INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

MBC - Mobile Business Collaboration

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Dissertação para obtenção do Grau de Mestre em

Engenharia de Redes de Comunicações

Júri

Novembro 2011

Acknowledgements

I owe my deepest gratitude to my teacher advisor, Prof. Luís Veiga, who has the attitude and the substance of a genius: He continuously gave me support and guidance throughout the research and during the writing of this document. Without his guidance and persistent help this dissertation would not have been possible.

I also would like to thank Eng. Paulo Chainho, my advisor from PT Inovação, for his tips and advices, during the design and development of this work.

I share the credit of my work with my colleagues from PT Inovação and IST. Their help during my learning of the technologies and the development phase of this work was invaluable.

I wish to thank my friends and family because without their friendship and patience, it would be impossible to carry out this work. However, my special thanks go for my parents, António and Teresa. Their love and affection inspired me during my darkest and uninspired days.

Finally, I also would like to thank my girlfriend, Mariana Daniel. She gave me motivation and strength to complete this work successfully.

Lisboa, November 18, 2011

Bruno Ramôa Lima

Dedication

This thesis is dedicated to my parents,

António José de Oliveira Lima

and

Teresa Ferreira Ramôa Lima,

who have given me the opportunity of an education from the best institutions and support throughout my life. They taught me that the best kind of knowledge to have is that which is learned for its own sake and that even the largest task can be accomplished if it is done one step at a time.

"Nothing can stop the man with the right mental attitude from achieving his goal; nothing on earth can help the man with the wrong mental attitude."
- Thomas Jefferson

Resumo

A mobilidade inerente dos dispositivos móveis está substituindo os ambientes de trabalho fixo, tornando este tipo de dispositivos uma espécie de bem indispensável, tanto a nível pessoal como profissional. A ascensão da Web 2.0 permite aos utilizadores interagirem e colaborarem, usando, por exemplo, aplicações web em dispositivos móveis.

Hoje em dia, SOA (*Service Oriented Architecture*) é o paradigma mais adotado para o desenvolvimento de aplicações distribuídas, aumentando a interoperabilidade entre sistemas heterogéneos. A tecnologia dos *web services* tornou-se a abordagem preferida para implementar soluções baseadas no paradigma SOA.

A gestão de negócios orientada aos processos tem como objetivos a conceção e controlo de estruturas organizacionais de forma flexível. Assim, estas organizações podem rapidamente adaptar-se às mudanças estruturais e operacionais. Os sistemas de BPM (*Business Process Management*) fazem a ponte entre os analistas de negócio e os desenvolvedores de software.

Este documento descreve uma plataforma de colaboração que permite a modelação e execução de tarefas específicas de um domínio, usando processos de negócio. A activação e actualização destes processos de negócio pode ser feita pelos utilizadores, usando uma aplicação cliente independente do terminal usado (*TV*, *Smartphone*, *Laptop*, *Tablet*), ou por um sistema externo, usando a tecnologia dos *web services*.

O projecto MBC visa a integração da solução proposta com a plataforma de colaboração desenvolvida pela PT Inovação, chamada PUC.

Abstract

The inherent mobility of mobility devices is replacing the fixed work environments, making such devices a kind of indispensable good, both personally and professionally. The rise of Web 2.0 allows user interaction and collaboration, employing, for instance, web applications in mobile devices.

Today, SOA (Service Oriented Architecture) is the most widely adopted paradigm for development of distributed applications, increasing the interoperability between heterogeneous systems. The web services technology has become the preferred approach to implement solutions based on SOA paradigm.

Process-oriented business management aims to design and control the organizational structures in a very flexible way. Thus, these organizations can rapidly adapt to changing conditions of the organization's structure and operation. The BPM (Business Process Management) systems make the bridge between business analysts and the software developers.

This document describes a platform which allows the modeling and execution of specific tasks of a domain, using business processes. The activation and update of these business processes can be performed by users, using a client application independent of the used terminal (TV, Smartphone, Laptop, Tablet), or by external systems, using the web services technology.

The MBC project aims the integration of proposed solution with the collaborative platform developed by *PT Inovação*, called PUC.

Palavras Chave
Keywords

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AOS (Arquitectura Orientada a Serviços)

Aplicação Web

Colaboração

Fluxo de Trabalho

Interoperabilidade

Serviços Web

Processos de Negócio

Keywords

Business Process

Collaboration

Interoperability

SOA (Service Oriented Architecture)

Web Application

Web Services

Workflow

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1 Introduction

1.1 Background and Motivation

A business process is "*a series of steps designed to produce a product or service. Most processes (...) are cross-functional, spanning the white space between the boxes on the organization chart. Some processes result in a product or service that is received by an organization's external customer. We call these primary processes. Other processes produce products that are invisible to the external customer but essential to the effective management of the business. We call these support processes*" (Rummler & Brache 1990).

Briefly, a business process is a sequence of activities performed by humans or systems to complete a business goal. Initially, processes were performed by humans who manipulated physical objects. Today, the information technologies (IT) allow systems to automate and dematerialize processes partially or totally. The automation of a business process, in whole or in part, is called workflow which is described by a document using a workflow language and is executed in a workflow engine. During the workflow execution, several documents, information or tasks can be passed from one participant to another, according to a set of procedural rules (Chen & Hsu 2001; Georgakopoulos et al. 1995).

People commonly collaborate with each other in their work life or simple daily social routines, so collaborative software (also called groupware) aims to support this kind of interaction. Groupware can be defined as "*computer based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment*" (Ellis et al. 1991). The groupware makes the work more efficient, reduces the time spent in group activities, reduces the cost of carrying out group activities, and allows certain types of group tasks that would be impossible without the computer support.

Business Process Management (BPM) systems are seen as more suitable for controlling well-structured processes. On the other hand, less structured processes are supported by groupware systems, which offer tools such as electronic mail, video conferencing, shared conferencing, etc. Groupware systems do not require logical knowledge of the processes, and at the moment these two types of systems are growing together (Scheer & Nuttgens 2000).

The treatment of business processes as a significant corporate asset has improved substantially the organizational performance (Van Der Aalst et al. 2003). The BPM systems aid the organizations in optimizing their business processes, increasing customer satisfaction, improving efficiency of business operations, increasing products quality, reducing costs, and meeting new business challenges and opportunities. Briefly, the business processes aim to increase efficiency by concentrating on the routine aspects of the work.

Over the past decade, there has been a lot of work in developing middleware for integrating enterprise applications. The concept of SOA (Service Oriented Architecture) has been developed to provide interoperability advantages for organizational systems. Web services have been the chosen technology to achieve SOA because they allow the development of loosely coupled distributed business applications that are highly interoperable and cross organizational boundaries (Charfi & Mezini 2007; Pasley 2005).

Nowadays, almost everyone has a mobile device such as mobile phones, smartphones, laptops, and tablets. The inherent mobility of this type of devices is replacing the fixed work environments, making such devices a kind of indispensable good. Mobility by itself implies that a theoretical ideal of access, anytime and anywhere, is achieved. Furthermore, the rise of Web 2.0 also allows users interaction and collaboration, anytime and anywhere.

Telco and IT company (*PT Inovação*) has developed a collaboration platform, called PUC (Plataforma Unificada de Colaboração or Unified Collaborative Platform), in an effort of providing a unified service architecture which may be used by external client applications, who want to provide collaborative functionality to the end-user, relieving developers from the intricacies of common challenges in the development of collaborative applications, such as: access control; concurrency control; session management.

The MBC project is also part of this initiative; it may be integrated with PUC platform. The purpose of this integration is enabling the collaborative sessions to be governed using business processes. The activation and update of these business processes can be performed by users, using a client application that should be independent of the used terminal (TV, Smartphone, Laptop, Tablet), or by external systems, using the web services technology.

1.2 Objectives and Contributions

In this work, we aim to develop a platform (MBC – Mobile Business Collaboration) which allows the modeling and execution of specific tasks of a domain. The modeling can be made using service nodes (also called work items) performing only the necessary customization, or using default node types. Thus, the system must provide a graphical tool for modeling business processes which allows customizing those service nodes.

The activation and update of these business processes can be performed by participants, using a graphical application, or by external systems, using the web services technology. The graphical application must be cross-platform and developed according to the Web 2.0 principles. Furthermore, the application should be lightweight to minimize the amount of transmitted data, the battery consumption, and the execution times.

The platform must support synchronous and asynchronous sessions. It must be able to aggregate several participants where each one plays a specific role. Moreover, the solution should be scalable, reliable, and interoperable with either legacy application.

The system should also provide a mechanism for monitoring the infrastructure since it may be necessary to perform cost accounting, maintain access information, and control processes' execution.

Our main goal is to integrate our MBC platform with the collaborative platform developed by *PT Inovação*, called PUC. Thus, it is possible to create, manage, and control collaborative sessions using business processes. However, our solution must be loosely coupled with the collaboration platform. Hence, the developed system may be used with another collaboration platform, such as Zarafa,[1] SOGo,[2] and Dimdim.[3]

Although our main domain is the PUC platform, we aim to develop a solution that can be used in others domains, for instance, an organization that wants to gather a rate of positive votes to approve a deal or management decision.

In order to comply with our motivation and address the above mentioned goals, in the state of the art chapter (refer to chapter 2) we survey the following topics: web applications; business processes; enterprise integration.

[1]Zarafa - http://www.zarafa.com
[2]SOGo - http://www.sogo.nu
[3]Dimdim - http://www.dimdim.com

1.3 Document Structure

This document is comprised of five more chapters after this introductory chapter.

In Chapter 2, we will present our state of the art analysis. It includes an extensive survey in topics that comprise web applications, business processes, and enterprise application integration.

In Chapter 3, we address our work's conception phase, by presenting the architectural designs of our solution's components. Here, we detail the communication process and interaction between the components and address each of them individually.

Next, in Chapter 4, we will address the challenges and relevant details of our implementation phase, in order to know how we turned our architectural designs into a software implementations that fulfil our objectives.

Our implementation will be evaluated in Chapter 5, an evaluation based on quantitative metrics for both server-side and client-side implementations. We also evaluate our client-side implementation qualitatively in order to produce a solution that properly satisfies the users.

Finally, in Chapter 6, we will review all the phases of this work as well as the document's chapters, and present our final conclusions; assert if the proposed objectives were accomplished and propose possible future work.

Additionally, this document also includes appendices that support our evaluation chapter with additional screenshots of own prototype.

2 State of the Art

In order to activate and update the business processes, the developed system must offer web services which will be used either by users through a web application, or external systems through an API (Application Programming Interface). Moreover, the developed system must support the modeling and execution of workflows. Finally, it is necessary to ensure that all developed components are interoperable with existent applications of an organization. To address the above issues, we present in this section three themes, which are: Web Applications (Section 2.1), Business Processes (Section 2.2), and Enterprise Integration (Section 2.3).

2.1 Web Applications

Over time, the web applications have evolved; the first-generation of web applications were developed in the early 1990s by using the basic web technologies such as HTML, web browsers, web servers, and CGI (Common Gateway Interface). The most used technology was based on RPC (Remote Procedure Calls). The second-generation web applications started using distributed object technologies, such as CORBA (Common Object Request Broker Architecture) and DCOM (Distributed Computing Object Model) (Chung et al. 1998), for development of more sophisticated applications. The third and current generation of web applications are taking advantage of developments in semantic web. The keystone of third generation is AJAX[1](Umar 2004).

AJAX

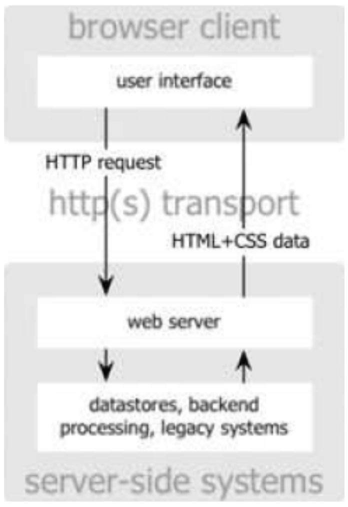
AJAX is a set of technologies (DOM, XML, XSLT, XMLHttpRequest, XMLHttpResponse, and Javascript) that allows increasing the interoperability between applications. AJAX was very important for the rise of Web 2.0 (Murugesan 2007).

[1]AJAX Tutorial - http://www.w3schools.com/ajax/default.asp

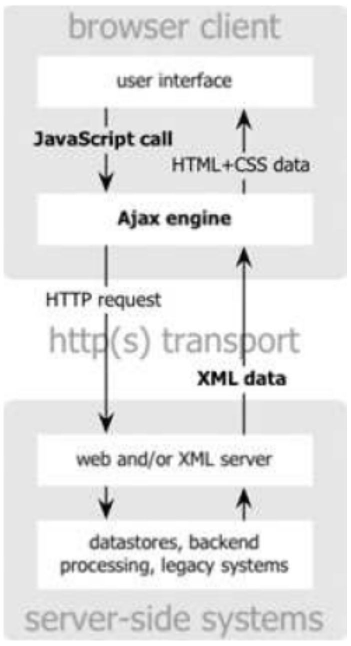
The classic web application model works like this: most user actions in the interface trigger an HTTP request to a web server; while the web server does some processing (retrieving data, talking to various systems, etc.) the user waits some time; after the web server processes the request, it returns an HTML page to the client. This approach makes a lot of technical sense, but it does not make for a great user experience. The traditional model for web applications is depicted in Figure 2.1(a) (Garrett et al. 2005).

AJAX applications eliminate the start-stop-start-stop nature of interaction on the web by introducing an intermediary AJAX engine between the user and the server. Instead of loading a webpage, at the start of the session, the browser loads an AJAX engine written in JavaScript. The engine is responsible for both rendering the interface the user sees and communicating with the server on the user's behalf. The engine allows the user's interaction with the application to happen asynchronously, independent of communication with the server. The AJAX model for web applications is depicted in Figure 2.1(b) (Paulson 2005).

Every user action that normally would generate an HTTP request takes the form of a JavaScript call to the AJAX engine instead. The engine makes those requests asynchronously, usually using XML or JSON, without blocking a user's interaction with the application (Paulson 2005).



(a) Classic model for web app



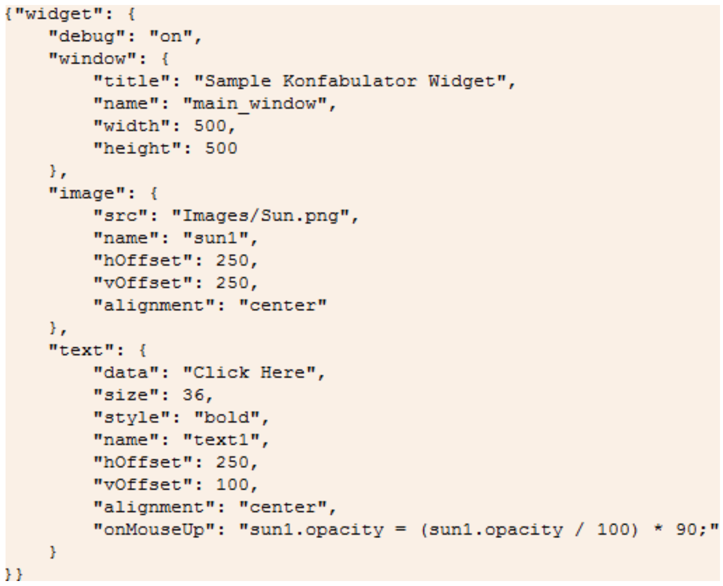
(b) AJAX model for web app

Figure 2.1: Classic and AJAX model for web applications

JSON

JSON[2] (JavaScript Object Notation) is a lightweight format used for computational data interchanging. JSON is quite simple, so it is increasingly used by developers. The JSON parsers are simpler than XML parsers, so this is the main advantage of JSON regarding the XML. The AJAX technology accepted the JSON format because JSON can be evaluated using the eval Javascript function which is present in all web browsers (Giurca & Pascalau 2008; Nurseitov et al.).

JSON is completely independent from the application's programming interface. There is a vast community support for this notation, spanning from a vast quantity of third-party open source libraries for almost any programming language available. Figure 2.2 shows an example of a message formatted using JSON.



```
{"widget": {
    "debug": "on",
    "window": {
        "title": "Sample Konfabulator Widget",
        "name": "main_window",
        "width": 500,
        "height": 500
    },
    "image": {
        "src": "Images/Sun.png",
        "name": "sun1",
        "hOffset": 250,
        "vOffset": 250,
        "alignment": "center"
    },
    "text": {
        "data": "Click Here",
        "size": 36,
        "style": "bold",
        "name": "text1",
        "hOffset": 250,
        "vOffset": 100,
        "alignment": "center",
        "onMouseUp": "sun1.opacity = (sun1.opacity / 100) * 90;"
    }
}}
```

Figure 2.2: Example of a message formatted using JSON

Web Services

Web services combine web and distributed objects into a single framework where the user-to-component interactions, as well as component-to-component, are conducted by using standard web technologies. The information is exchanged using SOAP[3] messages, and the network ser-

[2]JSON Project - http://json.org/
[3]SOAP Specifications - http://www.w3.org/TR/soap/

vices are described as set of endpoints in a WSDL[4] document. HTTP is commonly used for the transport layer, but it is not a striet dependency. The basic communication pattern is synchronous, but web services also support asynchronous communications (Umar 2004; Ibrahim 2010).

Some may argue that there is a disadvantage in implementing web services in JSON, due to the difficult management, security, and discovery of these type of services given that no contract is established, as it happens with SOAP and the WSDL format. But, simplicity and the much reduced overhead introduced in communication makes JSON a very popular option in the web community when used in conjunction with REST, which is described below (Hameseder et al. 2011).

REST

Web services introduce some overhead which cannot be ideal for mobile devices to process. Thus, Roy Fielding proposes another architecture style of networked systems, called REST[5] (Representational State Transfer).

This architecture style is not a standard, but it uses some standards such as HTTP, URL, XML (resource representation), and MIME types (text/xml, application/json, etc.). REST is an architectural style where each of the system's available resources are represented in an unique URL. The purpose is to use standard HTTP functions (GET, POST, PUT, and DELETE) to access and modify those resources (Costello 2007; Wilde 2007).

Widgets

With the emergence of the Web 2.0 a new kind of application has gained popularity. These applications are commonly known as widgets, which have the particularity of being lightweight web applications designed for single specific functions and quick access. The widgets are executed by a special execution runtime, which is generally known as widget engine. Widgets can be divided in three groups, Desktop, Mobile, and Web (Kaar 2007).

[4]WSDL Specifications - http://www.w3.org/TR/wsdl
[5]REST Way - http://www.xfront.com/REST-Web-Services.html

- **Desktop widgets:** generally seen in desktop operating systems of major vendors, like Microsoft's Windows Vista Sidebar. The widget engines that give users the possibility of keeping useful gadgets (as they are called) on their desktop, for instance, Clock Widget or CPU Monitor Widget. An important aspect is that these widgets are executed locally and typically they do not need web content.
- **Mobile widgets:** are similar to desktop widgets, where the widget engine must be also integrated with the host mobile operating system. The differences are related with the way how the widgets are deployed and executed. Thereby, a developer accustomed with desktop widget development must take into account the common mobile device limitations and development challenges.
- **Web widgets:** are commonly reusable components of a web site which can be embedded in other web pages. The difference in relation with desktop and mobile widgets is that they are not packaged and need not to be downloaded and installed locally on a client. Moreover, these kinds of widgets typically communicate with a web server.

2.2 Business Processes

The general function of a workflow system is to support the modeling and execution of business processes. Some standards like BPMN[6] and BPEL[7] have been proposed which are being adopted by industry (Liu et al. 2009). Despite of these standards being adopted, there are many other workflow solutions such as WS-CDL (Mendling & Hafner 2005), YAWL (Van Der Aalst & Ter Hofstede 2005), Triana (Taylor et al. 2003), and Taverna (Oinn et al. 2004). Triana and Taverna are used only in scientific computing, while YAWL is only used in business environment. WS-CDL[8] is a complementary language for BPEL that allows increase collaboration between partners.

When multiples parties, belonging to different enterprises, are involved in a business process, they need support for peer-to-peer interactions (decentralized process management). Hence, the web services composition has been adopted by industry for the development of

[6]BPMN Specifications - http://www.omg.org/bpmn/
[7]BPEL Specifications - http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=wsbpel
[8]WS-CDL Specifications - http://www.w3.org/TR/ws-cdl-10/

workflow engines. According to (Charfi & Mezini 2007) there are two complementary types of web services composition, *Orchestration* and *Choreography*.

Orchestration is the composition of business processes via web services where there is a central process (master process) that controls and coordinates the other processes. In this type of composition, each participant process has no knowledge that is part of a process composition, except the master process. Only the master process has intelligence about the entire process, and thus, the coordination of the excution is centralized. Because of this centralization, orchestration typically occur within the same corporation, since in that corporation it is simple to decide which is the master process. BPEL is the proposed standard language to achieve the web services orchestration.

Choreography is the composition of business processes via web services where there is not a master process that controls and coordinates the other processes. In this type of composition, each involved process knows that it is part of a composition, and it needs to interact with other process in orderly way so that the resulting composition can be successful. Decentralized process choreography is often used between processes or web services of different corporations. Each participant process knows exactly when to act, and with which participant process. Moreover, each participant process must know which operation to perform, and which are the exchanged messages. Choreography is more collaborative than orchestration. WS-CDL (Web Service Choreography Description Language) is the proposed recommended language to achieve the web services choreography.

Business Process Execution Language (BPEL)

IBM's WSFL (Web Services Flow Language) is an XML-based specifications to describe a public collaborative process and its compositions. Microsoft's XLANG is also an XML-based specification to describe executable business processes internal to a business. In July 2002, IBM, Microsoft, and BEA proposed BPEL 1.0, and in April 2003, BPEL 1.1 was submitted to OASIS for standardization via the web services BPEL Technical Committee. The output of this committee has been renamed to WS-BPEL2.0.

WS-BPEL, also called BPEL4WS or just BPEL, it is an executable workflow process that defines the flow of control and data between participant web services. It is XML-based language, with support to handle variables with scopes, loops, conditional branches, synchronous and asynchronous communications, concurrent activities with correlated messages, transactions, and exceptions. Increasingly, BPEL is used by developers for modeling business processes within the web services. This language represents each system as a service that implements a specific business function. The business process description is interpreted by a BPEL engine. It includes asynchronous message handling, reliability, and recovery (Pasley 2005; Courbis & Finkelstein 2004; Charfi & Mezini 2007).

BPEL engine handles multiple incoming messages through event handlers. It can ensure that a message is processed only when the business process reaches a given state. The business process instances can persist over extended periods of inactivity. The engine stores such instances in a database, freeing up resources and ensuring scalability. The engine ensures that all database accesses occur within the appropriate transaction and that system failures will never create inconsistency in a process's internal state. When failures occur, the engine provides automatic recovery. It is possible to extend the engine with non-functional aspects, such as the control of the engine by agents that monitor the execution and take actions if one service provider is not responding. However, some non-functional aspects can have performance impact, e.g. debugging. Thereby, these aspects should be enabled to be woven or unwoven on demand during executing (Courbis & Finkelstein 2004; Pasley 2005).

