This paper proves that using TCP/IP protocols allow deeper integration of embedded devices and relevant automation systems to the Internet. As a completion, it becomes clearly from the paper that WS (Web Services) are the most vanguard technologies and best fits in the work presented in the current paper.

Bertoni Machado et. al. in [10] propose a use case scenario that is build upon the idea of integration of embedded systems using web services. The paper provides some preliminary results for building web services for embedded devices using different toolkits. These results can help the developer to choose a toolkit when building such kind of application. The disadvantage of the work is that the utilized model is not clearly defined and the guidance for integration with enterprise information system is not further discussed.

Jammes and Smit in [11] present future directions for intelligent device networking based on service-oriented paradigms. In particular, the use of a high-level communications infrastructure based on Web Services at the device level is suggested. Key advantages of their approach are increased level of autonomous and interoperability, better manageability, and simplified application development. As pointed out by the authors this approach tend to facilitate the integration between automation and enterprise systems. However, the paper lacks a clear methodology for the realization of such integration.

A Model for Integration

The purpose of the presented work is to provide a model, capable of handling all features for any possible realization. That is why the level of abstraction in the model should be high. The communication should be seamless between tiers as well as between distributed components on a particular tier. The XML and the level of abstraction are obviously the semantic glue for interconnection of the separated parts of the model.

An enterprise process comprises a number of structured operations associated with data exchange and function calls among applications or systems residing in the different enterprise tiers. Developers of enterprise systems are aiming to standardize the communication model from one hand and technology from the other [5].

I.3. Overview

This section provides an overview of the proposed model and clarifies the reasons for existing of each tier and shows the interconnection between them (figure 1).

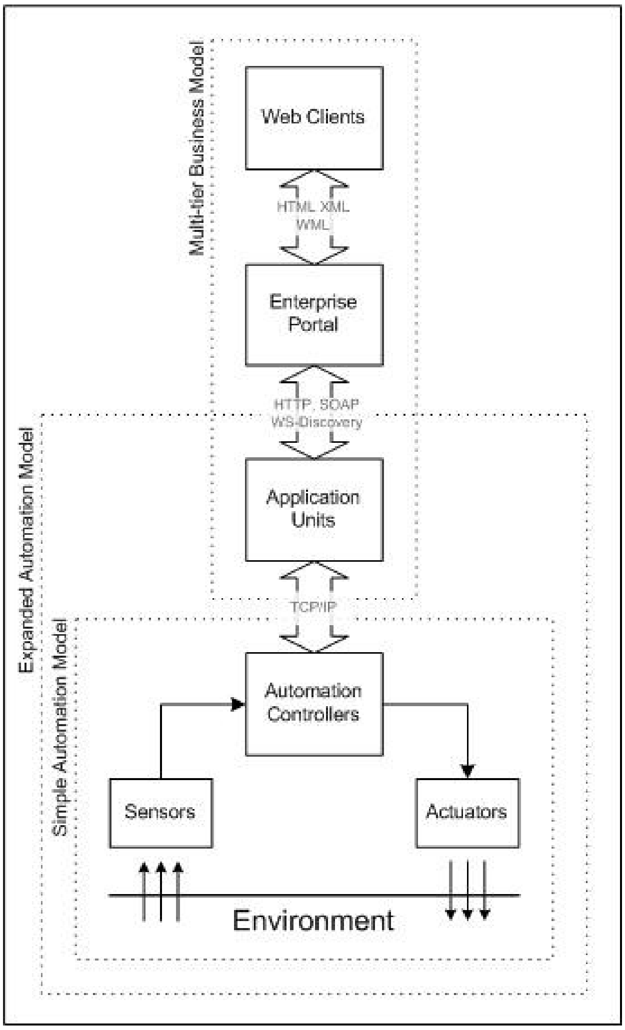

Figure 1. Model's overview

The novelty of the approaches used is the combining of business approaches with Simple Automation Models (SAM) by using semantic glue for complete interoperability between tiers. The interoperability should focus on the overlapping parts of the Multi-tier business model and the Expanded Automation Model (EAM). As a result of exchanged information, an N-tier Model for Distributed Automation comes into place. This model combines two completely different approaches and shows well integrated interoperability using simple socket programming in popular programming languages. The middleware technology used for the interoperation are the web services. This assures the possibility of distribution of functionality over large distances.