BPEL describes communication with partners, and messages exchanged by partners using WSDL. BPEL extends WSDL with partner link definitions to indicate whether client-server or peer-to-peer communication will be used. In client-server the client must initiate all invocations on the server. In peer-to-peer the partners can make invocations on each other, each partner uses WSDL to define its web service interface, and partner links define each partner's role and the interfaces they must implement. Client-server has problems of scalability, because connections must remain open during message processing, or when clients need to poll the server to check for results availability (Pasley 2005).

The BPEL language specifies the behaviour of business processes, as long as, the activities of the processes are assured by web services, but human interactions are not in its domain. Despite wide acceptance of web services in distributed business applications, the absence of human interactions is a significant gap for many real-world business processes (Russell & Van Der Aalst 2007; Gerstbach 2006).

Business Process Model and Notation (BPMN)

BPMN was developed by BPMI (Business Process Management Initiative), and it is currently maintained by the OMG (Object Management Group) since the two organizations merged in 2005. The current version of BPMN specification is 2.0, it not only defines a standard on how to graphically represent a business process like BPMN 1.x, but also includes execution semantics for the elements defined, and an XML format on how to store process definitions. A process defined with a graphical tool is a graph that describes the order in which a series of steps need to be executed using a flow chart (Lonjon 2004). Figure 2.3 shows an example of a business process modeling using BPMN.

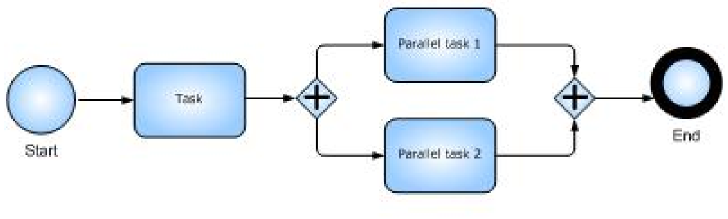


Figure 2.3: Modeling of a business process using BPMN

The main purpose of business processes models generally, and BPMN models in particular, is to facilitate the communication between domain analysts and developers. Furthermore, these models support decisions based on techniques such as cost analysis, scenario analysis, and simulation (Ouyang et al. 2009).

JBPM[9] (JBoss Business Process Management) is the open source WfMS (Workflow Management System) suited by JBoss. Initially, jBPM processes are created using a proprietary language of process definition called jPDL (jBPM Process Definition Language). jBPM5 is the latest version of the jBPM suite which is based on the BPMN 2.0 specification and supports the entire life cycle of the business processes (modeling, executing, monitoring, and management) (Koenig 2004).

[9]jBPM - http://www.jboss.org/jbpm/

JBoss Business Process Management (jBPM)

A workflow describes the order in which a series of steps need to be executed. It is especially useful in describing state-based and long-running processes. JBPM allows users to specify, execute, and monitor the business processes of their organization. This suite can be integrated into any Java application or can run standalone in a server environment (Bali 2009).

JBPM allows constructing business processes through drag and drop tools. It includes not only standard node types like start, end, split, join, but more advanced node for incorporating wait states, timers, events, composite nodes, etc. The process model is based on simple nodes, connections, and context that allows including new nodes types into an existing process language, or supporting completely different languages as a whole.

BPEL and BPMN

BPMN and BPEL are two standards for specifying and executing business process models that can be used together using some open-source tools known as BPMN2BPEL.[10] It aims at translating BPMN models into BPEL processes, thereby, the BPMN models are the input of the system, the BPMN2BPEL are the translating tools, and the BPEL is the engine for executing business processes. However, the development of these tools has disclosed fundamental differences between BPMN and BPEL, which make the translation very difficult, and in some cases impossible. It is beyond the scope of this work to discuss BPMN2BPEL tools, this can be found in an appendix of the BPMN standard specification.

Web Services Choreography Description Language (WS-CDL)

Choreography languages are a means to define the rules of collaboration between parties without revealing internal operations. They allow specifying when which information is sent to which party, and which options are available to continue the interaction. The WS-CDL is a W3C candidate recommendation for web service composition. WS-CDL is expected to be used in conjunction with BPEL. In this context, there are two possible scenarios (Mendling & Hafner 2005):

[10] BPMN2BPEL Project - http://code.google.com/p/bpmn2bpel/

1. business entities may agree on a specific choreography defined in WS-CDL in order to achieve a common goal. This WS-CDL choreography is then used to generate WS-BPEL process stubs for each party;
2. business entities may want to publish its processes' interface to business partners. In this scenario, a choreography description of the internal process has to be generated.

WS-CDL is a declarative XML-language for the specification of collaboration protocols based on web services. It provides a global public view on participants, collaborating in a peer-to-peer way by offering distributed web services, in order to achieve a common business goal. WS-CDL describes their observable behaviour through the order of the messages they exchange as well as the operations they offer (Mendling & Hafner 2005).

Yet Another Workflow Language (YAWL)

Despite the efforts of the workflow management coalition (WfMC), workflow management systems use a large variety of languages and concepts based on different paradigms. Some workflow management systems are based on Petri Nets (Peterson 1977), but typically add both product specific extensions and restrictions. Currently, most workflow languages support the basic constructs of sequence, iteration, splits (AND and XOR) and joins (AND and XOR). However, the interpretation of even these basic constructs is not uniform and it is often unclear how more complex requirements could be supported. Requirements can be indicated through workflow patterns (Van Der Aalst & Ter Hofstede 2005); *"Pattern is the abstraction from a concrete form which keeps recurring in specific non-arbitrary contexts"* (Riehle & Zullighoven 1996).

BPEL is currently the most widespread language for composing web services, but it lacks formal semantics. YAWL[11] is a new proposal of a workflow engine, which supports a concise and powerful workflow language, and handles complex data transformations and web service integration. YAWL defines twenty most used workflow patterns divided in six groups: basic control-flow, advanced branching and synchronization, structural, multiple instances, state-based, and cancellation. YAWL extends Petri Nets by introducing some workflow patterns for multiple instances, complex synchronizations, and cancellation. Furthermore, YAWL supports tools like editor and engine, which are freely available (Brogi & Popescu 2006).

[11]YAWL - `http://www.yawlfoundation.org/`

Triana

Triana[12] is a visual programming environment that allows users to compose applications from programming components by dragging and dropping them into a workspace, and connecting them together to build a workflow graph. It was initially developed to help in the flexible quick-look analysis of data sets.

Today, Triana can be used by applications in a variety of ways through the use of its ”pluggable software architecture”. It has many of the key programming constructs such as do, while, repeat until, if, then, etc. that can be used to graphically control the data-flow. Triana performs dynamic run-time type checking on requested connections to ensure data compatibility between components. It is divided into a set of modularized pluggable interacting components: GUI, Triana Controlling Service (TCS), Triana Engine, and/or other Engine (e.g. BPEL Engine) (Taylor et al. 2003).

Triana is good for automating repetitive tasks, such as performing a find-and-replace on all the text files in a particular directory, or continuously monitoring the spectrum of data that comes from an experiment that runs for days or even years. It is a good tool for classroom or teaching laboratory for simulated experimental data. Triana allows creating new features, if the supplied with Triana are not enough. Furthermore, it provides support for error handling, and it allows changing the parameters dynamically without interrupting the flow data.

Taverna

Taverna[13] is a powerful scientific workflow management application that allows designing and executing workflows. It provides a graphical workbench tool for both creating and running workflows. In Taverna, a workflow is considered to be a graph of processors, each of which transforms a set of data inputs into a set of data outputs. These workflows are represented in the Scufl language.

Scufl language is a high-level, XML-based, conceptual language in which each processing step of the workflow represents one atomic task. A workflow in the Scufl language consists of three main entities (Oinn et al. 2004):

[12] Triana - `http://www.trianacode.org/`
[13] Taverna - `http://www.taverna.org.uk/`

- **Processor** is a transformation that accepts a set of input data and produces a set of output data. During the execution of a workflow, each processor has a current execution status which is one of initializing, waiting, running, complete, failed or aborted. The main processor types currently available are: Arbitrary WSDL type, soaplab, talisman type, nested workflow type, string constant type, and local processor type;
- **Data links** mediate the flow of data between a data source and a data sink. The data source can be a processor output or a workflow input. The data sink can be a processor input port or a workflow output;
- **Coordination constraints** link two processors and control their execution. This level of control is required when there is a process where the stages must execute in a certain order and yet there is no direct data dependency between them.

Scufl workbench allows writing workflows without having to learn the Scufl language.

2.3 Enterprise Integration

The highly competitive nature of the current business environment creates tremendous pressure for global company operations. To rapidly respond to a changing environment, an enterprise must integrate business functions into a single system efficiently using information technology, and share data with third-party vendors and customers. Enterprise integration is a technical field of Enterprise Architecture which focuses on issues such as system interconnection, electronic data interchange, product data exchange, and distributed computing environments.

Enterprise Application Integration aims *"to connect and combine people, processes, systems, and technologies to ensure that the right people and the right processes have the right information and the right resources at the right time"* (Brosey et al. 2002). A typical scenario is of an enterprise that runs hundreds or thousands of applications which should be able to communicate and exchange data with each other, in order to work together for the business of the organization. In this section, we will address three approaches to solve enterprise integration issues, which are: ERP (Enterprise Resource Planning), EAI (Enterprise Application Integration), and ESB (Enterprise Service Bus). The ESB approach is based on SOA (Service Oriented Architecture), so we also describe SOA in order for the reader better understand this approach.

2.3.1 Enterprise Resource Planning (ERP)

ERP was pioneering in enterprise integration software. It offers a system that accomplishes the integration of different functions in an organization. These functions assist the businesses in managing the important parts of the business, including product planning, parts purchasing, maintaining inventories, interacting with suppliers, providing customer service, and tracking orders. However, ERP has a centralized management model and it focused historically on integration of internal business functions. Moreover, when the applications interact with each other using a point-to-point model, the maintenance costs increase and the reuse of the applications becomes more difficult (Lee et al. 2003). Hence, research was made and Enterprise Application Integration (EAI) emerged as an alternative or supplemental technology for the integration of internal and external business functions.

2.3.2 Enterprise Application Integration (EAI)

EAI is a framework used to perform integration of systems and applications across the enterprise. It is composed of a collection of technologies and services which form a middleware. EAI comprises message acceptance, transformation, translation, routing, guaranteed delivery, and business process management. Previously, integration of different systems required rewriting code on source and target systems, which in turn, consumed much time and money. Unlike traditional integration, EAI uses special middleware that serves as a bridge between different applications for system integration. Typically, the solution for EAI is to use Message-Oriented Middleware (MOM), this means the communication is asynchronous, but it can be synchronous as well. MOM products are usually built around a central message queue system, often called message broker, and all applications are connected to it. The message broker is able to store the messages, so the sender and receiver do not need to be connected at the same time (Lee et al. 2003; Parr & Shanks 2002; Menge 2007). There are two basic architectures to achieve this:

- **Hub-and-Spoke -** This architecture uses a centralized broker (Hub) and adapters, which connect applications to hub. Spoke connects to application and converts application data format to a format whose hub understands. On the other hand, hub brokers all messages, converts (transformation/translation) the incoming messages to a format that the destination system understands, and routes the messages to destination application. This architecture is easy to manage, but the scalability is a problem when the number of messages increase (Lee et al. 2003; Qureshi 2005).

- **Bus -** This architecture uses a central messaging backbone (Bus) for messages propagation. The applications publish messages to bus using adapters. These messages flow to subscribing applications using the messages bus. Subscribing applications have adapters, which take messages from bus and transform the messages into a format required for the application. The main difference between hub and bus topology is that for the bus architecture, the integration engine that performs messages transformation and routing is distributed in the application adapters. Since adapters have integration engine and run on same platform on which source and target applications run, this architecture is more scalable, but it is more complex to manage compared to hub topology (Lee et al. 2003; Wu & Tao 2010).

A big problem of EAI solutions is that they often use proprietary protocols, and platform specific interfaces and deployments. This leads to a total dependency of the applications on the infrastructure and causes interoperability problems with EAI products of alternative vendors. As a result, islands of EAI-based infrastructures can often be found. A proprietary implementation offers a lot of functionalities, as a suite of products, and it uses some proprietary formats to enhance the performance. However, these two features increase the cost.

2.3.3 Enterprise Service Bus (ESB)

ESB is usually based on open standards which decrease the cost. ESB is a distributed integration infrastructure that provides routing, protocol conversion, message format transformation, accept and deliver messages from various services and applications which are linked to ESB. Hereupon, the question on what exactly is the difference between ESB and EAI arises. Beyond the cost, which is significantly lower for ESB because it is based on open standards (no more technology lock-in), the ESB was developed to support the SOA paradigm, so it has all advantages offered by SOA (Lee et al. 2003; Menge 2007).

Service-Oriented Architecture (SOA)

SOA is a relatively newer form of information systems architecture and a real buzzword in the last few years in the domain of information system development. It can be defined as *"an architecture or development style that builds on distributed, loosely coupled, and interoperable components of software agents called services"* (Kanchanavipu 2008). SOA have become increasingly important as a paradigm for the development of distributed software systems. Thereby, the applications are built of a set of collaborative services running in a distributed environment. Hence, it can be considered a peer-to-peer architecture, totally distributed, with the services distributed between different resources.

The adoption of SOA may be unacceptable for some traditional enterprises because of the lack of sufficient control over the information assets. However, SOA represents a framework to integrate business processes and information/communication technologies in the form of components (services). Components are reusable, interoperable, and satisfy the needs and demands of dynamical business processes (Zalewski 2007; Geric 2010).

SOA has been developed to enhance the communication between organizations, it is a way to provide interoperability advantage for the systems, but having different types of SOA development architectures can still cause some interoperability problems. Therefore, seamless interoperability is a major concern. Development of theoretical and conceptual frameworks would be a good step toward achieving seamless interoperability in the SOA systems. Currently, researchers within this area are focusing more on the interoperability requirements, and their works can be divided into three categories, which are (Ibrahim 2010): Individual applications; Domain specifications; Conceptual framework.

SOA solutions typically have three fundamental entities (Figure 2.4), *Service Provider*, *Service Consumer*, and *Service Registry*. The service provider creates a service contract and registers its services to a central naming server, also called service registry. A service consumer can use this service registry to discover available services and retrieve a service contract which defines how the service can be used and how to connect to a particular provider. Service contract is very important to facilitate the collaboration between services, by using collaboration between different services is possible to build a more complex system (Menge 2007).

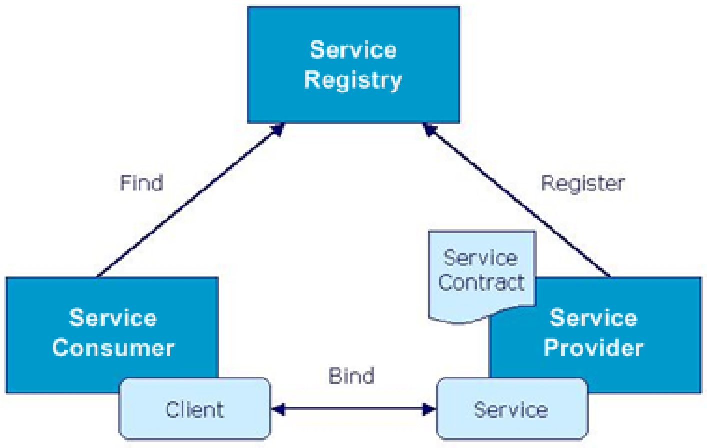


Figure 2.4: SOA's Architecture

ESB and SOA

The fundamental goals of business integration are linking business systems across the enterprise and extending business services to customers and trading partners. If several applications interact with each other using point-to-point model, the relation between application become complex. This will bring high maintenance costs and make the reuse of the applications difficult. Today, enterprises need powerful integration solutions, but they want them to be based on open standards and to support SOA. ESB is an ideal solution for such issues because it provides universal mechanism to interconnect all the services required in the business composite solutions, without compromising security, reliability, performance, and scalability. Moreover, ESB must coordinate the interactions of the various resources and providing transactional support. The general goal is to provide interoperability, without writing code (Menge 2007; Wu & Tao 2010).

In order to support SOA, the ESB service containers have to support web service technologies. The open source ESB solutions are typically built on top of JMS (Java Messaging Service) middleware systems. In addition to the runtime environment, an ESB must also provide a development environment with tools for creating web services. Existing systems are fundamental to the ESB because reusing rather than replacing concept. ESB provides essentially the same functionality as the existing systems, but they are exposed as secure and reliable web services that the organization or its business partners can reuse (Pasley 2005; Menge 2007). Typically ESB features are:

- **Connectors/Adapters** - it is the ability of an ESB to send requests and receive responses from integration services and integrated resources. In this point, ESB has to support several standards, such as SOAP, WSDL, UDDI, JMS, JCA (J2EE Connector Architecture), TCP, UDP, HTTP, SSL (Secure Sockets Layer), JBI (Java Business Integration), RMI (Remote Method Invocation), JDBC (Java Database Connectivity), SMTP, POP, etc. These can be adapters for popular application packages, such as ERP, SCM (Supply Chain Management), and CRM (Customer Relationship Management). Using prefabricated adapters reduces the work required to integrate applications into a SOA;
- **Routing** - it is the ability to decide the destination of a message during its transport. Routing services are an essential feature of an ESB because they allow decoupling the source of a message from the ultimate destination. The common standard used for addressing is the URI (Uniform Resource Identifier). There are several types of routers: content-based, recipient list, splitter, aggregator, and resequencer. The different routers can be combined to create complex message flows. All routers can be implemented as dynamic routers;
- **Mediation** - it refers to all transformations or translations between different resources, including transport protocol, message format, and message content. It is very important because applications rarely agree on a common data format. XSL (Extensible Stylesheet Language) and XPath (XML Path Language) are powerful tools for working with XML messages;
- **Security** - it is the ability to encrypt and decrypt the content of messages, authenticate, perform access control, and assure secure persistence;
- **Management** - it is the ability to provide audit and logging facilities for monitoring infrastructure, and possibly also for controlling process execution;
- **Process Orchestration** - ESB may include an engine to execute business processes described with the BPEL. This engine coordinates the collaboration of the services connected to the bus.

2.3.4 Discussion

Table 2.1 summarizes the comparison among ERP, EAI, and ESB according to some parameters. The ESB and EAI are very similarly, but ESB allows building systems or applications more loosely coupled than EAI because ESB is based on open standards and EAI is proprietary. Moreover, the ESB has a cost of development much smaller than EAI, by the same reasons presented above. Then, in the next section (refer to section 2.3.5), we will present some enterprise integration solutions based on the ESB approach.

Evaluation Parameter	**ERP**	**EAI Hub**	**EAI Bus**	**ESB**
Topology	Single/Multi Server	Hub	Bus	Bus
Architecture	Centralized	Centralized	Decentralized	Decentralized
Integration Effort	High	Medium	Medium	Low
Coupling	Strongly	Moderately	Moderately	Loosely
Scalability	Low	Medium	High	High
Management	Easy	Easy	Complex	Complex
Development	Proprietary	Proprietary	Proprietary	Standard
Cost	High	Medium	Medium	Low

Table 2.1: Comparison among ERP, EAI, and ESB

2.3.5 ESB Solutions

In this section, we present the following ESB solutions: JBoss ESB,[14] Apache ServiceMix,[15] OpenESB,[16] and PEtALs.[17] This solutions are based on JBI (Java Business Integration). At the end of this section, we present another ESB solution, called Mule ESB.[18]

Java Business Integration (JBI)

JBI is an ESB specification proposed by Sun Microsystems (Oracle). It is divided into three parts:

- **Normalized Message Router (NMR)** provides the mediation to allow components to interoperate in a standard way;
- **JBI Component Framework** provides the pluggable infrastructure for hosting JBI components;

[14]JBoss ESB - `http://www.jboss.org/jbossesb`
[15]Service Mix - `http://servicemix.apache.org/home.html`
[16]OpenESB - `http://open-esb.org/`
[17]PEtALs - `http://petals.ow2.org/`
[18]Mule - `http://www.mulesoft.org/`

- **Management Module** provides a set of standards based on JMX[19] to manage the JBI environment and the components themselves.

There are two kinds of components in JBI environment:

- **Service Engine (SE)** provides business logic and transformation services to other components, e.g. BPEL engine;
- **Binding Component (BC)** provides connectivity to services external to the JBI environment, e.g. web services.

Developers can develop standard JBI components (adapters) to connect external application systems using the ESB, and thus, they achieve interoperability between legacy systems (Ning et al. 2008; Kruessmann et al. 2009).

JBoss ESB

JBoss ESB is the next generation of EAI, based on the SOA paradigm, and without the vendor-locking. In the JBoss ESB, mediation is a deployment choice and not a mandatory requirement. Thereby, JBoss ESB may perform mediation using XSLT (eXtensible Stylesheet Language for Transformation) or Smooks Framework[20] for XML and non-XML data transformation. Moreover, it provides process orchestration via BPEL or jPDL (jBPM Process Definition Language), message encryption, and access control lists (ACLs). ACLs are important and complimentary to security protocols. JBoss ESB has support for HTTP/HTTPS, FTP/SFTP, JMS, SOAP, UDDI, SMTP, POP, SQL, Hibernate, JCA, Sockets, and local file system.

Monitoring and others JBoss ESB's capabilities can be obtained by plugging in other services or layering existing functionality on the ESB. The JBoss ESB can be seen as the fabric for building, deploying, and managing event-driven SOA applications and systems.

Apache ServiceMix

Apache ServiceMix is the JBI implementation of the Apache Software Foundation combining the functionality of SOA and EDA (Event-Driven Architecture) to create an agile ESB. It uses

[19]JMX - `http://java.sun.com/javase/technologies/core/mntr-mgmt/javamanagement/`
[20]Smooks Framework - `http://docs.codehaus.org/display/MILYN/Smooks`

JMS to carry the messages on the bus. The used implementation of JMS is Apache ActiveMQ. The message queues which have been created especially for this can be monitored with JMX Console. As it uses JMS for message exchange, the bus provides message persistence and supporting for transactions. ServiceMix provides the following connectors: HTTP, FTP, JMS, SOAP, SMTP, POP, and local file system. It allows services to be integrated through different APIs and across different transport technologies, and it contains a number of WS-* implementations built on JBI, such as WS Notification.

ServiceMix supports any BPEL engine, rule engine, transformation engine, scripting engine, or other integration component, such as specific JBI binding components. However, it does not content a BPEL engine, if BPEL engine is desirable it can be installed as JBI component. The description of endpoints using WSDL is the main difference between OpenESB and ServiceMix. Service Mix uses the Apache XMLBeans[21] for the whole configuration, even services are configured with XMLBeans. However, the more powerful option of Service Mix is Camel[22] that is a open source integration framework.

OpenESB

OpenESB was developed by an open source community under the direction of Sun Microsystems (Oracle). It implements the JBI specifications and provides integration based on open standards. OpenESB is strongly linked with the Netbeans IDE and the Glassfish Application Server. Glassfish ESB is an Open ESB distribution that provides everything necessary for developing, installing, and running integrations solutions, supported by graphical tools.

OpenESB has a Composite Application Service Assembly (CASA) editor that provides a graphical overview of integration applications, which are called assemblies. Furthermore, the OpenESB has several components for data transformation, orchestration, and connectivity. It has support for HTTP, FTP, JMS, SOAP, SQL, JDBC, and SAP[23] systems. The logic layer can be expressed in BPEL, EJB,[24] and POJO (Plain Old Java Object). OpenESB needs BPEL to connect binding components and service engines.

[21]XMLBeans - http://xmlbeans.apache.org/
[22]Camel Framework - http://camel.apache.org/
[23]SAP - http://www.sap.com/country-selector.epx
[24]EJB - http://java.sun.com/products/ejb/

PEtALs

PEtALs is an open source ESB solution for large SOA architectures. PEtALs ESB is built with and on top of agile technologies like JBI and Fractal. Fractal (Bruneton et al. 2006) is a modular and extensible component model that can be used with various programming languages to design, implement, deploy, and reconfigure various systems and applications. On the PEtALs point of view, all the container services, such as service registry, message router, message transporter, discovery, etc., are provided by the Fractal framework.

PEtALs is not only a JBI container, it also contains tools for management, monitoring, and to create JBI components. Moreover, the Petals offers guaranteed service delivery. Therefore, when a service cannot be delivered, request is saved and delivered later. One other powerful feature is the possibility to replace software components at runtime. PEtALs has connectors for common standards: HTTP, FTP, SOAP, JMS, SMTP, POP, JDBC, POP, IMAP.

PEtALs uses BPEL for processing orchestration and XSLT for transformation. Furthermore, it performs access control and provides quick assembly of services with EIP (Enterprise Integration Patterns), POJO, and JCA. Distributed architecture provided by the PEtALs ensures high availability and eliminates single point of failure. Therefore, it is highly distributable and scalable.

Mule (Menge 2007)

Mule is an open source messaging platform based on SOA. It has a service container called UMOs (Universal Message Objects) which is highly distributable object broker. The container uses a generic message endpoint interface to facilitate the communications between systems.

UMOs are able to connect to external applications, other UMOs, or other Mule instances. The unified technology and independent methods of interacting with disparate resources makes it very easy to use UMOs for the integration of applications. However, it may be necessary to develop applications adapters.

The Mule provides all integration services which are essential to ESB, such as support for transactions, transformations, routing, logging, auditing, management, security, event processing, and even process orchestration using BPEL. Mule is able to handle various communication mechanisms, including HTTP, FTP, TCP, UDP, JMS, SOAP, SMTP, POP, IMAP, JDBC, RMI, and others.

Mule was designed for fast development of distributed network, and it is highly scalable, lightweight, fast, and simple to adopt. An important principle of an ESB is to use as much declaration and configuration as possible, and avoid writing code. Therefore, Mule uses a XML configuration file in which the connectors, routers, transformers, message endpoints, and UMOs are declared.

Discussion

As stated before, this work aims to develop a platform interoperable with some collaboration platform, and so, it should be possible to govern collaborative sessions using business processes. The ESB approach arose in order to keep the interoperability between enterprise applications. To close this section, we will make a discussion about the ESB solutions presented above (Table 2.2).

Evaluation Parameter	**JBoss ESB**	**ServiceMix**	**OpenESB**	**PEtALs**	**Mule**
Topology	Centralized	Centralized	Centralized	Centralized or Distributed	Centralized or Distributed
Routing	Content-based	Splitter; Aggregator; Content-based		Content-based; Priority-based	Filter; Aggregator; Resequencer; Content-based
Mediation	XSLT; Smooks	XSLT; Spring	XSLT	XSLT	XSLT
Scalability	No	No	No	Yes	Yes
Security	Yes	No	No	Yes	Yes
Management	No	Yes	No	Yes	Yes
Orchestration	BPEL; jPDL	BPEL; Camel	BPEL	BPEL	BPEL
Choreography	No	No	No	No	No

Table 2.2: Classification of the ESB Solutions

According to the *Table 2*, it can be seen the presented solutions are very similar. However, scalability is an important requirement, so the PEtALs and Mule solution are more suitable to enforce this requirement. Mule is the most popular open source ESB, so it has more documentation available than the PEtALs. Furthermore, it was adopted by large enterprises like Google, Cisco, Amazon, etc.

2.4 Summary

In this chapter, we did an extensive survey in topics and available technologies that we determined as essential for the conception and development of our own solution.

As the objective of this work is to develop a graphical application cross-platform and according to the Web 2.0 principles to update the state of the business processes , we started by the study of some technologies used in the development of the web applications (refer to section 2.1). Moreover, since the web application (client) needs to communicate with servers, so we also survey some technologies to perform this requirement. The technologies approached were: AJAX; JSON; REST; Web Services; Widgets.

The MBC platform provides the general functions of a workflow system, which are the modeling and execution of business processes. Thereby, we survey some standards, as well as some workflow systems, that have been adopted by industry (refer to section 2.2).

BPEL is the proposed standard language to achieve the web services orchestration. On the other hand, the main purpose of the BPMN is to facilitate the communication between domain analysts and developers.

JBPM 5 is the latest version of the jBPM suited by JBoss Community. This suite is based on the BPMN 2.0 specifications and supports the entire life cycle of the business processes (modeling, executing, monitoring, and management).

The proposed solution comprises several entities. Therefore, we make an extensive survey about enterprise application integration (refer to section 2.3). The best solutions are based on web services (SOA) and provide several features. However, these solutions are a little complex.

3 Solution's Architecture

The objective of this chapter is to present the architectural design model of our solution. In the state of the art chapter (refer to chapter 2), we did an extensive survey of the concepts and challenges about web applications, business processes, and enterprise integration. Hence, our solution's architecture leverages the insights and experiences of the studied concepts and the tools that have been applied. The solution's architecture overview is comprised by several entities, which are depicted in Figure 3.1:

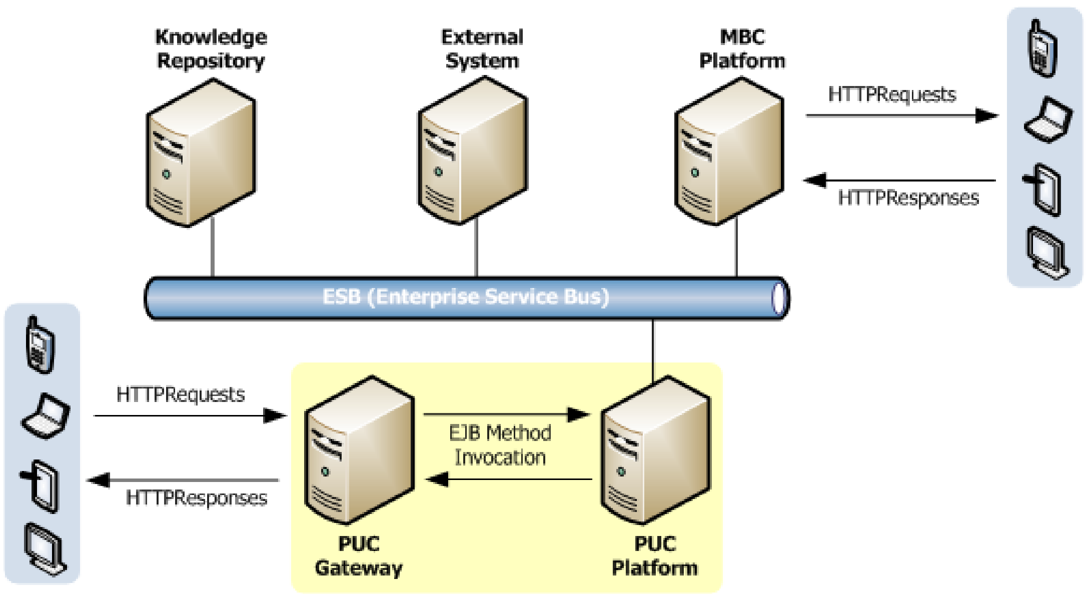


Figure 3.1: Architecture Overview

- **ESB** is the communication channel between the several entities and it is responsible for the interoperability between them. This entity is based on a ESB architecture;
- **MBC Platform** is the main entity of this work. It provides several functionalities and includes a business process suite to support the entire life cycle of business processes;
- **Knowledge Repository** stores the business processes of the organization, and it allows the collaborative modeling of business processes;

- **PUC Platform** is the collaboration platform developed by *PT Inovação*. Our solution assumes that the core groupware functionality is hereby deployed;
- **PUC Gateway** acts as a proxy server for the mobile terminals, mediating access to the provided core collaborative functionality residing in PUC;
- **External System** represents, for instance, a legacy application that the organization wants to continue to use while adding or migrating to a new set of applications.

We also developed a **Web Application** which is employed by users to activate and update the business processes. However, the business processes can also be activated and updated by external systems (entities).

Hereupon, the proposed architectural design is focused on fulfilling the following non-functional requirements:

- **Scalability:** the proposed solution already offers a good performance for heavier loads. However, the system can be easily modified to accommodate even heavier loads by, for instance, changing the database software;
- **Extensibility:** we use an object oriented design in both server and client-side architectures that is easily extended with new components. Moreover, we use a multi-tier architecture that provides a model for developers to create flexible and reusable applications;
- **Interoperability:** all entities are connect through a central bus based on a ESB architecture that allows to easily connect new entities. The interoperability is achieved through some formats conversation, however, it is necessary ensure that there is no incompatibility of features;
- **Data Persistence:** the proposed solution allows storing the data in an external database. Thus, it is possible to recover the system from some errors, for instance, system crash. Furthermore, the system consumes less memory since it only needs to have part of the data loaded in the memory;
- **Lightweight Application:** we develop a web application that invokes web services based on the REST architectural style which is the most lightweight alternative.

As the reader may recall from this document's introduction (refer to chapter 1), one of the goals of this work is to integrate our MBC platform with the collaborative platform developed by *PT Inovação*, called PUC. This collaborative platform already accomplishes access control, concurrency and session management requirements, and offers a persistent information base. It also provides a core of collaborative functionality through a set of application interfaces and resource management controllers. By integrating our solution with the PUC, we gain immediate support to create, manage, and control collaborative sessions using business processes.

The architectural choices and development of PUC is not in this work's scope. Nevertheless, we present a brief overview of PUC's architecture, in Section 3.1, in order for the reader better understand some of the choices made in our design. Likewise, we present a brief overview of the Knowledge Repository's architecture, in Section 3.2. In Section 3.3, we present the ESB's architecture. Next, in Section 3.4, we present MBC's architecture with a single detailed analysis for each component.

3.1 PUC's Architecture

PUC is born from the need of converging different collaboration services that were once separated and part of different and non interoperable platforms. PUC aims to solve this issue by providing an abstract and unified framework of collaboration service enablers to third party applications. The framework presents itself as a layered architecture (Figure 3.2):

- **Application layer:** in-house or third-party applications that want to use PUC's service enablers through the framework's public API (Application Programming Interface);
- **Management layer:** provides the core business logic of the available collaboration services (conversation and session management, management of collaborative resources, etc.);
- **Persistence layer:** contains the necessary code for database management. It runs as a service accessed by the manager components;
- **Resource layer:** holds the resource connectors which are responsible for establishing a network connection with the resource servers while abstracting their own network protocols from the resource manager's business logic.

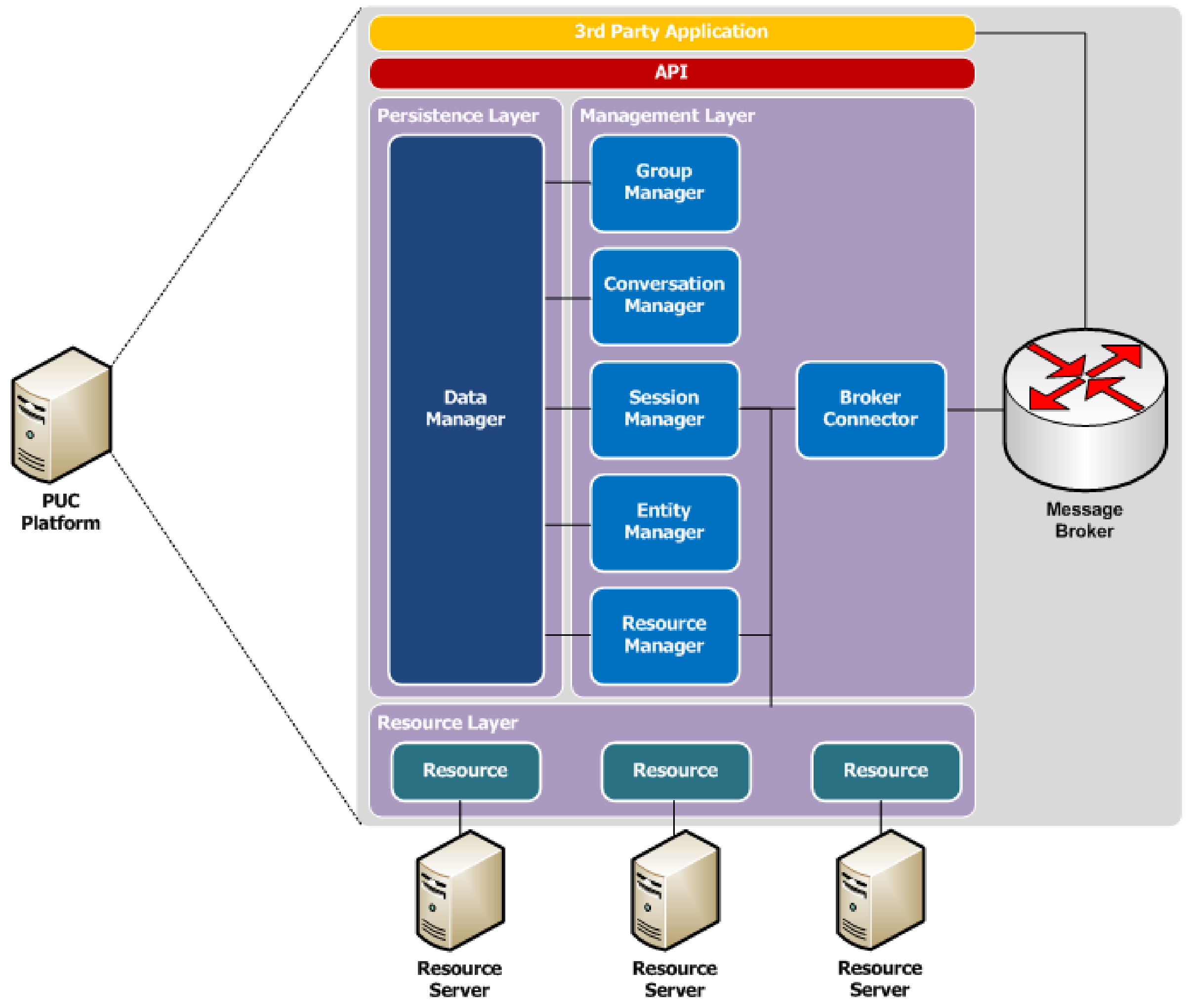


Figure 3.2: PUC's Architecture

There is a **Broker Connector** component that connects to a message delivery service which publicizes the received events launched by the platform in order to be consumed by client applications.

The **PUC Gateway** depicted in Figure 3.1 acts as a proxy server for the terminals, mediating access to the provided core collaborative functionality residing in PUC. This entity was developed by João Sousa, a previous IST MSc student.

The unified public **API**, the extensible core, and the resource layers allow new resource servers, with new network protocols, that can be added with minimal impact for the platform developer and no cost for the client application developer.

3.2 KR's Architecture

Knowledge Repository (KR) stores the business processes of the organization. Thereby, it is possible for a partner to get a business process from another partner, and it is also possible to reuse business processes in different scopes. Moreover, it allows some collaboration in the modeling of the business processes through of a business process graphical editor.

In order to store the business processes, we use the Drools Guvnor[1] that is a centralised knowledge repository developed and maintained by JBoss Community.[2] The Guvnor provides a rich web-based GUI (Graphical User Interface) that allows managing the knowledge base. Moreover, it can be integrated with the Oryx editor which allows modeling business processes that are stored in the repository. Oryx[3] is a web-based editor for modeling business processes hosted at Google Code. When the user opens a resource with extension .bpmn, the repository loads the Oryx widget.

The changes in the business processes are saved in the repository which provides a version control system. When a user is editing a resource (business process), Guvnor locks this resource, and thus, it does not allow that other users edit the same resource at the same time. Guvnor uses the Apache Jackrabbit,[4] which is a fully implementation of the Content Repository for Java Technology API (JCR, specified in JSR 170[5] and 283).[6]

Guvnor is deployed as a WAR (Web Application Archive) into an application server, which provides user interfaces over the web (REST API). Figure 3.3 shows the major components of the knowledge repository's architecture.

3.3 ESB's Architecture

ESB is the communication channel between the several systems. It receives the data from one system, if necessary it performs some mediating, and then it delivers information to the target system. Thus, the interoperability is achieved through some format conversion, however, it

[1]Drools Guvnor - `http://www.jboss.org/drools/drools-guvnor.html`
[2]JBoss Community - `http://community.jboss.org/`
[3]Oryx editor - `http://code.google.com/p/oryx-editor/`
[4] Jackrabbit - `http://jackrabbit.apache.org/`
[5]JSR 170 - `http://www.jcp.org/en/jsr/detail?id=170`
[6]JSR 283 - `http://jcp.org/en/jsr/detail?id=283`

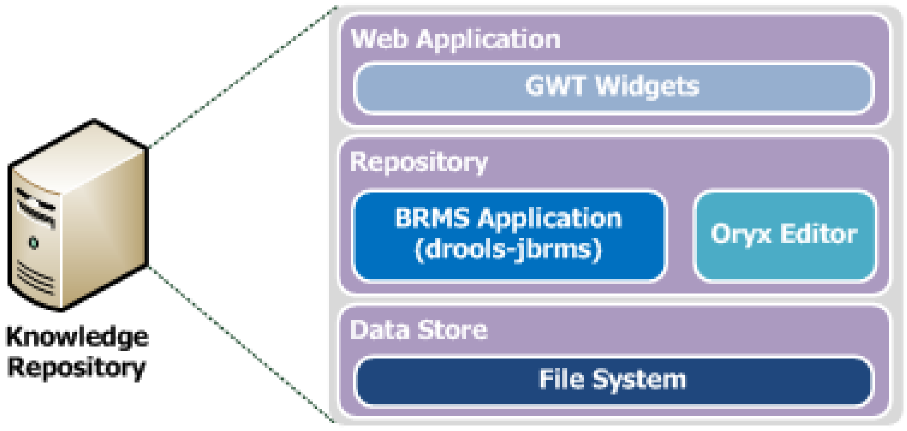


Figure 3.3: Knowledge Repository's Architecture

is necessary to ensure that there is no incompatibility of features. This entity provides three types of connectors: EJB Connector; WS Connector; REST Connector. The involved systems in the communication process can use different connectors, for instance, system A can use EJB Connector to send and receive information from the bus, and likewise system B can use the WS Connector to perform the same operations, thus the system A and B can communicate with each other despite they use different communications ways. Figure 3.4 shows an example of the communication process between the MBC and PUC platform.

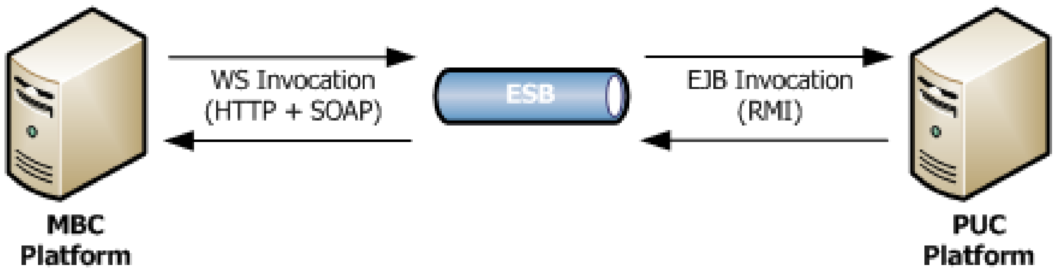


Figure 3.4: Communication process using the ESB

ESB comprises two components, Connector and Adapter (Figure 3.5). The Connector is used to get an interface to communicate with the target system. On the other hand, the connector uses the Adapter to perform some mediation before it sends the data to the other connector. As stated before, we provide only three types of connectors because our solution just needs these types. We do not use an existing implementation of ESB because this entity is quite simple for the scope of this work, and the existing implementations are quite complex which are used in other contexts.

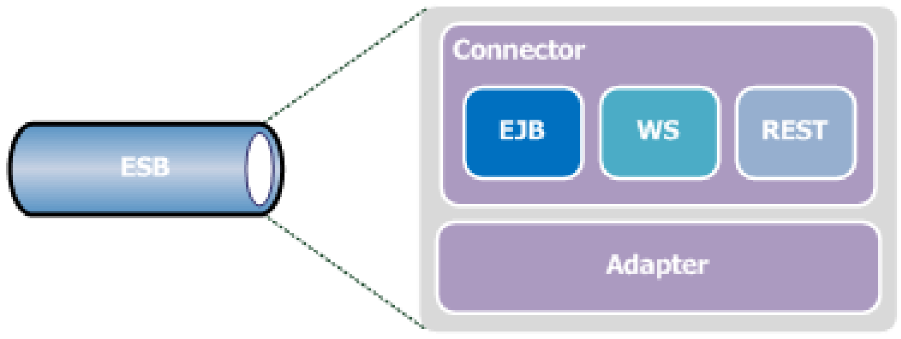


Figure 3.5: ESB's Architecture

3.4 MBC's Architecture

The MBC (Mobile Business Collaboration) platform provides a web application which can be used by users to update the business processes. Moreover, it also provides web services which can be used by external systems. The actual activation of business processes is carried out by the workflow engine which is provided by the jBPM suite.

The choice of jBPM suite is due to its extensive functionality and great support offered by developers and community. Another reason is due to *PT Inovação*'s long history of JBoss suites usage, of which we can take benefit from.

MBC platform uses a knowledge agent to get processes from the repository. If a process is already loaded in the knowledge base, it is not necessary get it from the repository, unless its version has changed.

Furthermore, the proposed solution uses an external database to assure the persistence of the data, and it uses external resources to send notifications to the users, such as the email resource.

The solution's architecture proposed (Figure 3.6) comprises four layers, which are: Domain Layer; Business Layer; Service Layer; Presentation Layer. Each layer also comprises one or more components. A multi-tier application architecture provides a model for developers to create flexible and reusable applications.