In fact in the world of embedded systems most of useful stuffs like RTOS or TCP/IP stack are open source. The advantages of using open source software are the possibility for adjusting the code to the particular application needs and that it is distributed freely. On the other hand, the open source software is commonly functionally incomplete and sometimes poorly documented. Thus, off-the-shelf technologies are not always applicable for the needs of the proposed abstract model and must be extended.

I.4. Tiers functionality and technologies

Generally, the proposed model consists of four tiers: client, presentation, service, and automation. Each tier of the model provides a particular functionality. Following, a description of the functionality and technologies of each tier is presented (figure 2).

• Client tier. Situated at the front-end of the system, this tier allows clients interaction with the system for getting information and setting preferences. The clients request services from the system using regular Internet browser or via web services. Different responses can be constructed depending on the client's platform (PC, PDA, cellphone).

• Presentation tier. This tier has two main functionalities. First, it is responsible for handling client's requests, acting as a single point of entrance and forming the appropriate view for particular type of clients. Second, it summarizes the information from other tiers together with some external information and make a global decision. The server working on this tier is called enterprise web portal and can be based on a portal technology [12] or dynamic web server technologies [13].

• Service tier. This tier offers different functions exposed as web services. Some of these services may be external, third-party services. For the location of the internal services a private UDDI registry as suggested in [2] is used. A granular decision making occurs on this tier. The information from the lower automation tier is analyzed and granulated before send to the upper presentation tier.

• Automation tier. This tier consists of automation controllers that use sensors and actuators to obey some predefined behavior logic. A characteristic of most controllers is their limited resources and presence or absence of RTOS (real time operating system). That is why the use of general purposes protocols with their huge overhead is not adequate. On the other hand, if a strongly customized protocol is used it may narrow the operation distribution. A better solution seems to be the use of open, TCP/IP based protocols, optimized for the specific tasks. It will be a trade-off solution that inherits benefits from both approaches. Such protocol will benefit from the ever increasing count of embedded controllers with build-in support of TCP/IP protocol suit. Examples of such protocols are CNDEP [14], BacNet, KNX-over-IP, and etc. This tier can be further separated into two logical parts: a set of sensors and actuators for interaction with the environment and a micro-controller responsible for preliminary decision making and networking.

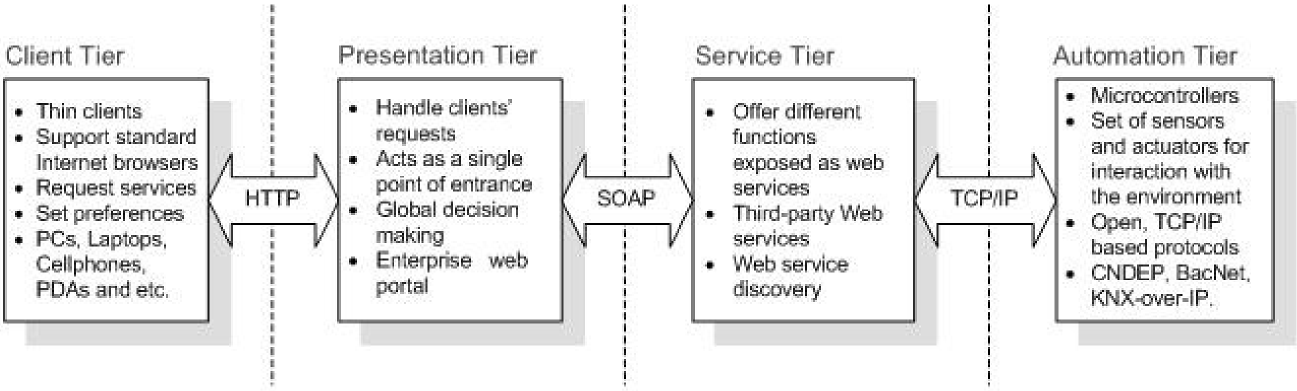

Figure 2. Tiers functionality and interaction.

Possible Areas of Application

Discussed model possesses high enough level of abstraction to be implemented in various application areas. The difference of each implementation is the specific content of the exchanged messages and the specific functionality on the service and automation tiers. There are some existing projects in the practice, involved in various environments – smart homes and offices, industrial automation, e-health, e-agriculture, assistive environments for individuals with special needs, and etc. [6], [11].