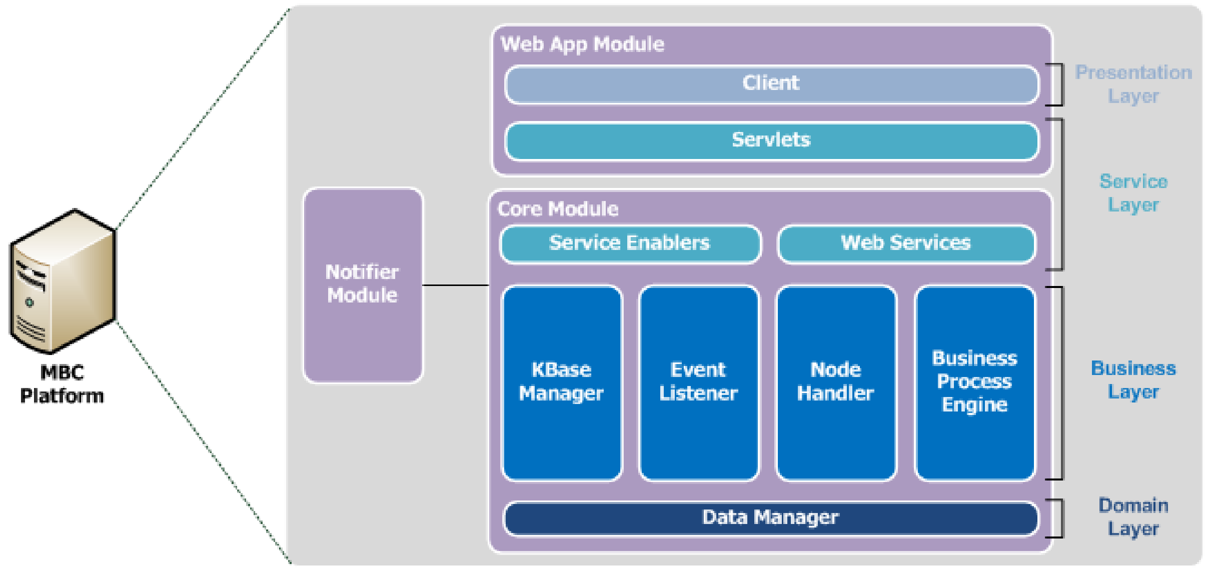


Figure 3.6: MBC's Architecture

3.4.1 Presentation Layer

The top-most level of the application is the graphical user interface (Client Component). The main function of the Client Component is to translate tasks and results into something the users can understand. For instance, the users can choose and start a business process using the available interface. The Client Component's architecture is depicted in Figure 3.7.

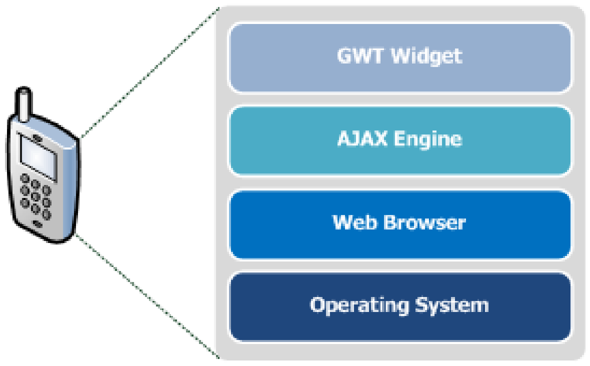


Figure 3.7: Client Component's Architecture

3.4.2 Service Layer

The service layer comprises three components: Servlets; Web Services; Service Enablers. The main function of this layer is to explore the business layer functionalities.

Servlets

The servlets provides a REST API which is used by the client component to perform user requests. Each servlet has a specific business tasks associated. However, there is one servlet to perform generic business tasks. The available servlets are:

- **User Servlet:** to get, create, update, and delete users;
- **Process Servlet:** to get, create, update, and delete processes;
- **Human Task Servlet:** to get, create, update, and delete human tasks;
- **Web Services Servlet:** to perform generic business tasks, for instance, the *Sign-in Service*.

Web Services

This component implements the API provided through the WSDL contract. All available services defined in the WSDL contract must be implemented by this component. When an entity invokes the MBC's web services using the HTTP and SOAP technology, this component receives the request, performs the service, and finally sends the answer to the caller entity.

Service Enablers

The Service Enablers implement the services in order to explore the core functionalities. They move and process data between the two surrounding layers (presentation and business layer). In order to mask domain objects in an external representation, this component uses the DTO (Data Transfer Object) design pattern to transfer the data from business layer to external entities as well as to the presentation layer. The DTOs do not have any behaviour except for storage and retrieval of its own data (selectors and getters), and furthermore they are objects that can be serialized. Hence, we expose only the necessary information of each domain object, for instance, the *User DTO* does not have the password field for security reasons.

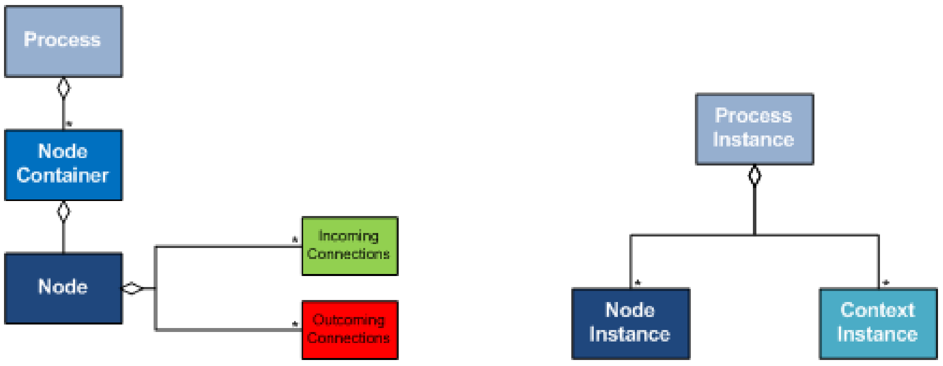
3.4.3 Business Layer

The business layer is the main layer of the MBC platform. It comprises four components: KBase Manager; Event Listener; Node Handler; Business Process Engine.

Business Process Engine

This component is provided by the jBPM suite, and it is responsible for the business process execution. The engine can communicate with external applications in order to update the business process's information, and thereby it can reach the needed information to complete the process.

Whenever the engine starts a new business process it creates a new instance for that process definition and maintains the state of that specific instance. The available states are: *Pending, Active, Completed, Aborted, and Suspended*. The internal structure of a *Process* is defined by several *Node Containers* and each one has one *Node*, as we can see in Figure 3.8(a). On the other hand, we can see in Figure 3.8(b) that each *Process Instance* has several *Node Instances* and *Context Instances*. The *Context Instances* store the variables / information that the process uses.



(a) Structure of the process definition (b) Structure of the process instance

Figure 3.8: Internal structure of a business process

KBase Manager

KBase Manager is the agent responsible for get the business processes' definitions from the central repository. Moreover, this agent also creates and loads sessions when the system needs to communicate with process engine. When the agent gets a new process, it parses and compiles the process definitions, and saves the results in a knowledge base. The knowledge base is shared across sessions because the task of creating a knowledge base can be rather heavyweight since this task involves parsing and compiling the process definitions. However, the knowledge base can be dynamically changed at runtime.

A new session is created only when the business process is started. We decided to create a new session for each process instance, but we could use the same session for all instances. Multiple sessions allow us to have multiple independent processing units, and it also allows the system more scalability.

KBase Manager is used to look up the business process definitions whenever necessary. When a process is loaded into the knowledge base, the agent assigns it a validity period. Thus, when the validity period expires, the agent retrieves the business process from repository again, but only when a new request is received. The validity period aims to improve the performance when the system receives a lot of requests to start the same business process at the same time. However, the business processes can be updated at any time. Hence, to reflect this change in the new requests, the system has to load again the business process definitions into the knowledge base (after the expiration of validity period).

Event Listener

The jBPM suite provides methods for registering and removing listeners. A listener can be used to listen for process-related events, like starting or completing a business process, entering and leaving a node, etc. An event object provides access to related information, like the process instance and node instance. The Event Listener component just receives the events and processes it. At the moment, we use this component to remove unused objects from the database, when process instance ends.

Node Handler

The domain-specific tasks are targeted to one particular application domain. However, we proposed the development of work items that can be used across domains. For instance, we develop a work item (*ApproverNode*) that approves some deal or management decision, which can be used in several domains performing some customization. All work items are driven according to the fluxogram in Figure 3.9. So, the work item has at least two stages, First and Last. Basically, in the first stage we read the work item parameters (input data), and in the last state we write the results (output data) in the database. In the last stage, we also send the *Complete Command* to the business process engine. All other stages are specific and optional for each work item.

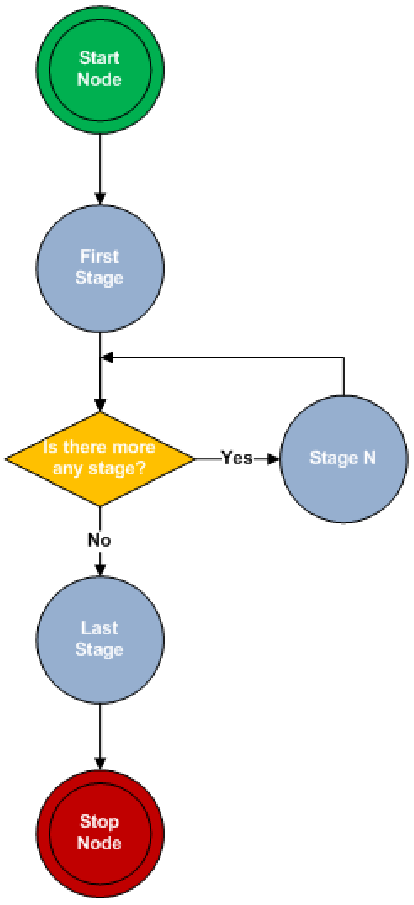


Figure 3.9: Execution flow of a work item

All work items have the same Node Handler associated. The Node Handler is responsible for selecting the appropriated service for the running work item. On the other hand, the service is responsible for the implementation of the functionalities provided by the work item. When the service completes the task, the work item is completed, so the service sends this information to the engine. The engine goes to the next node. If there is no next node, the business process ends. The execution flow of a business process is depicted in Figure 3.10. The work item service can send commands to engine, such as *Complete* and *Abort*.

The work item services can be implemented in the core, or they can be implemented in an external system. Thus, it is possible change the service implementation without requiring the updating of the MBC platform core. Hence, we can use different work item services depending on the context. Moreover, decoupling the execution of work items from the process itself allows process definition to be more declarative. In Section 3.5, we will describe the developed work items as well as the location of the services' implementation.

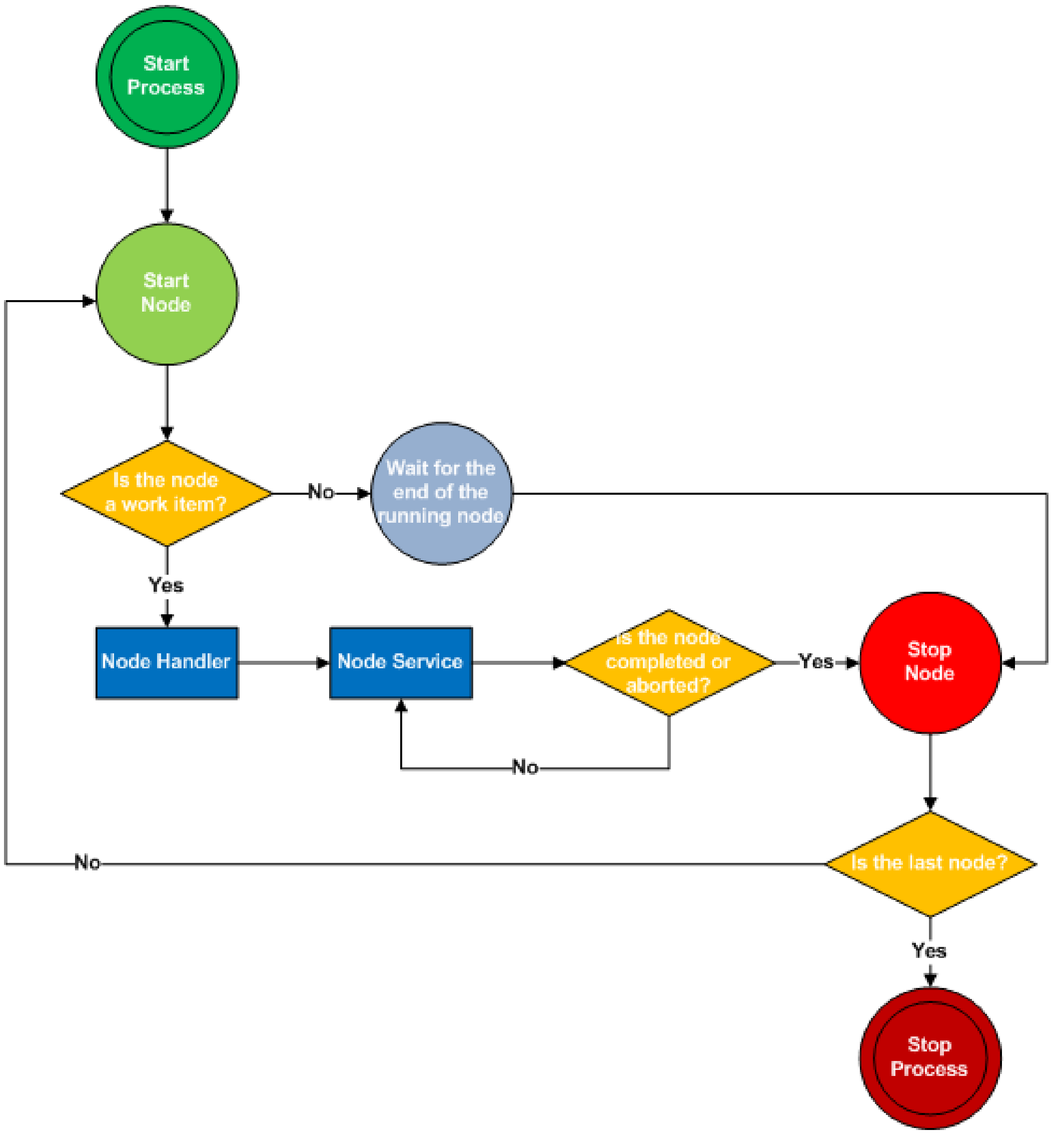


Figure 3.10: Execution flow of a business process

3.4.4 Domain Layer

The down-most level of the application is the Data Manager. The main function of the Data Manager is to ensure the persistence of the process instances as well as of all data required by the system. This component loads/stores data from/in the database, whenever necessary.

We use the DAO (Data Access Object) design pattern to access to data from database. The DAO design pattern provides a technique for separating object persistence and data access logic from any particular persistence mechanism or API. There are clear benefits to this approach from an architectural perspective. The DAO design pattern approach provides flexibility to change an application's persistence mechanism over time, without the need to re-engineer application logic that interacts with the DAO tier. The DAO design pattern also provides a simple and consistent API for data access that does not require knowledge of JDBC, EJB, or Hibernate interfaces.

3.4.5 Notifier

This component is used to send notifications to the users. We only developed the *Email Notifier* which sends emails. However, this component can be easily updated to support other notifiers, for instance, a *SMS (Short Message Service) Notifier*.

3.5 Prototypical Examples

As stated before, we developed work items that can be used across domains. Work items represent atomic units of work that need to be executed. These nodes specify the work that should be executed in the context of a process in a declarative way, specifying what should be executed (and not how) on a higher level (no code) and hiding implementation details. Table 3.1 shows the developed work items as well as the location of the services' implementation.

Work Item Name	**Service's Implementation**
ApproverNode	MBC (core)
SelectUserNode	MBC (core)
SelectFeatureNode	MBC (core)
PUCNode	PUC (resource)
WSNode	ESB

Table 3.1: Developed Work Items

ApproverNode - This node approves some deal or management decision, for which is necessary a rate of positive votes. The participants have different vote weight according to the its privilege level. If the rate of positive votes is equal or greater than a selected rate, the work item goes to next stage. Otherwise, the business process is aborted after the total weight of negative votes is found that prevents deal approvement. At each stage, the users receive a notification using, for instance, the email resource. The purpose of the notification is alert the users that they have a pending task in the MBC portal (web application). When a business process is aborted, the actors (users) receive a notification informing them that the task was cancelled. If the actors of some stage do not answer to notification, the system resends another notification (repeats the stage). The system tries N times and then, if the work item does not have yet the necessary information so it can go to the next stage, the process is aborted.

SelectUserNode - The purpose of this node is to create a list of users (participants), which can be used by the other work items of the same process. At each stage, the users also receive a notification. The flow of execution is very similar to the *ApproverNode*. Unlike the *ApproverNode*, *SelectUserNode* typically is used to gather the list of participants and save it in the database. Hence, in this situation a business process must have more than one work item.

SelectFeatureNode - The purpose of this node is to create a list of features, which can be used by other work items of the same process. At each stage, the users also receive a notification. The flow of execution is also very similar to the *ApproverNode*. Again, unlike the *ApproverNode*, *SelectFeatureNode* typically is used to gather the list of features and save it in the database. Hence, in this situation a business process must have more than one work item.

PUCNode - This work item has a flow of execution very similar to the previous work items. The purpose of this node is to schedule a session in the PUC platform. If the work item opens a session successfully in the PUC platform, it completes the job. Otherwise, it aborts the process. The session is open at the specified date. At each stage, the users also receive a notification.

WSNode - This node is used for web services composition. Basically, we use this work item to invoke web services deployed elsewhere. This work item can save and share data with other work items of the same process. Thus, it is possible to use the results of the invocation of a web service, as input data for invocation of another web service. The purpose of this work item, in this project, is to open a session in the PUC platform using the web services composition.

3.6 Summary

During the course of this chapter, we have presented the architectural overview of all entities of the proposed solution (Figure 3.1). We have also detailed each entity component individually, starting with PUC platform (refer to section 3.1), following for the Knowledge Repository (refer to section 3.2), and then the ESB (refer to section 3.3). Finally, we presented the MBC platform's components, with a single detailed analysis for each one (refer to section 3.4).

The proposed architectural design is focused on offering: *Scalability; Extensibility; Interoperability; Data Persistence; Lightweight Application.*

All of our architectural designs follow a layered design that properly makes use of already available third-party solutions in order to support the above mentioned requirements.

Concerning the work items (refer to section 3.5), we proposed the development of work items that can be used across domains, performing some customization. Each work item has a service which is responsible for the implementation of the functionalities provided by the node. Hence, changes in the domain can be implemented by adapting the work item service. We developed the following work items: *ApproverNode; SelectUserNode; SelectFeatureNode; PUCNode; WSNode.*

All the hereby described components were designed with the intent of promoting a good implementation that properly fulfils the accomplishment of the above mentioned requirements. In the next chapter, we will describe the implementation details and challenges.

4 Solution's Implementation

In the previous section, we presented the architectural design model of our solution which is composed by multiple and loosely coupled entities, each one with in-house developed and third party components. Now, we will be delving in the description of our development process and followed implementation models, in order to turn our earlier proposed design from a concept into a coherent software implementation.

Several practises have been followed in order to minimise effort and development time, such as:

- **Incremental approach:** by favouring a bottom-up development process that guarantees that components which serve another are completed first in an incremental fashion (Braude & Bernstein 2011);
- **Safeguard extensibility:** by always guaranteeing that new components can be easily added to our implementation on every development phase;
- **Do not reinvent the wheel:** by leveraging available technologies for the development of our solution. Preferably, technologies that are widely used today.

Object Oriented programming is a widely followed model in *PT Inovação* of which its in-house development teams have a solid knowledge base. Therefore, in order to exploit this knowledge base and comply with the above mentioned practises, we use a Java based object oriented implementation.

Putting this matter aside, we are now in position to present this chapter's roadmap, which starts by describing the technological tools that we chose to support our own in-house developed components (refer to section 4.1). The reader can refer to the implementation details of the MBC platform's components, in sections: 4.2.1 for the web module implementation; 4.2.2 for core module implementation, and finally 4.2.3 for the notifier module implementation.

Note: We do not detail the ESB module (refer to section 3.3) because it is quite simple and it does not have any relevant detail. Moreover, it only uses technologies that we also used for the development of the other modules.

4.1 Used Technologies

We have managed to leverage several technologies that support our own components. Here, we present an overview of these technologies which are used on the server-side, client-side, or even in both sides (Table 4.1).

Note: in this section, we will not present a detailed description of some technologies because we have already done in the state of the art chapter (refer to chapter 2), or in the solution's architecture chapter (refer to chapter 3).

Tecnology	**Version**	**Entity**
Drools	5.2	MBC
EJB	3.1	MBC; ESB
Java EE	6	MBC; ESB
JBoss AS	6.0	MBC; ESB; KR
JBPM	5.1	MBC
Gson	1.7	MBC; ESB
Guvnor	5.2	KR
GWT	2.2	MBC (web app client)
Hibernate	3.6	MBC
MVEL	2.1	MBC
Oryx Designer	1.0.0.052	MBC

Table 4.1: Used Technologies

4.1.1 Drools

Drools[1] introduces the business logic integration platform which provides a unified and integrated platform for Rules, Workflow, and Event Processing. The framework provides generic solutions for non-functional concerns like persistence, transactions, events, etc. Drools allows users to seamlessly combine processes and rules. It provides rule engine integration (Drools Expert),[2] for instance, the rules can define which processes to invoke. Drools supports domain

[1]Drools Platform - `http://www.jboss.org/drools`
[2]Drools Expert - `http://www.jboss.org/drools/drools-expert.html`

specific tasks inside processes using a special node that represents this interaction. This node allows process designers to define the type of task, the actor(s), the data associated with each task, etc.

4.1.2 Java EE and JBoss AS

Java EE or Java Platform Enterprise Edition[3] is a platform whose objective is to reduce the development complexity of enterprise oriented Java applications, by providing an extensive set of APIs to developers that wish to deploy distributed and modular multi-tier services.

The platform's version 6.0 (Java EE 6) focused on offering easier application development by improving some of the features introduced in previous versions, for instance, by providing annotations that ease the definition of web services. Applications developed with Java EE are supported by an Application Server (AS) which is responsible for hosting and executing the several modules of which they are composed of.

For the development of our server-side implementation, we chose JBoss AS.[4] It is an open-source implementation developed by *Red Hat*. Our choice is due to its extensive functionality and great support offered by developers and community. Another reason is due to *PT Inovação*'s long history of JBoss AS usage, of which we can take benefit from.

4.1.3 EJB

Enterprise Java Bean (EJB) is the Java EE server-side component that runs inside the EJB container and encapsulates the business logic of enterprise applications. These applications involve large number of data accessing concurrently by many users.

EJB technology is used to perform various types of task, such as: interacting with client, maintaining session for the clients retrieving and holding data which are stored in a database, and communicating with server. It provides two types of interfaces, Local and Remote.

Local interface is used to make local connections (inside the same JVM - Java Virtual Machine);

Remote interface is used to make remote connections (RMI - Remote Method Invocation).

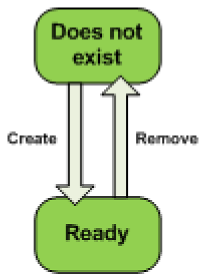
[3]Java EE - http://www.oracle.com/technetwork/java/javaee/overview/index.html
[4]JBoss AS - http://www.jboss.org/jbossas

There are several types of enterprise beans: Session; Singleton; Entity; Message. However, we only use the Session and Singleton.

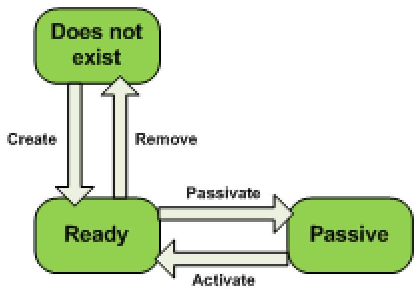
Session bean is the enterprise bean that directly interacts with the user and contains the business logic of the enterprise application. A session bean can neither be shared nor can persist its value (means its value cannot be saved to the database). A session bean can have only one client. As long as the client terminates, session bean associated with this client is also terminated and the data associated with this bean is also destroyed. Session beans are divided into two types, Stateless and Stateful.

Stateless session bean does not maintain a conversational state with the client. When a client invokes the methods of a stateless bean, the instance of bean variables may contain a state specific to that client only for the duration of a method invocation. The life cycle of a stateless bean is depicted in Figure 4.1(a);

Stateful session bean retains its state across multiple method invocations made by the same client. If the stateful session bean's state is changed during a method invocation, then that state will be available to the same client on the following invocation. The life cycle of a stateful bean is depicted in Figure 4.1(b).



(a) Life cycle of a stateless session bean



(b) Life cycle of a stateful session bean

Figure 4.1: Life cycle of a EJB

Singleton bean means that the container has only one instance for this bean which can be invoked concurrently by multiple threads, like a servlet. It supports two modes of concurrent access, Container-Managed Concurrency and Bean-Managed Concurrency.

Bean-Managed Concurrency means that the container sends all invocations into the bean and lets the singleton bean instance decide how and when to synchronize access;

Container-Managed Concurrency means that the container will enforce concurrency via locking method access to the bean. Two modes, called locks, exist and can be assigned to both the bean class and methods of the bean class.

Write lock means that the caller holds an exclusive lock on the bean for the duration of the method call and all other threads for that or any other method must wait;

Read lock means that all callers have full concurrent access to the methods.

Over again, we use this technology due to *PT Inovação*'s long history of EJB usage, of which we can take benefit from. Furthermore the EJB technology is widely used for developing large and distributed applications because it simplifies the development process once the developer only has to concentrate on solving the problem.

4.1.4 Gson

Gson is a Java library that can be used to convert Java objects into their JSON representation. It can also be used to convert a JSON string to an equivalent Java object. This library provides a set of tools. However, we only use three of these tools in our implementation, namely:

- **Serializer:** serializes Java objects to a JSON representation. All original data structures are maintained in the text representation;
- **Deserializer:** deserializes the JSON string into a Java object of the specified type. All original data are recovered;
- **Parser:** parses JSON strings into a parse tree of *JsonElements* (*JsonArray*, *JsonPrimitive*, etc.)

Java object migration is essential to standardise our data model in both client and server implementations. By using Gson tools we instantly convert Java objects from server to client, or JavaScript objects to Java objects while automatically complying with a uniform data model on both sides.

Furthermore, we also use JSON to represent some data of the domain objects. For instance, *ServiceNode* object has two fields, *Parameters* and *Results*. We use a JSON representation to store the data of these fields in the database. So, we achieve a standardised and generic model to persist the data. Hence, the external systems can use the same *ServiceNode* (work item) to store different data types using a specific implementation of the work item's service.

4.1.5 GWT

Google Web Toolkit (GWT)[5] is a toolkit for building complex web applications. Its main advantage is to allow us write AJAX applications in Java and then compile the produced source code to a highly optimised JavaScript that runs across all modern desktop browsers, including even, some mobile browsers.

GWT also makes the interaction with handwritten JavaScript possible by using its Java Script Native Interface (JSNI). Hereby, we use overlay types to convert JavaScript objects into Java objects.

In order to support communication with back-end servers in its applications, GWT also provides the *GWT RPC Framework* that transparently makes calls to GWT Java servlets through a customised RPC protocol, and takes care of object serialisation and other details. However, we retrieve JSON data via HTTP, using a REST style architecture because this communication way is the most lightweight and interoperable alternative.

4.1.6 Hibernate

Hibernate is an open-source Java persistence framework which aims to store an object oriented data graph, built in Java, into a relational database. In the genesis of such tools is the difference between the relational paradigm (used by most database management systems) and object-oriented (used by Java applications), and the need to establish a correspondence between the two data models (object / relational mapping). This mapping is then used by Hibernate to support reading and writing of persistent objects within a unit of work.

A unit of work records all transactions of a business transaction that can affect the database and ensures atomicity. When a unit of work ends successfully, the transactions recorded are propagated to the database. If the unit of work aborted, all transactions recorded are discarded, as if the unit of work had never existed. Only the operations within an active unit of work are performed in the context of a database transaction.

Hibernate Entity Manager implements the programming interfaces and lifecycle rules as defined by the JPA (Java Persistence API) 2.0 specification. Together with *Hibernate Annotations*,

[5] GWT Overview - http://code.google.com/intl/pt-PT/webtoolkit/overview.html

this wrapper implements a complete JPA persistence solution on top of the mature *Hibernate Core*. The *Entity Manager API* is used to access a database in a particular unit of work. It is used to create and remove persistent entity instances, to find entities by their primary key, and to query over all entities.

4.1.7 MVEL

MVEL[6] (MVFLEX Expression Language) is a powerful expression language for Java-based applications. The expression language is a scripting language which allows easier access to Java components. This turns the development easier for web-content designers who have little or practically no knowledge of the core Java Language. MVEL is typically used for exposing basic logic to end-users and programmers through configuration such as XML files, JSON files, or annotations.

JBPM suite uses MVEL to read the metadata of the work items once the MVEL allows us to do more advanced configuration files. The files are defined using the JSON representation, as we will see ahead.

4.2 MBC Platform

In this section, we present all the relevant implementation details of the MBC platform. The MBC platform implementation was divided in three modules (Figure 3.6), which are: Web Application Module; Core Module; Notifier Module. We begin by addressing the web application module (refer to section 4.2.1), and then the core module (refer to section 4.2.2). At the end of this section, we will describe the notifier module (refer to section 4.2.3).

4.2.1 Web Application Module

As seen before, the MBC platform provides a web-based GUI which allows users to interact with the system. The module responsible by this implementation is called Web Application, which is divided in three packages (Figure 4.2): Client; Server; Shared.

[6]MVEL Project - `http://mvel.codehaus.org/`

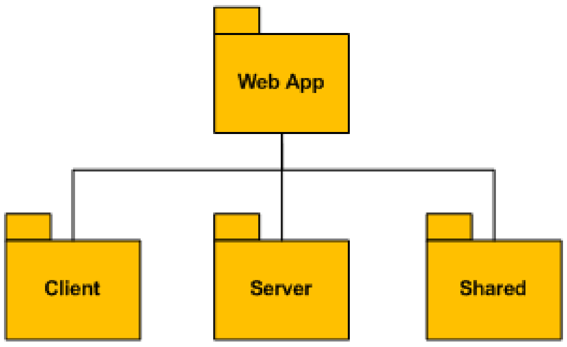


Figure 4.2: Web Application's Structure

Shared Package

Shared package holds the classes that are used in both sides, client and server, for instance, *FieldVerifierClass*. All classes used in the client code have to be translated to JavaScript code, except the classes that use native JavaScript. The translation is performed by using the GWT tools.

Client Package

Client package holds the classes that are used in the client-side. Mainly, this package holds the widgets for the web front end, which were developed by using the user interface (UI) elements provided by GWT. The client structure is depicted in Figure 4.3, which follows the lines of object-oriented design.

The application starts at the *EntryPointClass*. This class loads the widgets on-demand because the loading of all widgets at same time is very heavy to the terminal devices. Furthermore, typically the users do not use all features of an application in the same session. However, the first time that a widget is loaded it can take some time, this being the main drawback.

The users can have pending tasks stored in the database. The tasks, or also called human tasks, are created by work item services. These tasks are used to update the state of the work items. When a user performs the *Sign-in Service*, it receives the pending tasks. Each task has an associated widget type. The human task widgets are also loaded on-demand, thus, in a first approach, the application only creates a hyperlink in the user interface.

As stated before, we use JSON representation to exchange data between client and server.

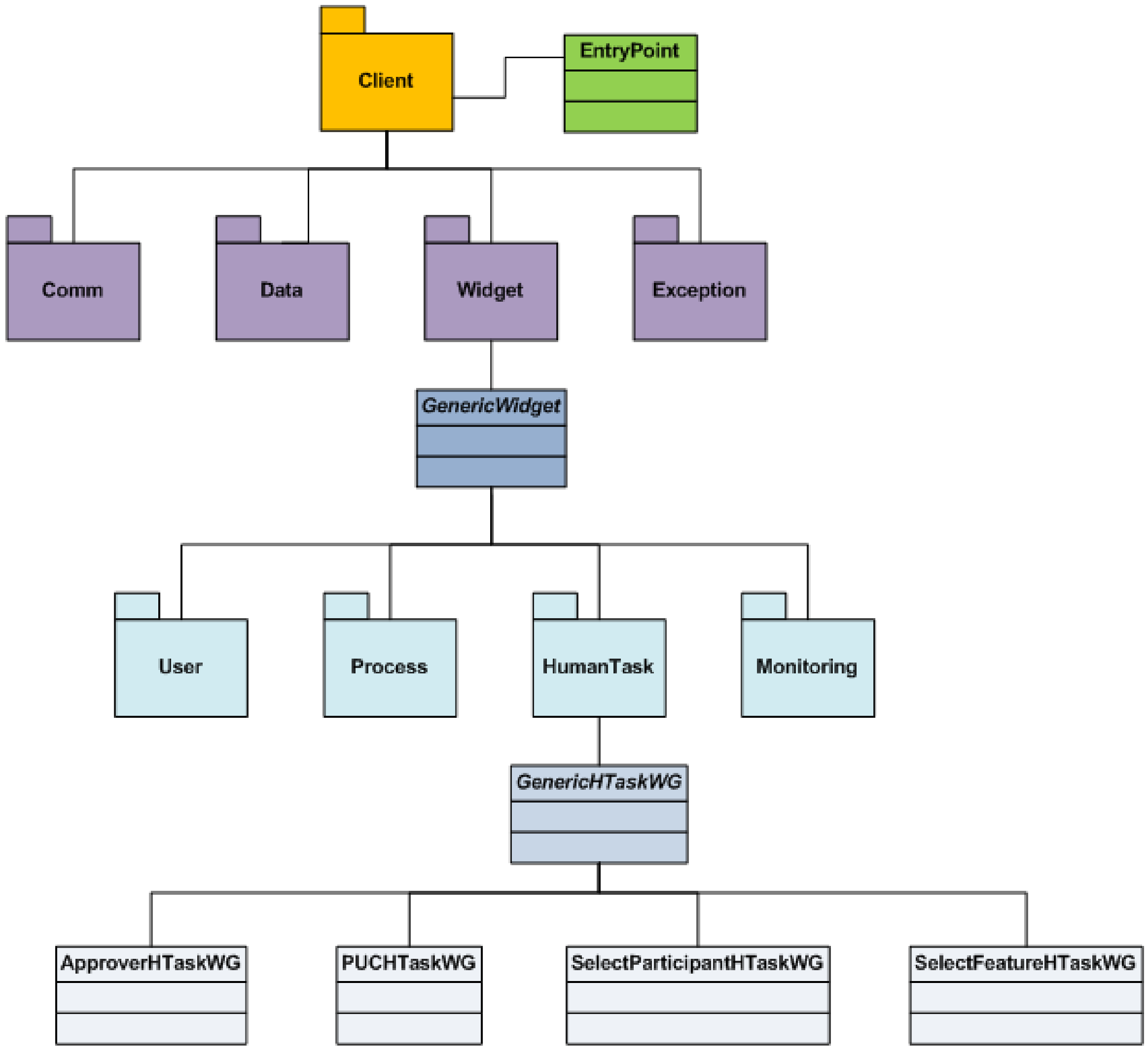
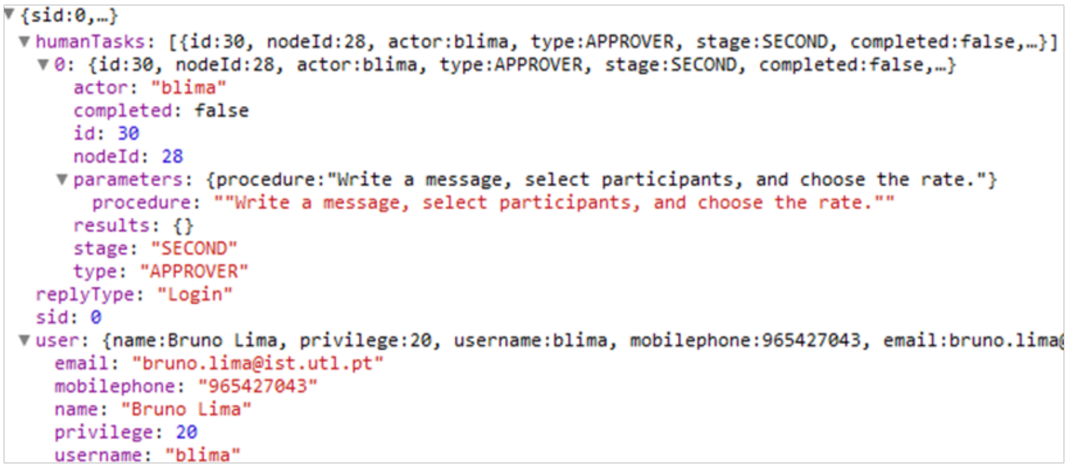


Figure 4.3: Web Client's Structure

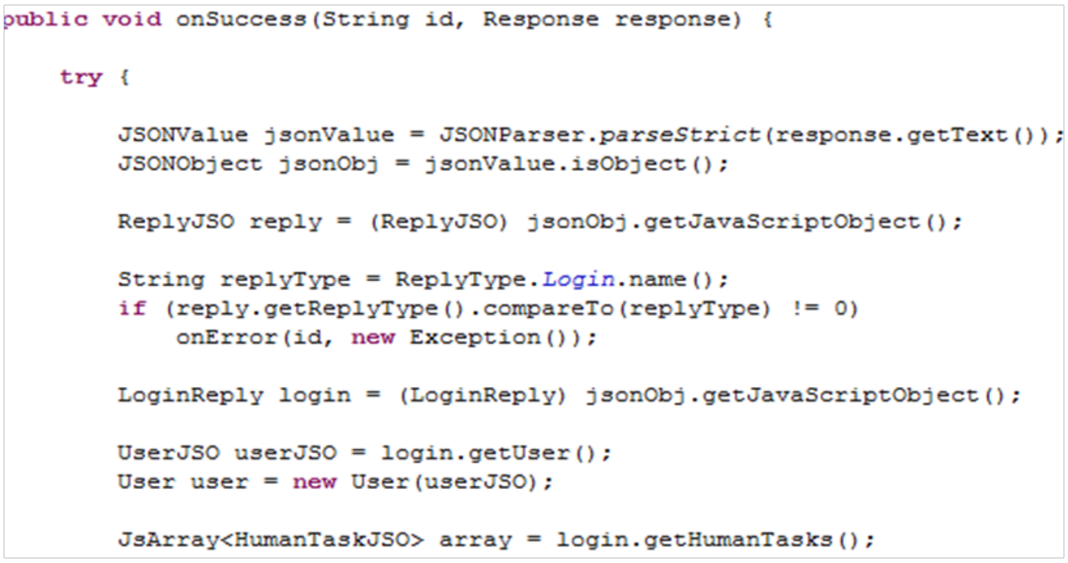
Figure 4.4 shows a reply from the *Sign-in Service* sended by server. The reply has a type (replyType), the session identifier (sid), the user information (user), and the human tasks (humanTasks). When the user completes the task (using the human task widgets), some of that information is sended to server. The server uses the information to retrieve and update the work items.

In the client, we parse the JSON string to *JavaScriptObject* (Figure 4.5). The classes that have JSO termination are defined using native JavaScript (also called overlay types). The overlay types can be used like Java objects, in the development phase.



```
▼{sid:0,…}
 ▼humanTasks: [{id:30, nodeId:28, actor:blima, type:APPROVER, stage:SECOND, completed:false,…}]
  ▼0: {id:30, nodeId:28, actor:blima, type:APPROVER, stage:SECOND, completed:false,…}
     actor: "blima"
     completed: false
     id: 30
     nodeId: 28
    ▼parameters: {procedure:"Write a message, select participants, and choose the rate."}
       procedure: ""Write a message, select participants, and choose the rate.""
     results: {}
     stage: "SECOND"
     type: "APPROVER"
  replyType: "Login"
  sid: 0
 ▼user: {name:Bruno Lima, privilege:20, username:blima, mobilephone:965427043, email:bruno.lima(
    email: "bruno.lima@ist.utl.pt"
    mobilephone: "965427043"
    name: "Bruno Lima"
    privilege: 20
    username: "blima"
```

Figure 4.4: Reply from the *Sign-in Service*



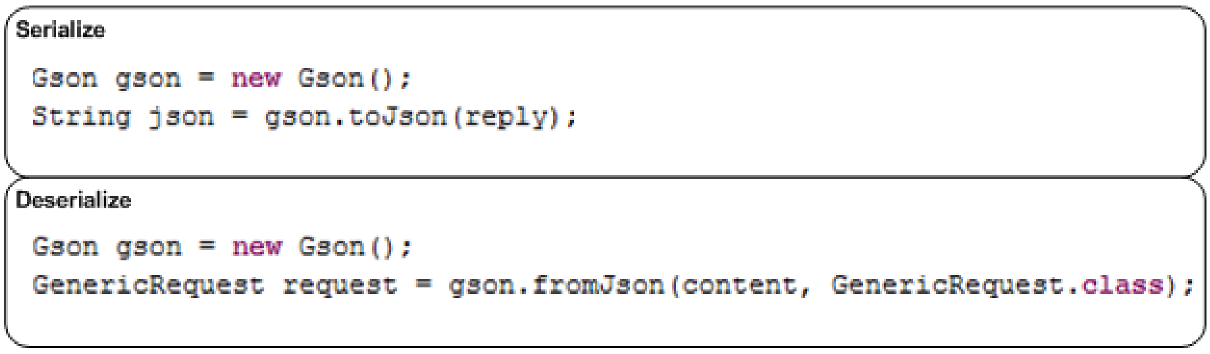
```java
public void onSuccess(String id, Response response) {

    try {

        JSONValue jsonValue = JSONParser.parseStrict(response.getText());
        JSONObject jsonObj = jsonValue.isObject();

        ReplyJSO reply = (ReplyJSO) jsonObj.getJavaScriptObject();

        String replyType = ReplyType.Login.name();
        if (reply.getReplyType().compareTo(replyType) != 0)
            onError(id, new Exception());

        LoginReply login = (LoginReply) jsonObj.getJavaScriptObject();

        UserJSO userJSO = login.getUser();
        User user = new User(userJSO);

        JsArray<HumanTaskJSO> array = login.getHumanTasks();
```

Figure 4.5: Java code to parse the reply from the *Sign-in Service*

Server Package

Server package holds the classes that are used in the server-side. Basically, this package holds the servlets implementation. The servlets respond to HTTP requests performed by clients using some method provided by HTTP protocol (GET, POST, PUT, and DELETE). Each method executes a different service, for instance, the GET method is used to retrieve an object from server (database).

The payload of the HTTP protocol is filled with a JSON object. We use Gson tools to serialize and deserialize the data. When a servlet receives a request, it deserializes the JSON object into a correspondent DTO. On the other hand, when the servlet sends a reply to the client, it serializes the DTO into the correspondent JSON representation (Figure 4.6).



Serialize

```
Gson gson = new Gson();
String json = gson.toJson(reply);
```

Deserialize

```
Gson gson = new Gson();
GenericRequest request = gson.fromJson(content, GenericRequest.class);
```

Figure 4.6: Java code to serialize and deserialize Java objects

The MBC platform provides a servlet for each domain object that is used in the communication between client and server (refer to section 3.4.2). Nevertheless, the system also provides a servlet that only accept requests using POST method. This servlet is used to perform generic business tasks, for instance, the *Sign-in Service*. The service name, as well as other parameters, are described using JSON representation.

4.2.2 Core Module

Core module represents the main work of our implementation. This module comprises components from service, business, and domain layer (Figure 3.6). These components were developed based on EJB technology. For instance, the Service Enablers component was developed using stateless beans, which explore core functionalities. We use stateless beans because the client's state does not need to be saved between the method invocations, also favouring scalability. Furthermore, these beans can be executed in any application server.

KBase Manager is a singleton bean, thus the container only has one instance for this bean, which can be invoked concurrently by multiple threads (clients). This bean stores the knowledge base which is shared between sessions (clients). As stated before, the task of creating a knowledge base can be rather heavy-weight. Figure 4.7 shows the singleton bean definition as well as the map of versions. The map is used to control the validity of a resource (business process). The validity period is defined in seconds, and it can be changed in the ESB's configuration file.