I.5. Use case scenario

In this section we propose one possible application of the model – effective management of a HVAC (heating, ventilating, and air conditioning) system in residential buildings. The architecture of the hypothetical scenario is shown on figure 3.

For the description of the system a bottom-up

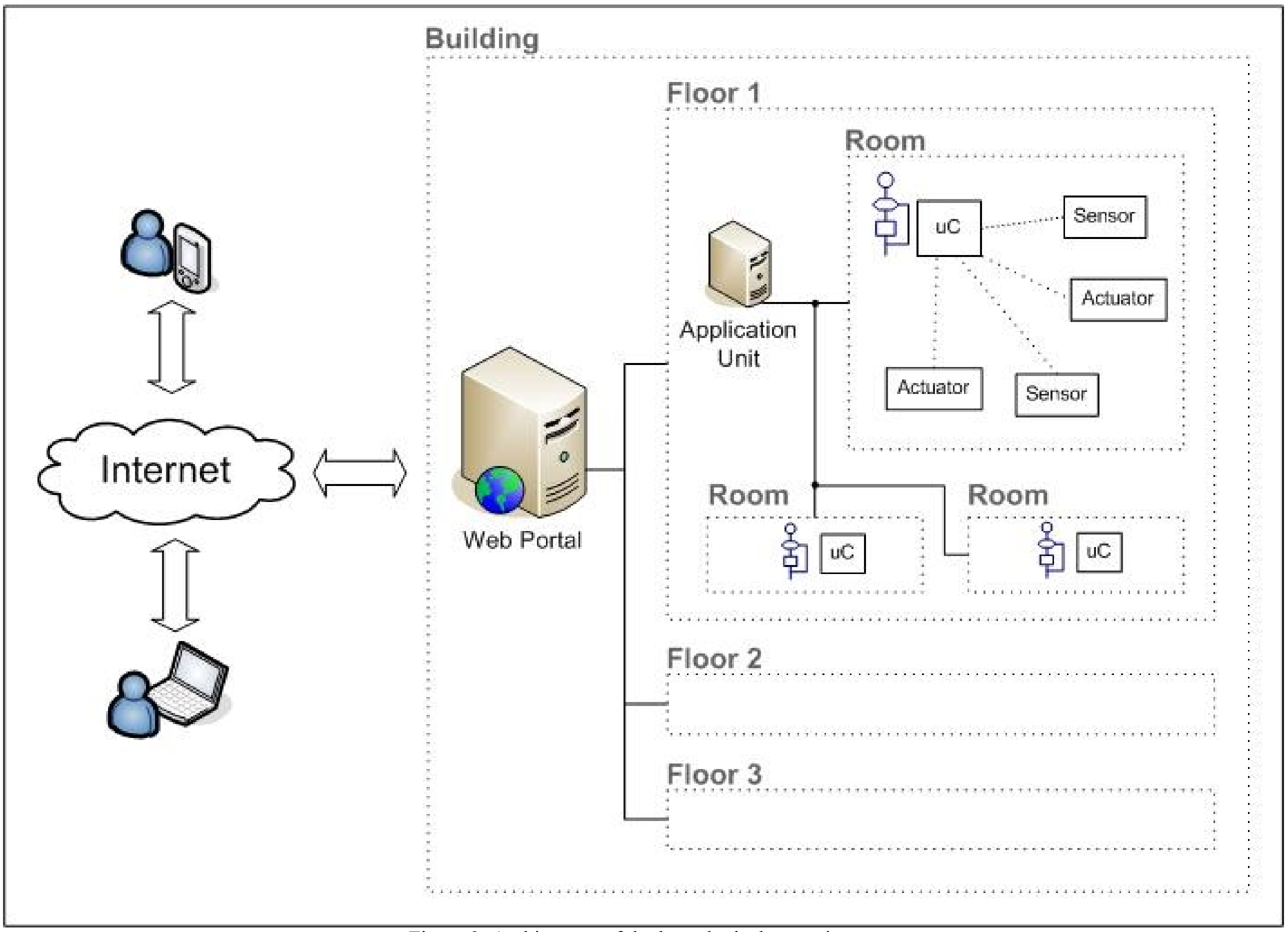

Figure 3. Architecture of the hypothetical scenario.