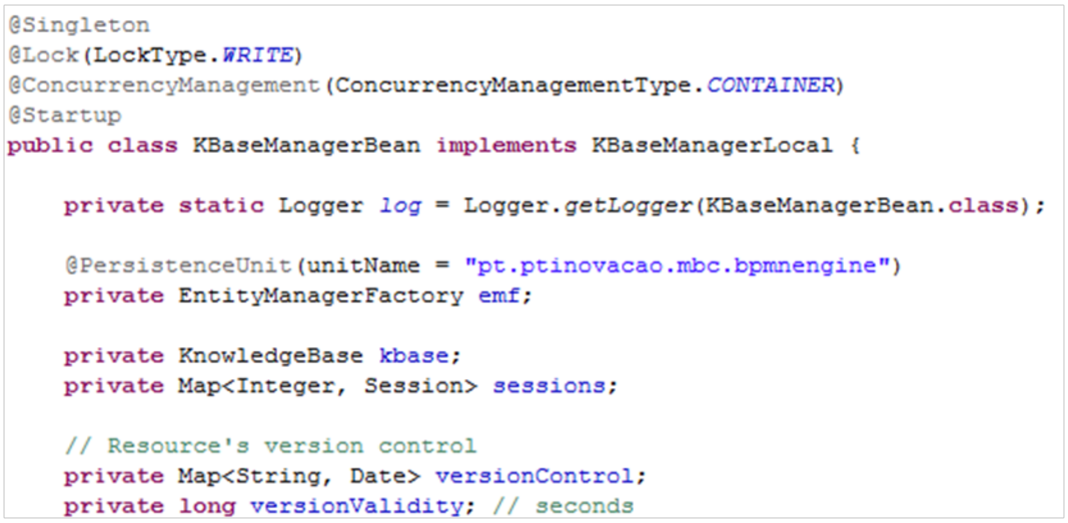

```
@Singleton
@Lock(LockType.WRITE)
@ConcurrencyManagement(ConcurrencyManagementType.CONTAINER)
@Startup
public class KBaseManagerBean implements KBaseManagerLocal {

    private static Logger log = Logger.getLogger(KBaseManagerBean.class);

    @PersistenceUnit(unitName = "pt.ptinovacao.mbc.bpmnengine")
    private EntityManagerFactory emf;

    private KnowledgeBase kbase;
    private Map<Integer, Session> sessions;

    // Resource's version control
    private Map<String, Date> versionControl;
    private long versionValidity; // seconds
```

Figure 4.7: Java code of the KBase Manager Bean

The communication with the repository is performed using the central bus (ESB). Basically, the ESB provides a bean that can be accessed remotely. This bean uses an HTTP client to access the Guvnor since this platform provides a REST API. Figure 4.8 shows an example of a URL to get a resource from repository. The *mbc* is the package name, the *LATEST* is the version, and the *ApproverProcess* is the resource name. The resource's version can be changed in the ESB's configuration file.

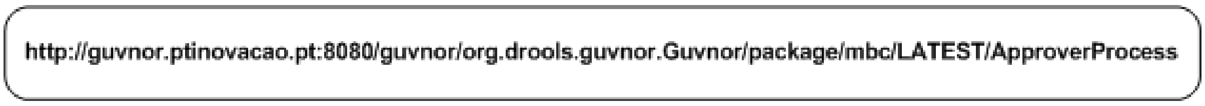
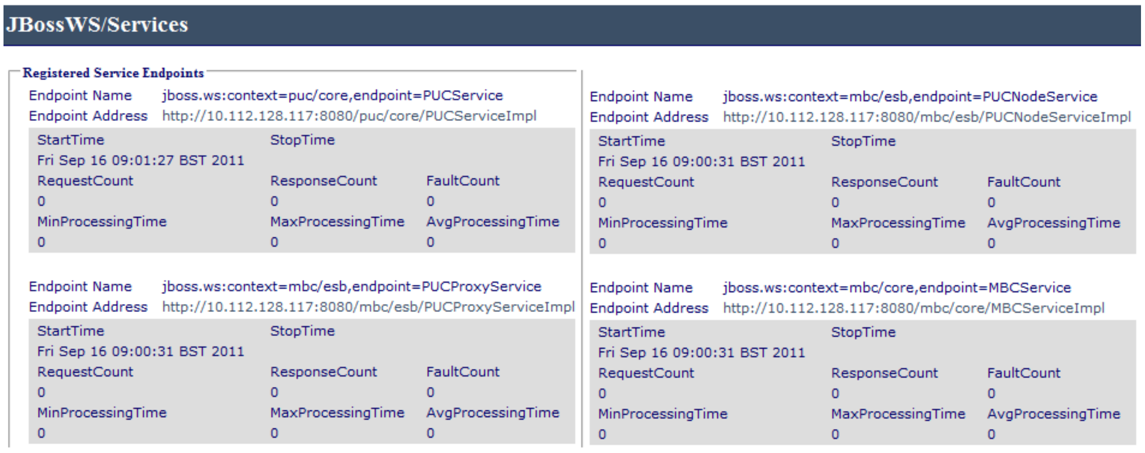

http://guvnor.ptinovacao.pt:8080/guvnor/org.drools.guvnor.Guvnor/package/mbc/LATEST/ApproverProcess

Figure 4.8: Example of a URL for the Guvnor's REST API

Web Services can be developed based on two development styles, Contract Last (bottom-up approach) and Contract First (top-down approach). When we use a bottom-up approach, we start with the Java code, and let the web service contract to be generated from that (using ws-provide tool). When we use top-down approach, we start with the WSDL contract, and use Java to implement the said contract (using ws-consume tool).

We use top-down approach because services with contracts obtained this way may easily cooperate in a service oriented architecture, and the contracts tend to have longer lifespans and usually require less maintenance. However, the web service development required more effort and time. We develop the following web services (Figure 4.9):

- **PUCService:** explores some PUC platform's functionalities;
- **MBCService:** explores some MBC platform's functionalities;
- **PUCProxyService:** used by *WSNode* to communicate with the PUC's web services;
- **PUCNodeService:** used by *PUCNode* to communicate with the *MBCResource* (PUC).


JBossWS/Services

Registered Service Endpoints

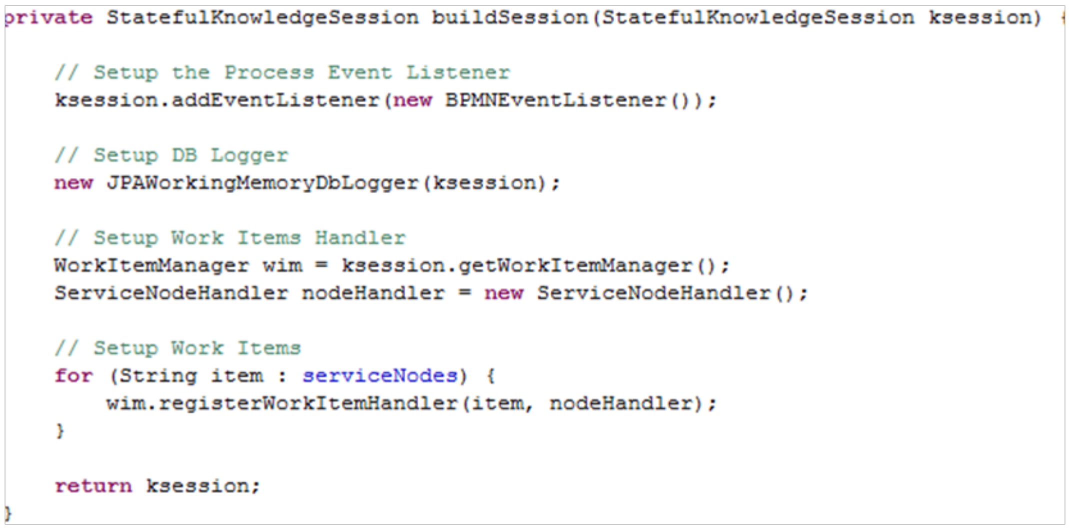
```
Endpoint Name     jboss.ws:context=puc/core,endpoint=PUCService
Endpoint Address  http://10.112.128.117:8080/puc/core/PUCServiceImpl
  StartTime                     StopTime
  Fri Sep 16 09:01:27 BST 2011
  RequestCount                  ResponseCount       FaultCount
  0                             0                   0
  MinProcessingTime             MaxProcessingTime   AvgProcessingTime
  0                             0                   0

Endpoint Name     jboss.ws:context=mbc/esb,endpoint=PUCProxyService
Endpoint Address  http://10.112.128.117:8080/mbc/esb/PUCProxyServiceImpl
  StartTime                     StopTime
  Fri Sep 16 09:00:31 BST 2011
  RequestCount                  ResponseCount       FaultCount
  0                             0                   0
  MinProcessingTime             MaxProcessingTime   AvgProcessingTime
  0                             0                   0

Endpoint Name     jboss.ws:context=mbc/esb,endpoint=PUCNodeService
Endpoint Address  http://10.112.128.117:8080/mbc/esb/PUCNodeServiceImpl
  StartTime                     StopTime
  Fri Sep 16 09:00:31 BST 2011
  RequestCount                  ResponseCount       FaultCount
  0                             0                   0
  MinProcessingTime             MaxProcessingTime   AvgProcessingTime
  0                             0                   0

Endpoint Name     jboss.ws:context=mbc/core,endpoint=MBCService
Endpoint Address  http://10.112.128.117:8080/mbc/core/MBCServiceImpl
  StartTime                     StopTime
  Fri Sep 16 09:00:31 BST 2011
  RequestCount                  ResponseCount       FaultCount
  0                             0                   0
  MinProcessingTime             MaxProcessingTime   AvgProcessingTime
  0                             0                   0
```

Figure 4.9: List of deployed web services in the JBoss AS

Node Handler selects appropriated service for the running work item. However, the node handler instance has to be registered in the session. Therefore, when a session is created by KBase Manager component, the node handler instance is registered in the engine's work item manager (Figure 4.10). For each work item of a process, the engine calls the correspondent node handler instance. Nevertheless, all instances are created from the same class (*ServiceNode-Hander.class*).

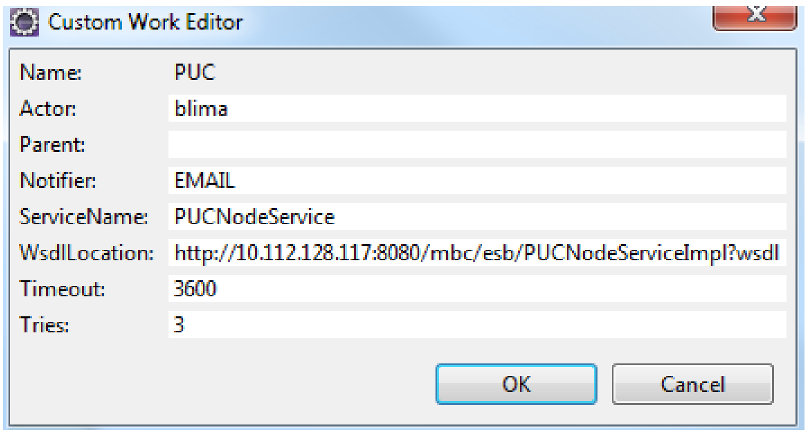
The work items can have several parameters, but some of them are indispensable for the node handler. Figure 4.11 shows the customization parameters of the *PUCNode*. As seen before, the work item service can be implemented by an external entity. In this case, the *WsdlLocation* and *ServiceName* parameters have to be filled. In case of these parameters are not filled, the node handler assumes that the work item service is implemented in the core module. The service name is defined by the user, or it is the concatenation of the node name plus the "NodeService" string, for instance, *ApproverNodeService*.

When the work item service is implemented by an external entity, the Node Handler uses a web service client to invoke the remote services. We create a WSDL contract that defines the



```
private StatefulKnowledgeSession buildSession(StatefulKnowledgeSession ksession) {

    // Setup the Process Event Listener
    ksession.addEventListener(new BPMNEventListener());

    // Setup DB Logger
    new JPAWorkingMemoryDbLogger(ksession);

    // Setup Work Items Handler
    WorkItemManager wim = ksession.getWorkItemManager();
    ServiceNodeHandler nodeHandler = new ServiceNodeHandler();

    // Setup Work Items
    for (String item : serviceNodes) {
        wim.registerWorkItemHandler(item, nodeHandler);
    }

    return ksession;
}
```

Figure 4.10: Java code to register the work items



Custom Work Editor

Name:	PUC
Actor:	blima
Parent:	
Notifier:	EMAIL
ServiceName:	PUCNodeService
WsdlLocation:	http://10.112.128.117:8080/mbc/esb/PUCNodeServiceImpl?wsdl
Timeout:	3600
Tries:	3

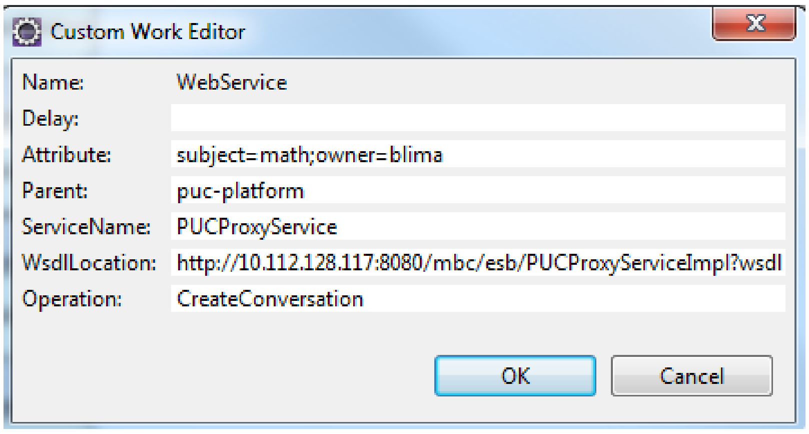
Figure 4.11: Customization of the *PUCNode*

several services used by MBC platform to perform the work items' operations. Thereby, the external entities have to implement the web service for this WSDL contract. The *WsdlLocation* parameter gives us the location where the web service is deployed. The web service client can invoke any web service that implements the defined WSDL contract.

The *PUCNode* service is implemented in the PUC platform. So, we create a web service in the ESB that implements the WSDL mentioned above. This implementation invokes the work item's operations defined in the PUC platform using the provided remote bean (Figure 3.4). Basically, this bean represents the concrete implementation of the *PUCNode's* operations. We added a new resource to the PUC platform, called *MBCResource*, where that bean was implemented.

The *WSNode* service is implemented in the ESB. Basically, in this case, the ESB works like a web service proxy. The MBC platform invokes the services deployed in the ESB, and the ESB invokes the target web service using the suitable web service client. The operation, as well as the attributes, are defined in the work item parameters (Figure 4.12). In this project, we developed a web service that uses the PUC's web service client to invoke the available PUC's web services.

The *Parent* parameter is a reference that can be used to share data between work items of the same business process. The service can store in the database the results of the work item execution, and these results can then be used by another work item using the known reference. For instance, we can have a work item that stores the selected participants in the database, and the next work item can use this information to send some notification to those participants.



Name:	WebService
Delay:	
Attribute:	subject=math;owner=blima
Parent:	puc-platform
ServiceName:	PUCProxyService
WsdlLocation:	http://10.112.128.117:8080/mbc/esb/PUCProxyServiceImpl?wsdl
Operation:	CreateConversation

Figure 4.12: Customization of the *WSNode*

Data Manager uses a container-managed entity manager. Thus, the container is responsible for the opening and closing of the entity manager (this is transparent to the application). It is also responsible for transaction boundaries.

We create a data access object (DAO) for each domain object. However, all domain objects use the same entity manager. The MBC platform has two persistence contexts, one for the domain objects, and another for the business process engine's data.

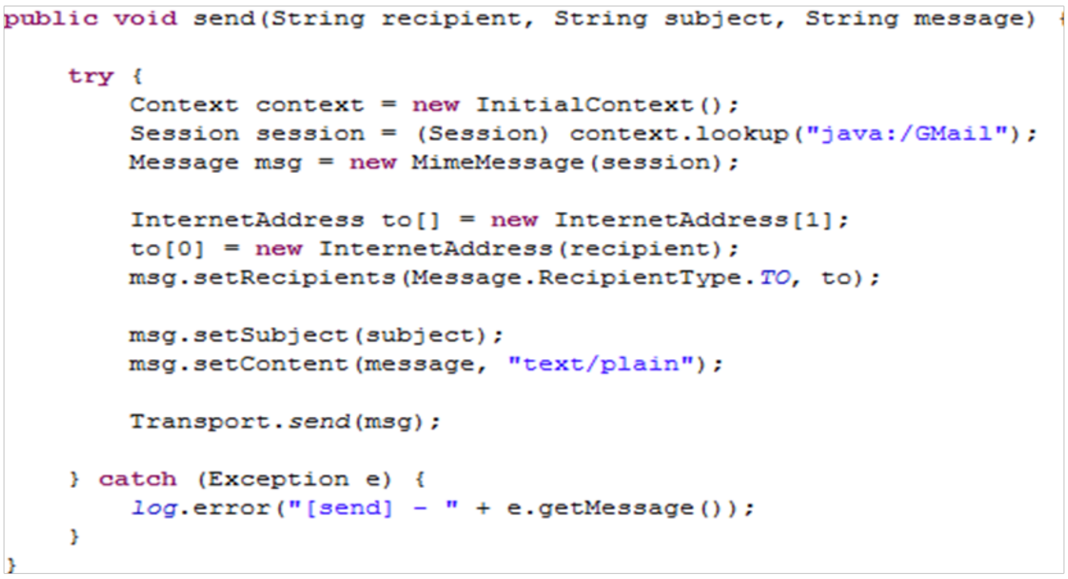
The engine, by default, does not persist the business processes instances, if unexpected failure occurs, all running instances are lost. Moreover, without data persistence the system cannot remove the running instances from memory and restore them at some later time. Therefore, we set up the engine to store the data in the database, through the entity manager defined in the session's environment by the KBase Manager component. Moreover, we also set up the engine with a logger. The logger stores process-related information in a database, for instance, the start and end date. This logger is provided by BAM (Business Activity Monitoring) module from jBPM suite, which can be integrated with jBPM Console.[7]

The Data Manager component uses an external object-relational database system, which is a open source implementation provided by PostgerSQL[8] community, to store the data.

4.2.3 Notifier Module

The notifier module is used to send notifications (email, sms, etc.) to the MBC's users. As stated before, we only develop the *Email Notifier*.

The *Email Notifier* uses the email service provided by JBoss AS. We configured this service in order to use a *Gmail* account to send the emails to the users. The service is retrieved from JNDI (Java Naming and Directory Interface) lookup (Figure 4.13).



```
public void send(String recipient, String subject, String message) {

    try {
        Context context = new InitialContext();
        Session session = (Session) context.lookup("java:/GMail");
        Message msg = new MimeMessage(session);

        InternetAddress to[] = new InternetAddress[1];
        to[0] = new InternetAddress(recipient);
        msg.setRecipients(Message.RecipientType.TO, to);

        msg.setSubject(subject);
        msg.setContent(message, "text/plain");

        Transport.send(msg);

    } catch (Exception e) {
        log.error("[send] - " + e.getMessage());
    }
}
```

Figure 4.13: Java code to retrieve the *Email Service*

[7]jBPM Console - http://community.jboss.org/wiki/BPMConsole
[8]PostgreSQL - http://www.postgresql.org/

4.3 Summary

In this chapter, we addressed the challenges and relevant details of our implementation phase, in order to know how we turned our architectural designs into software implementations that fulfil our objectives.

We were able to leverage a significant set of supporting technologies (refer to section 4.1), in both server and client-side implementations. The JBoss AS was used in order to deploy all components developed based on Java EE.

Our development was divided in four modules: *Web Application*; *Core*; *Notifier*; *ESB*. However, we do not detail the ESB module because it does not have any relevant detail. Moreover, it uses the web services and EJB technologies, which we also used for the development of the other modules.

Web application module (refer to section 4.2.1) is divided in three packages: *Client*; *Server*; *Shared*. Basically, the client is a JavaScript application, and the server is a set of servlets developed based on REST architectural style. The client was totally developed using GWT, which permits developers to create complex web applications with a Java based source. We use JSON representation to exchange data between client and server.

The core module (refer to section 4.2.2) was developed based on EJB technology. This module represents the main work of our implementation. It comprises components from service, business, and domain layer. We develop web services, with contract-first approach, in order to explore some functionality and provide more interoperability between entities.

Finally, the notifier module (refer to section 4.2.3) uses the email service from JBoss AS, configured to use a *Gmail* account, in order to send emails (notifications) to the MBC's users.

5 Evaluation

Now, in this section, we present the evaluation of our solution, which has been built in hopes of ultimately being a usable and commercially viable solution that aims to be deployed in *PT Inovação*'s context. Hereby, we will analyse our test results and try to make a realistic evaluation, considering this ultimate objective. Our solution's assessment is based on qualitative (refer to section 5.2) aspects and quantitative (refer to section 5.3) metrics.

Concerning our server-side implementation (MBC platform), we analyse the *performance* and *scalability*. The performance includes the amount of memory and CPU load used, according to the number of users per business process, and the number of business processes per user.

Moreover, we also analyse the behaviour in the database server, when the MBC platform receives several requests, at the same time. Basically, we monitor the number of open connections between the database server and MBC platform.

In the client-side, we measured the application loading time and content length. Furthermore, we also measured the time to serve the requests to the server and their respective content length. For an analysis of the application's *presentation* and *usability*, we also present screenshots of own prototype.

Before we explain the performed tests, we will decribe the testing environment in next section (refer to section 5.1).

5.1 Testing Environment

In order to really evaluate the performance and the scalability of our server-side components, we need a testing environment composed by hundreds or even thousands of clients that simultaneously make requests to our MBC platform.

The test infrastructure shows how our system can scale in face of multiple and simultaneous requests with variable data loads. Our testing environment is depicted in Figure 5.1.

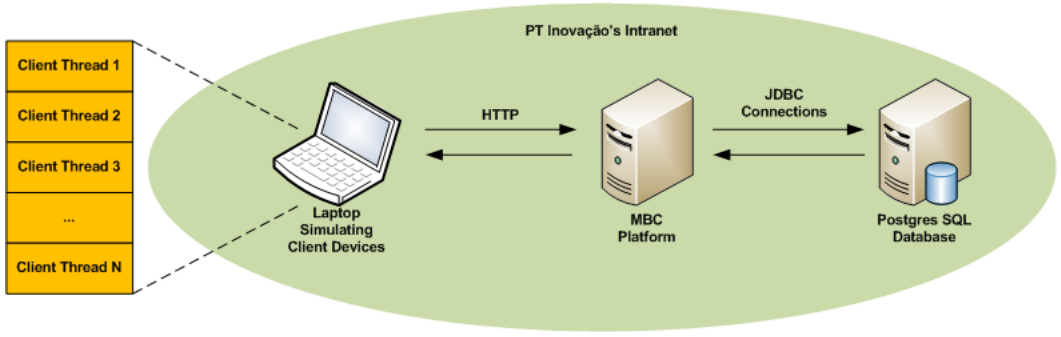


Figure 5.1: Testing Environment

For the purpose of simulating multiple and concurrent mobile client accesses, we developed a Java based application that creates a set of client threads that concurrently execute specific requests, using MBC platform's web services.

Furthermore, we developed another Java based application that monitors the CPU and memory consumption. This application uses the SIGAR API,[1] which provides a portable interface for gathering system information. The developed application saves periodically the gathered values in a file.