approach will be used. Networks of controllers, with sensors and actuators, are built up on every floor of the building. These controllers use preconfigured behavior logic to control the environment parameters. They are accessed through optimized, TCP/IP based standard communication protocols. On the upper tier a floor application unit analyzes and manages the work of each controller. Since it has a view over the whole floor it can make decisions based on that knowledge and to use predictive adjustment of behavior logic of individual controllers. However, no information about the neighbor floors is available and so cannot be taken into consideration here. This is possible on the next tier, where one central computer called Web Portal summarizes the information from all floors in the building, together with some external information like whether forecast, information for prices (if more than one energy source is available), disruption in energy supplying (if planned) and inhabitant's preferences. These can be accessed as Web services offered by suppliers or third parties.

Such a system is supposed to improve the energy efficiency of a building for several reasons. First, a zoned heating can be introduced. This will allow a more granular application of heat similar to non-central heating systems. Second, a predictive logic based on information for condition in neighbor rooms, neighbor floors, weather information, inhabitant's preferences, prices and disruption information can be used on different tiers of the system.

Figure 4. Application Unit.

The experimental implementation of the system uses the following software and hardware components. For the Web Portal an Apache Tomcat 5.5.14 JSP/Servlet container from Apache Software Foundation is used, running on HP ProLiant ML110 at 3.2GHz, with 1GB RAM and OS Debian Linux 2.4.27-2-386. For the application units Single Board Computers (SBC) running on 800MHz with 256MB RAM are used. The SBCs' platform used is VIA EPIA Mini-ITX (figure 4), running OS Debian Linux 2.4.27-2-386 [15]. For the automation controllers both IPC@Chip [16] (figure 5) and DS Tini [17] (figure 6) platforms are used.

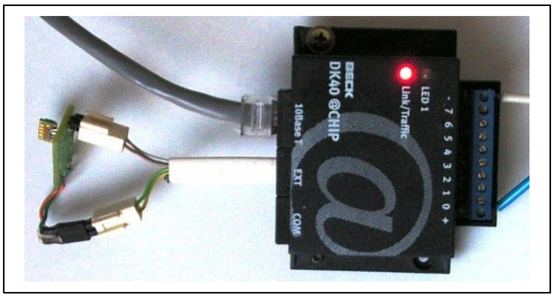

Figure 5. IPC@Chip embedded platform.

For sensing the environment an intelligent sensor SHT71 [18] from Sensirion is used. Communication between application unit and automation controller uses CNDEP [14] protocol. Communication between Web Portal and application units is based on SOAP and Web Services. For the realization of the web services an Apache AXIS platform is used. Pictures of adopted hardware in Automation tier

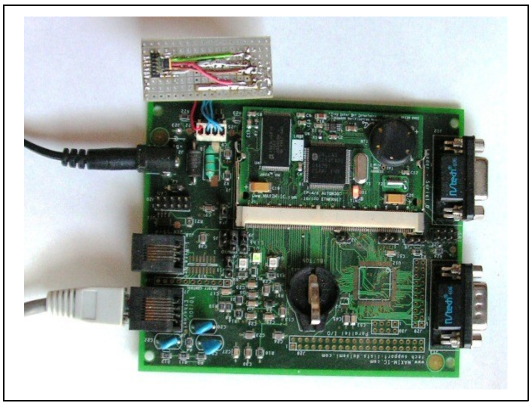

Figure 6. DS Tini embedded platform.

I.6. Results and Discussions

The hypothetical scenario is partly implemented in "Virtual Laboratory of Computer Networks and Distributed Systems" in Technical University of Sofia, branch Plovdiv (http://net-lab.tu-plovdiv.bg) and the implemented parts are tested for functionality. Test bed experiments are executed for collecting some performance metrics of the automation tier work and estimating the communication between distributed Application units (figure 7).

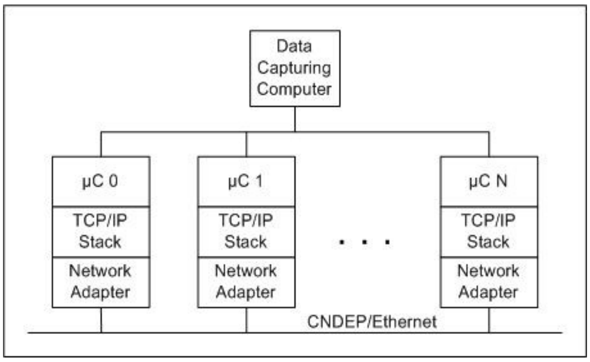

Figure 7. Test-bed configuration.

The protocol chosen for communication between services and automation tier is custom made. It is implemented as application protocol over UDP transport. Some experiments are made for calculating the minimum, maximum and average values for the latency of the request/response pairs. This latency is calculated by extracting the RTT (Round Trip Time) for the local network from the measured time between send and receive operations. They have no remarkable deviation from its mean value, so the protocol used is suitable enough for soft real-time communication (Table I). Despite of the increasing intelligence of sensors and actuators they need some time to produce their task. Depending on the used sensor accuracy, needed time for turning out vary from 14 ÷ 210 ms [14], [18], [19].

TABLE I
LATENCY OF CNDEP

command	controller	IPC@Chip		DS TINI	
		HR	**LR**	**HR**	**LR**
TEST	**min**	10.9	-	17.4	-
	max	14.5	-	21.6	-
	avg ± σ	13.4 ± 1.4	-	19.1 ± 0.1	-
GET	**min**	251.2	96.6	415.9	218.3
	max	262.7	122.2	463.3	286.8
	avg ± σ	254.7 ± 0.2	102.4 ± 0.3	418.9 ± 0.5	242.1 ± 0.9
SET	**min**	11.9	-	51.2	-
	max	16.4	-	57.1	-
	avg ± σ	14.1 ±0.7	-	52.8 ± 0.1	-

Aforementioned results are significant for proposed model. All communications between tiers are realized on standard protocols and technologies. This leads to predictable results for latency estimation and usage of popular measurement techniques. On other hand, it is considered that no significant improvement should be done to the used well-known principles.

Series of experiments are executed investigating two different CNDEP implementations - using binary data (CNDEP) and using XML encoded data (xCNDEP). The first implementation is suitable for fast communication, and the second – for interoperabilty (Figure 8). [20]

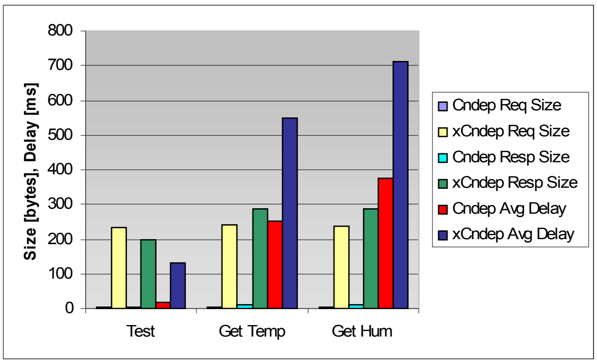

Figure 8. CNDEP vs. xCNDEP.

As a summary of the presented results the dependences relying on a current realization for any particular systems could be outlined. These dependences concern design for simple automation level and all involved components as well as business model design and all tiers it includes.

Conclusions and Future Work

An abstract N-tier model for distributed automation systems, together with utilized technologies are discussed in the paper. This model is suitable for building distributed systems in various environments – smart homes and offices, industrial automation, e-health, e-agriculture, assistive environments for individuals with special needs, and etc. It is based on the adaptation of the automation model and enterprise information systems model, in order to provide interoperability, distribution of functions, increased reliability, and scalability. The main advantage of the model is that it can be used as a methodology for integration of enterprise information systems with factory automation subsystems from all the plants.

Among the limitations of the model are the facts that it is not entirely distributed, it is rather based on a mixture of hierarchical and distributed approaches. Another limitation is the presence of a single entry point (the Web Portal) that could also be a single point of failure or intrusion.

Security issues are another consideration not completely addressed in the proposed model. The web services chosen for realization of communication in the middle tiers should provide authentication, authorization, confidentiality and data integrity.

The model should be further analyzed, precisely tested, and possibly optimized. A series of test-beds should be taken for estimation a number of performance metrics for the model – tiers interaction delay, service work latency, distribution of the possibility for accessing particular services and functions. The results from these test-beds should be used for tuning the model and for creating a simulation model. The simulation will provide a base for testing the proposed abstract model for different applications. Apart from these test-beds and simulation and analysis of the possible data flows must be taken in order to create specific policies for QoS and security in the model.

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