Test Machines

Considering the technical specifications of our test machines, we had the following:

Client Machine

- Intel Core i5 - 540M (2.53 GHz , 3 MB L3 cache)[2]
- 4 GB 1333 MHZ DDR3 SDRAM

Server Machine

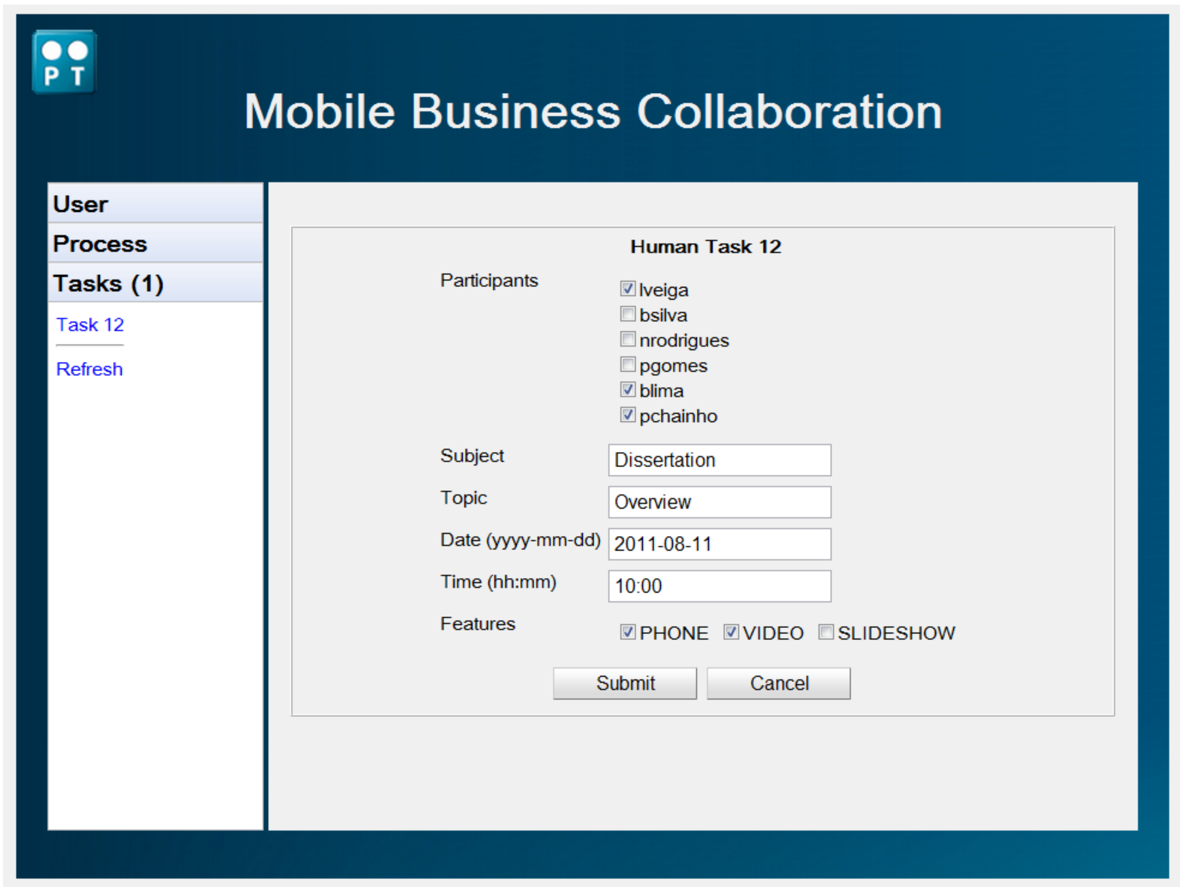
- Intel Core 2 DUO - E6750 (2.66 GHz , 4 MB L2 cache)[3]
- 2 GB 667 MHZ DDR2 SDRAM

[1]SIGAR API - http://support.hyperic.com/display/SIGAR/Home
[2]Intel 540M - http://ark.intel.com/products/43544
[3]Intel E6750 - http://ark.intel.com/products/30784/

5.2 Qualitative Evaluation

For qualitative evaluation, we considered the *presentation* and *usability* aspects, using for this purpose the *PUCNode* once the widgets for the other nodes are similar. Furthermore, as stated before in the architecture chapter (refer to chapter 3), we also considered the solution's *extensibility* and *interoperability* aspects.

Figure 5.2 shows the second stage of the *PUCNode* that is used by the users to fill and select some parameters, which are used to create a new session in the PUC platform.



Human Task 12

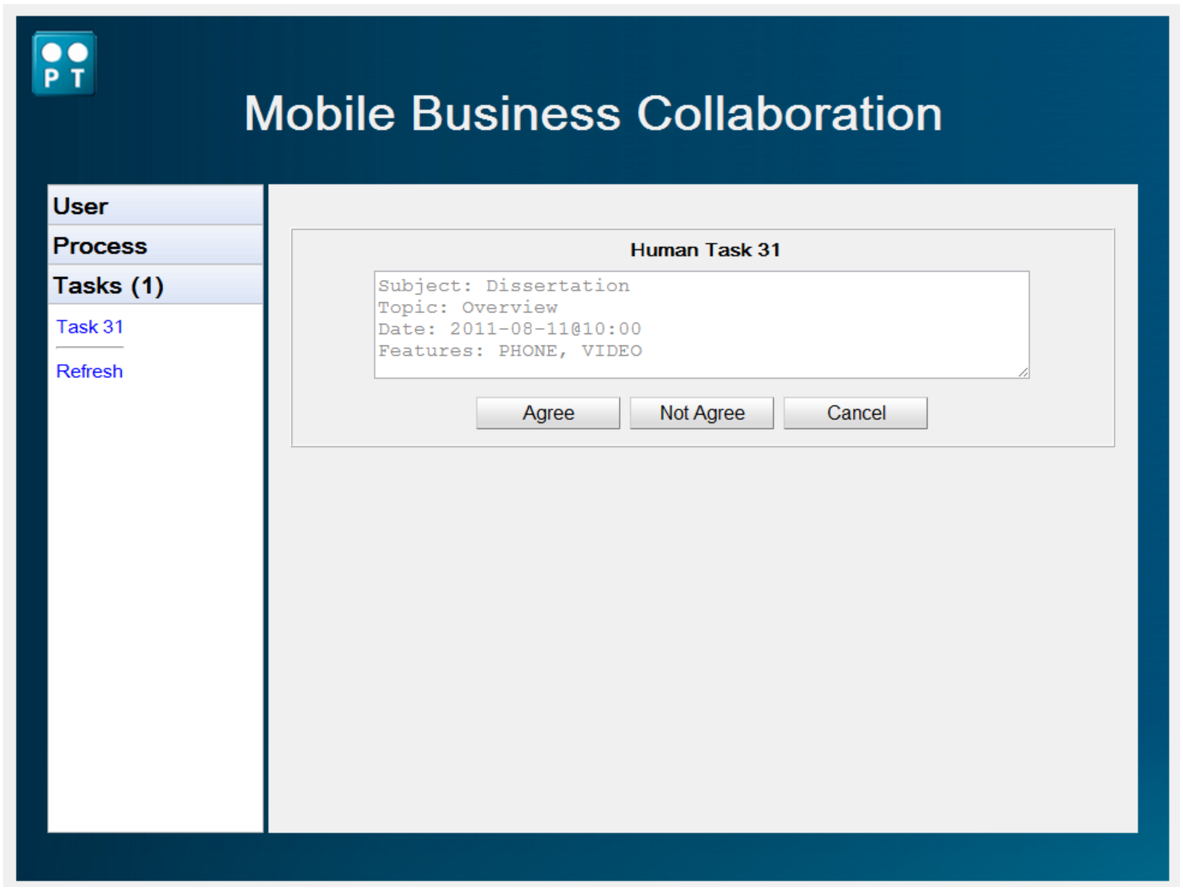
Participants	☑ lveiga ☐ bsilva ☐ nrodrigues ☐ pgomes ☑ blima ☑ pchainho
Subject	Dissertation
Topic	Overview
Date (yyyy-mm-dd)	2011-08-11
Time (hh:mm)	10:00
Features	☑ PHONE ☑ VIDEO ☐ SLIDESHOW

Figure 5.2: *PUCNode* Widget in the 2nd stage

Likewise, the Figure 5.3 shows the third stage of the *PUCNode* that is used by participants to agree or not agree with the scheduling of the session.

In Figure 5.4 is depicted a screenshot of the modeling of a business process using the Oryx editor. This process comprises several work items developed by us.

Here, we can conclude that our client application generally provides a good user experi-



```
Subject: Dissertation
Topic: Overview
Date: 2011-08-11@10:00
Features: PHONE, VIDEO
```

Figure 5.3: *PUCNode* Widget in the 3rd stage

ence. It has a clear presentation, it is easy to use, and it is very functional. Furthermore, our application is a lightweight solution which can be used in some terminals, such as TV, Smartphone, Laptop, and Tablet.

Regarding the *extensibility* and *interoperability* aspects, they are achieved as explained in architecture chapter (refer to chapter 3).

5.3 Quantitative Evaluation

The quantitative evaluation is divided in three parts: MBC platform; Database; Client. However, our *performance* and *scalability* evaluation was mainly focused on the MBC platform. We performed load tests to measure the memory and CPU consumption using the *ApproverNode*.

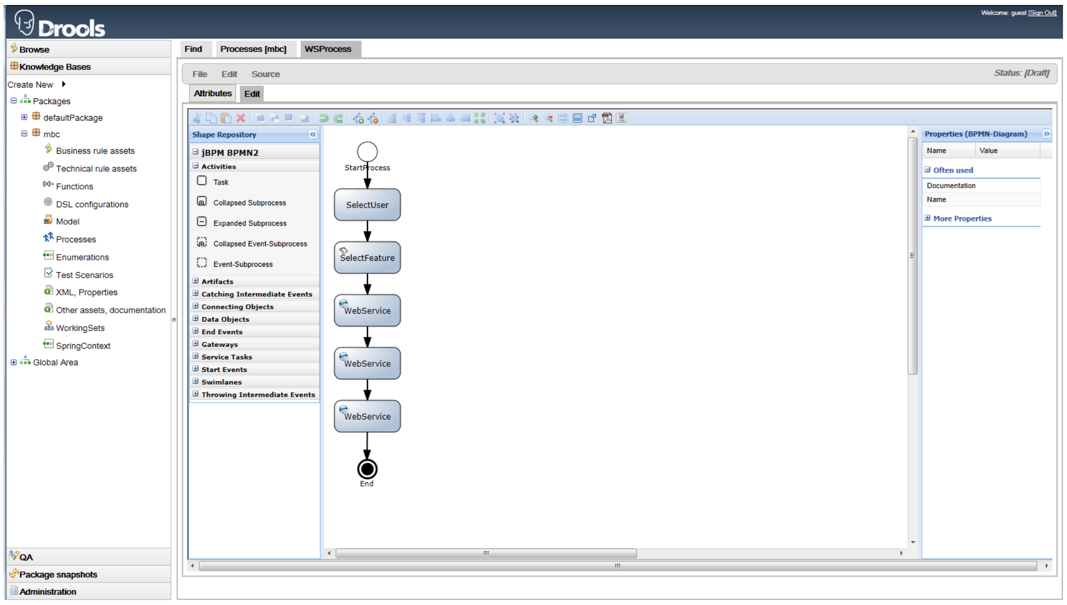


Figure 5.4: Modeling of a business process using the Oryx Editor

MBC Platform

We performed two kinds of tests in order to evaluate the performance and scalability of the MBC platform. The tests are defined by the number of clients in simultaneous execution, and the number of business processes per user as well as the number of users per process.

We used a uniform random distribution (u.r.d.) because it enables a good characterization that spans different user population sizes and amount of business processes. Furthermore, it allows a better simulation of the real world. We used a function to generate random numbers (integers), which generates sequences of numbers with different probabilities. Hence, if we generate a sequence of numbers, defined in a finite interval, the average of the generated numbers may not be the median value of the interval. For instance, in the interval [2; 6] the median value is 4, so the average of the generated sequences should be 4, if the numbers had the same probability and the sequence size was unbounded. Thus, in the analysis of the tests' results, we took this aspect into account.

In the first test, we increase the number of running business processes with a variation of the number of users per business process. The number of users per process varies randomly between 2 and 6 (u.r.d. with average 4). Thus, for 400 business processes, the system may have at maximum 2400, and on average 1600 users connected, since the same user is not associated with more than one business process. The results are depicted in Figure 5.5 and 5.6.

The average CPU utilization grows linearly with the number of running business processes, and it never exceeds 65% (Figure 5.5). The growth is not completely linear because we used a u.r.d., and the total of users has slight random variation in each sample, for reasons stated before. However, these values are substantially the same.

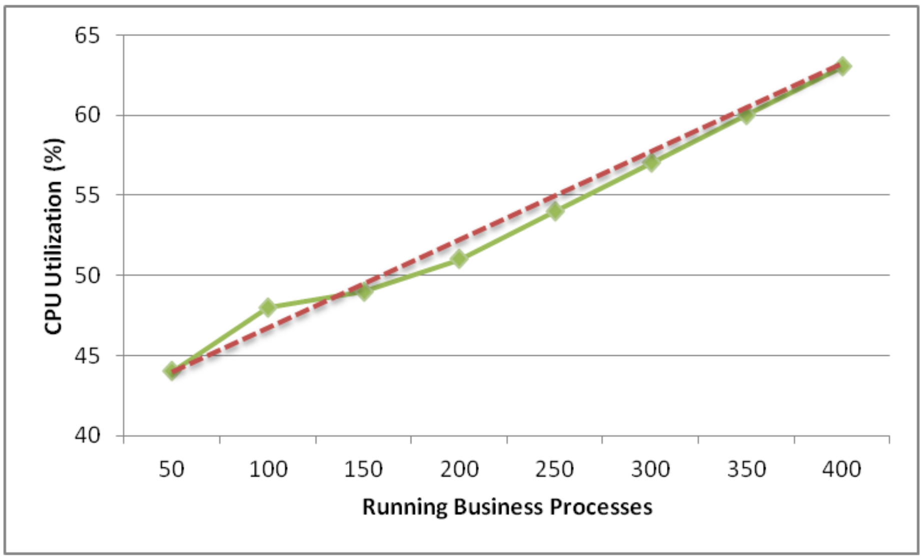


Figure 5.5: CPU utilization growth with the number of running business processes

Likewise, the memory utilization also grows with the number of running business processes (Figure 5.6). Once again, the growth is not completely linear due to the reasons stated above.

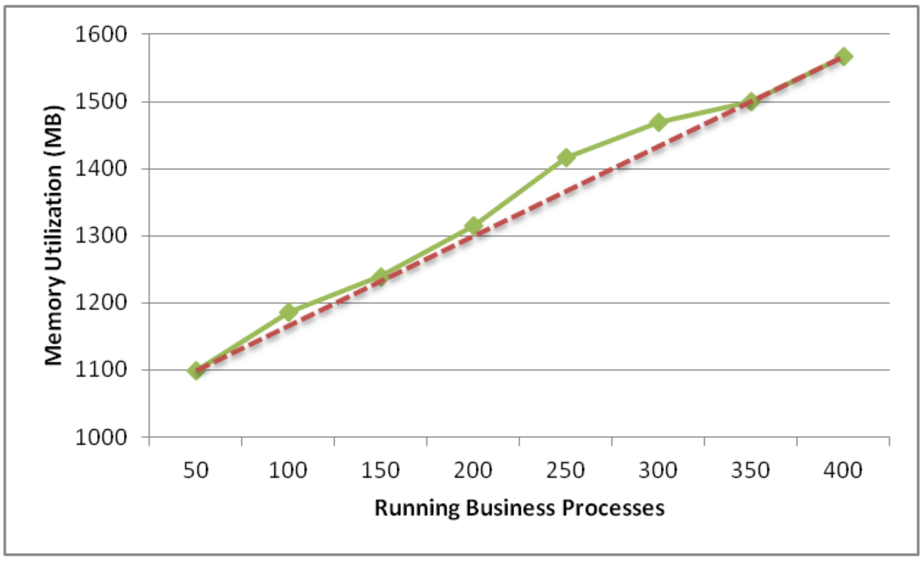


Figure 5.6: Memory utilization growth with the number of running business processes

In the second test, we increase the number of active users with a variation of the number of business processes per user. The number of business processes per user varies randomly between 1 and 3 (u.r.d. with average 2). Thus, for 100 users, the system may have at maximum 300, and on average 200 running business processes since the same business process is only associated with one user. The results are depicted in Figure 5.7 and 5.8.

The measured values of CPU utilization are lower than in the first test because the number of users is much lower. In the second test we have a maximum of 100 users, while in first test the system may have 2400 users (Figure 5.7).

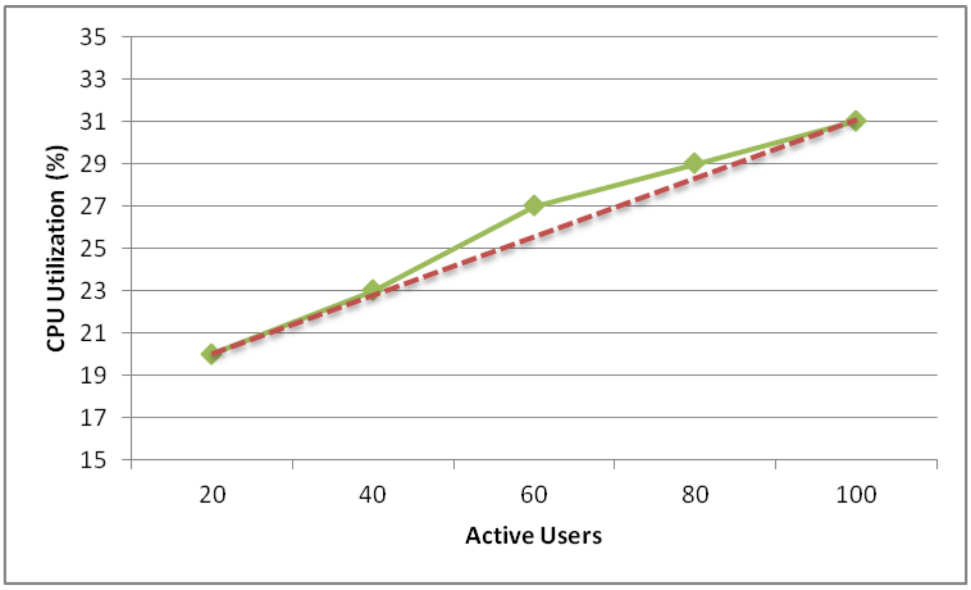


Figure 5.7: CPU utilization growth with the number of active users

Regarding memory, the measured values are very similar because we use an external database, and it allows removing the running instances of business processes from memory and restoring them at some later time (Figure 5.8).

In both tests, we measured values that are acceptable according to the typical features of an enterprise server. For instance, the server that we used (refer to section 5.1) for tests has enough capacity for our application's requirements.

In a scalable system we expect that the CPU and memory utilization grows linearly with the number of running business processes and active users, so we may consider our solution as a scalable system.

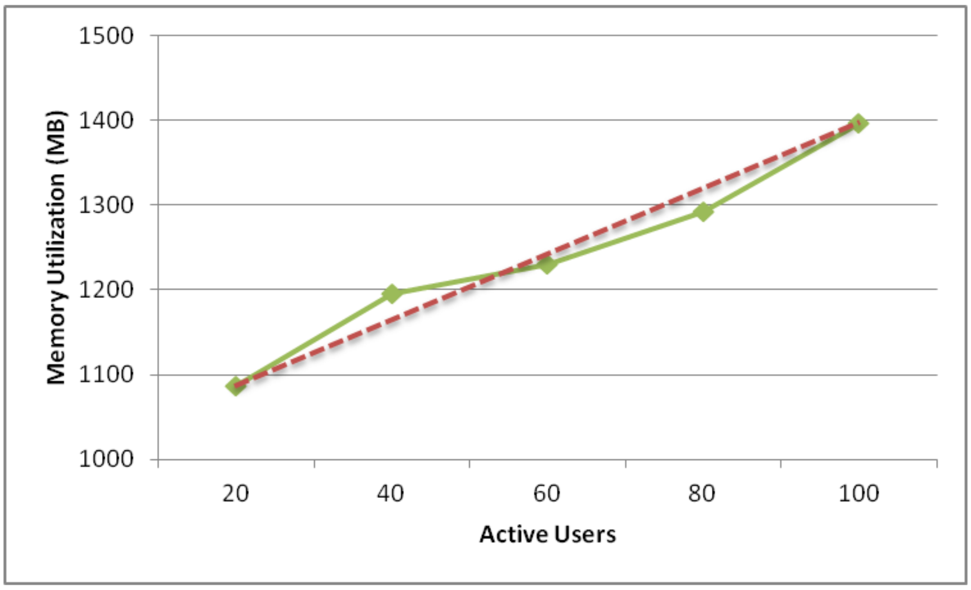


Figure 5.8: Memory utilization growth with the number of active users

Database

In order to analyse the usage of database local connections, we periodically gathered the number of open connections using a SQL command. We used the same two tests described above. The results of these tests are depicted in Figure 5.9 and 5.10.

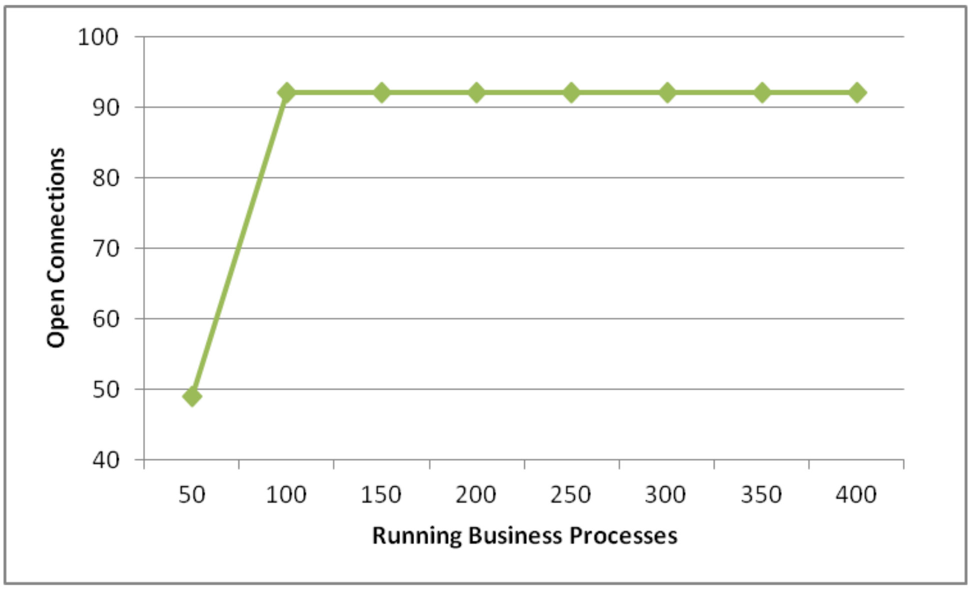


Figure 5.9: Open connections growth with the number of running business processes

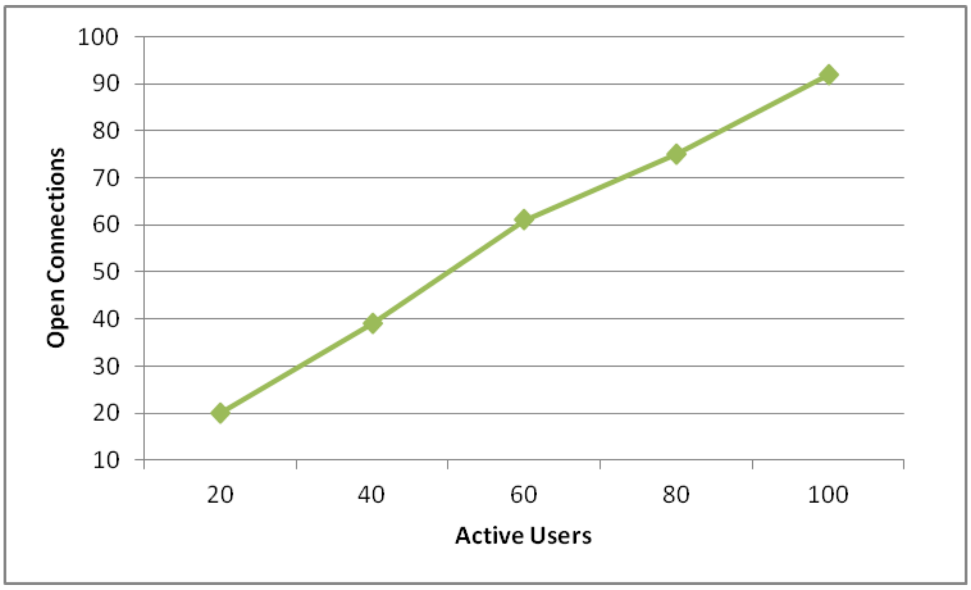


Figure 5.10: Open connections growth with the number of active users

We verified that the system has some limitations regarding open connections because we are using an open source database, which has a threshold of 100 connections. Although this value can be raised, this is not recommended since the management of connections may not be safe.[4]

When the system does not have more available connections in the pool (set of available connections), it waits by one (by default 30 seconds). After this time, if the pool does not have yet one available connection, the request is aborted and one exception is thrown. In the third test (Figure 5.9) in spite of the threshold of open connections having been reached, the waiting time typically was enough so that all requests finished successfully. However, in some situations, this time was not enough and some requests were indeed aborted.

Client

In the client-side, we used the *PUCNode* to measure the application loading time and content length as well as the time to serve the requests to the server and their respective content length. These results are depicted in Table 5.1.

The measured values are different between the first times and following times because in the following times there is static content, like images, which are not downloaded from server,

[4] `http://www.postgresql.org/docs/8.2/static/runtime-config-connection.html`

as they are saved in cache. All of these values are acceptable according to the typical features found today for our target devices (TV, Smartphone, Laptop, Tablet).

The content length varies according to the type of request performed. Furthermore, the widgets have fields with variable length, so the resultant length of JSON strings also varies. The time for sending data increases according to the length of the resultant message (JSON string).

We tested our web application in several browsers, including Microsoft Internet Explorer, Mozilla Firefox, Google Chrome, and Apple Safari (Appendix A.1). Our application works fine in all of these browsers, using a laptop device running Windows 7 operating system. Moreover, we also tested the web application in a smartphone device running Android 2.3 operating system (Appendix A.2). Again, our application operates correctly. However, the usability in the Smartphone device is poorer than Laptop because of the screen size.

Loading time (1st time)	532 ms
Loading content length (1st time)	459 KB
Loading time (next time)	113 ms
Loading content length (next time)	1.26 KB
Time for sign-in service (1st time*)	31ms
Content length for sign-in service (1st time*)	6.33 KB
Time for sign-in service (next time*)	21 ms
Content length for sign-in service (next time*)	327 B
Time for sign-in service (next time**)	39ms
Content length for sign-in service (next time**)	894 B
Time for sending data - 1st stage	414 ms
Content length for sending data - 1st stage	149 B
Time for sending data - 2nd stage	95 ms
Content length for sending data - 2nd stage	149 B

* without pending tasks
** with three pending tasks

Table 5.1: Results of the client-side evaluation

5.4 Summary

In this chapter, we performed an evaluation of our solution based in qualitative aspects (refer to section 5.2) and quantitative (refer to section 5.3) metrics.

For qualitative aspects, we considered the application's *presentation* and *usability* as well as the solution's *extensibility* and *interoperability*. Regarding the quantitative metrics, we considered the solution's *performance* and *scalability*. The quantitative evaluation is divided in three parts: *MBC platform*; *Database*; *Client*.

Concerning our server-side implementation (MBC platform), we measured the amount of memory and CPU load used. Moreover, we also analyse the load in the database server, including the number of open connections. The obtained results show that the MBC platform is stable, and it is scalable according to the measured values of memory and CPU consumption. The measured values are acceptable according to the typical features of an enterprise server.

The database software used has a threshold of 100 open connections. Thereby, we had to setup the tests considering this threshold in order that no request was aborted.

In the client-side, we measured the application loading time and content length. Furthermore, we also measured the time to serve the requests to the server and their respective content length. We can conclude that the client application provides a good user experience, and it is a lightweight application, which can be used in several terminals, such as TV, Smartphone, Laptop, and Tablet.

The solution complies with the *extensibility* and *interoperability* requirements, as stated before in the architecture chapter (refer to chapter 3).

In the final chapter, we will look into our evaluation results and present our final conclusions, which will validate the accomplishment of our objectives and will propose possible future work.

6 Conclusions

We have now reached the end of this document. Thereby, we will present our final conclusions, by first, presenting a review on all the phases of this work and this document's chapters, in Section 6.1. Then, we will look the functionalities provided by our solution, in Section 6.2. We end our conclusion by presenting possible future work in our solution that we have identified during the course of our work, in Section 6.3.

6.1 Review

Our objectives led us in an elaboration of an extensive survey in topics related with web applications, modeling and execution of business processes, and enterprise integration (interoperability between enterprise applications). This allowed us to build a necessary knowledge base for our solution's design phase. It should be clear by now that the accomplishment of work's goals requires special attention to all of the aforementioned issues. The survey of these topics was presented in the state of the art chapter (refer to chapter 2).

However, the survey performed was not enough to accomplish the work's goals. Thereby, we extended the study of technologies in the architecture chapter (refer to chapter 3). This latter study had revealed quintessential for the conception of a system architecture that capitalised in the usage of supporting technologies and transport mechanisms widely used on the web.

The implementation (refer to chapter 4) aimed to maximise extensibility and interoperability of all developed code. Moreover, we aimed the integration of the proposed solution with external entities, such as the PUC platform.

All of the undertaken work definitely paid off, as the evaluation phase, which we presented in the evaluation chapter (refer to chapter 5), revealed very promising results, both quantitatively and qualitatively.

6.2 Functionalities

The developed solution allows modeling business processes collaboratively, using the Oryx editor. The business processes are stored in the central repository. Thereby, it is possible for a partner to get a business process from another partner, and it is also possible to reuse business processes in different scopes.

The activation and update of the business processes can be performed by users, using a web application that is independent of the used terminal (TV, Smartphone, Laptop, Tablet), or by external systems, using the web services technology.

The modeling of the business processes can be made using service nodes performing only the necessary customization, or using default node types. We developed several work items, which allow, for instance, an organization that wants to gather a rate of positive votes to approve a deal or management decision. We also developed a work item that allows to schedule a new session in the PUC platform, and still, we developed a work item that allows to invoke web services deployed elsewhere. All developed work items can save and share data with other work items of the same process.

We use the *Email Notifier* to send notifications to the MBC's users. The purpose of the notifications is alert the users that they have a pending task in the MBC portal (web application).

In the end, we find that the system had a stable behaviour for the used load in the tests, and it is a good solution to use with mobile devices since the measured values are compatible with the capacity and communication costs of these types of devices.

6.3 Future Work

During the course of this work, we have identified a set of functional requirements and desired properties that we would like to see implemented in future, such as:

Security Mechanisms: the current implementation does not yet support message ciphering and user authentication mechanisms. Guaranteeing the confidentiality, integrity and authentication of the exchanged messages is an essential requirement for collaborative applications that require minimal security;

Database's Software: the current implementation uses a database's software that has a threshold of 100 open connections. So, we propose the replace of the database's software in order of the solution allows a greater number of simultaneous transactions;

Additional Features: we would like to add additional features to our application prototype, such as: management of the users role and policies over session; sending notifications using a sms gateway; enriching and extension of the user interface; integration of the solution with a e-commerce platform; integration of the MBC platform with jBPM Console.

We hope that the gained knowledge base, during the course of this work, is sufficient for the future development of the above mentioned requirements and properties, and that our solution, as it is today, becomes useful for future commercial developments in *PT Inovação*'s context.

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A Appendices

A.1 Screenshots of the Web Browsers

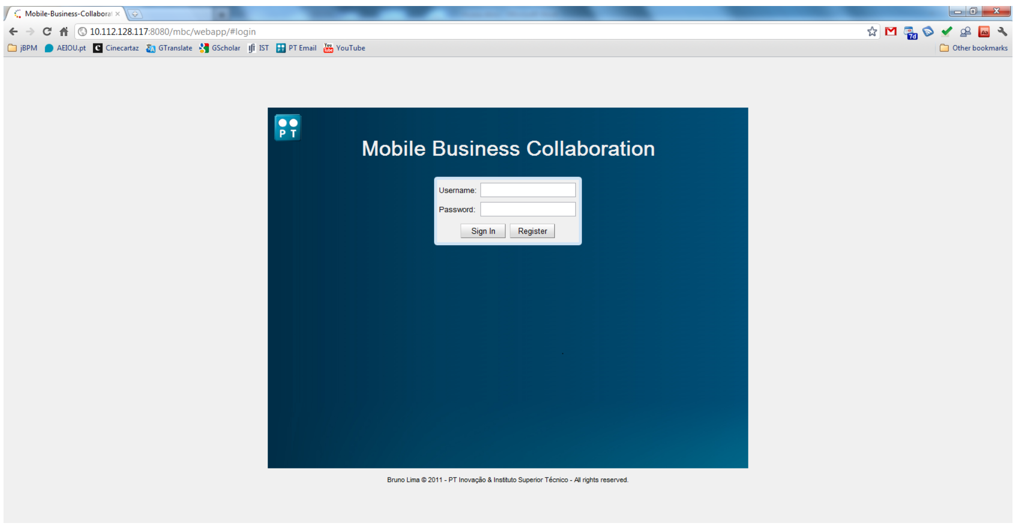
Mobile-Business-Collabora
10.112.128.117:8080/mbc/webapp/#login
Mobile Business Collaboration
Username:
Password:
Sign In
Register
Bruno Lima © 2011 - PT Inovação & Instituto Superior Técnico - All rights reserved.

Figure A.1: Login Widget in the Google Chrome Browser

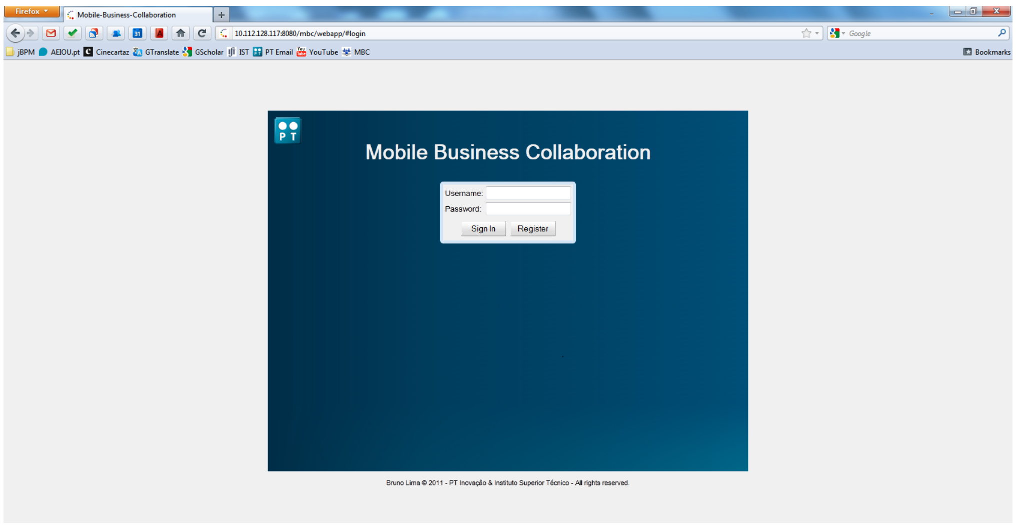
Mobile-Business-Collaboration
10.112.128.117:8080/mbc/webapp/#login
Mobile Business Collaboration
Username:
Password:
Sign In
Register
Bruno Lima © 2011 - PT Inovação & Instituto Superior Técnico - All rights reserved.

Figure A.2: Login Widget in the Mozilla Firefox Browser

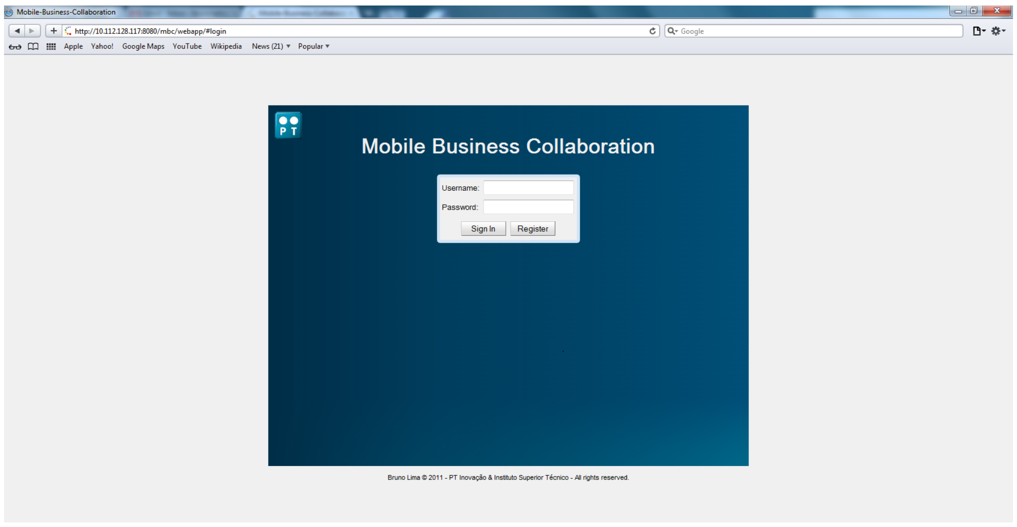
Mobile-Business-Collaboration
http://10.112.128.117:8080/mbc/webapp/#login
Apple Yahoo! Google Maps YouTube Wikipedia News (21) Popular
Mobile Business Collaboration
Username:
Password:
Sign In
Register

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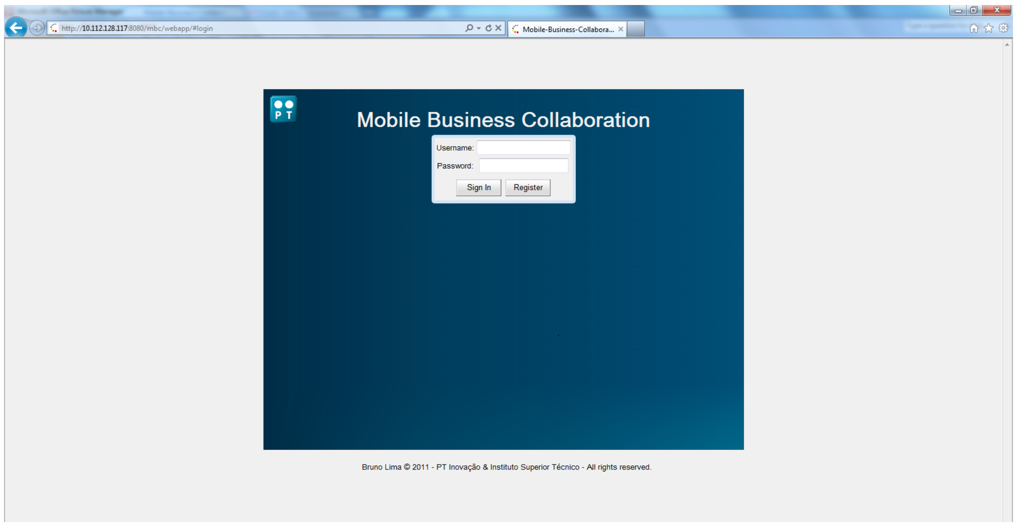
Figure A.3: Login Widget in the Apple Safari Explorer Browser


http://10.112.128.117:8080/mbc/webapp/#login
Mobile-Business-Collabora...
Mobile Business Collaboration
Username:
Password:
Sign In
Register

Bruno Lima © 2011 - PT Inovação & Instituto Superior Técnico - All rights reserved.

Figure A.4: Login Widget in the Microsoft Internet Explorer Browser

A.2 Screenshots of a Smartphone Device

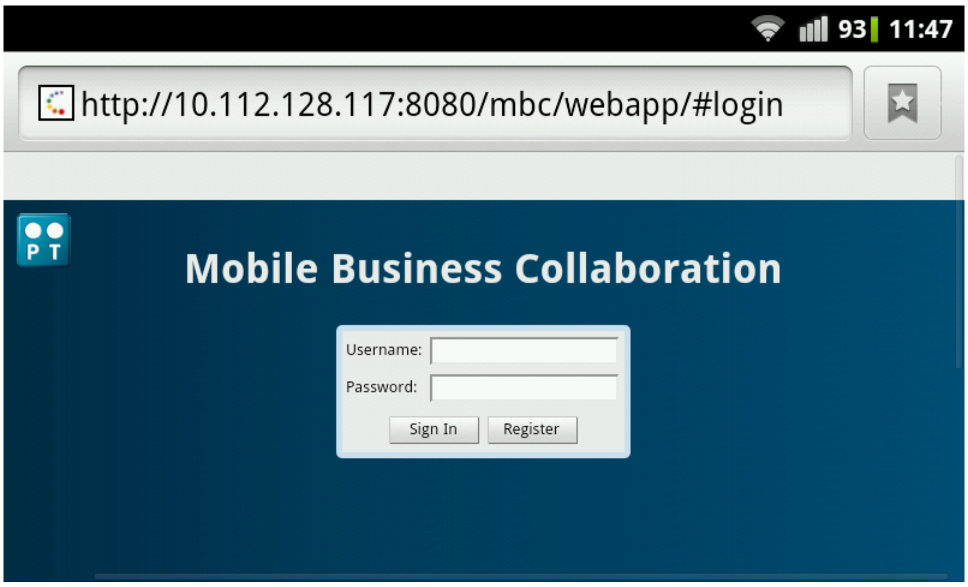
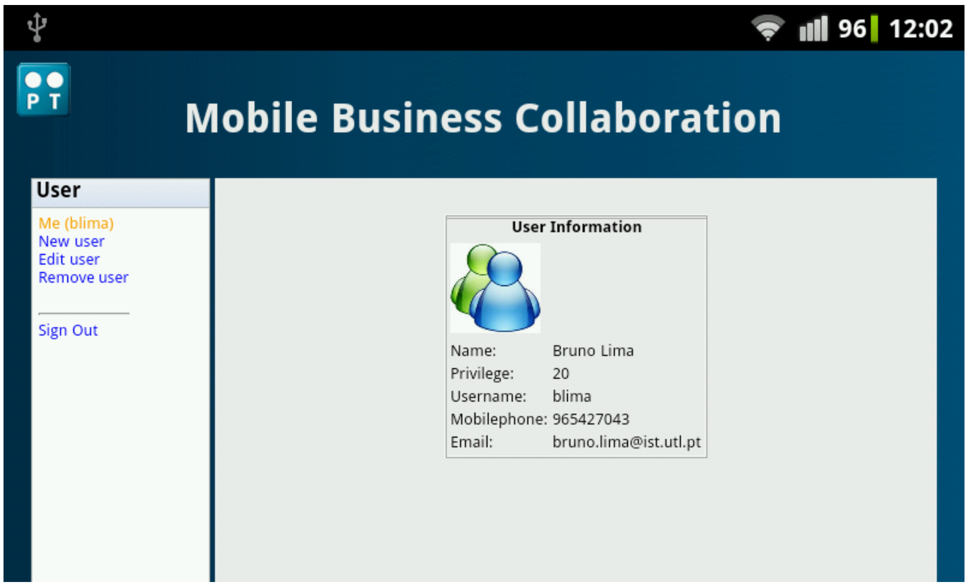
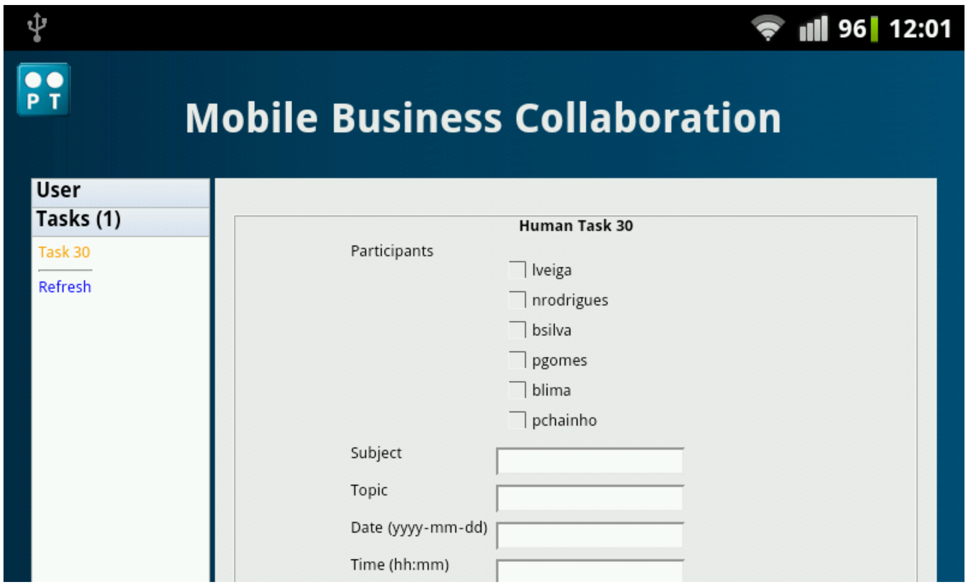

93 11:47
http://10.112.128.117:8080/mbc/webapp/#login
P T
Mobile Business Collaboration
Username:
Password:
Sign In
Register

Figure A.5: Login Widget in a Smartphone Device



Name: Bruno Lima
Privilege: 20
Username: blima
Mobilephone: 965427043
Email: bruno.lima@ist.utl.pt

Figure A.6: User Widget in a Smartphone Device


96 12:01

Mobile Business Collaboration

User

Tasks (1)

Task 30

Refresh

Human Task 30

Participants	lveiga
	nrodrigues
	bsilva
	pgomes
	blima
	pchainho
Subject	
Topic	
Date (yyyy-mm-dd)	
Time (hh:mm)	

Figure A.7: *PUCNode* Widget in a Smartphone Device