Peer-to-Peer Web Services for Distributed Rural ICTs

Ronald R. R. Wertlen, Alfredo Terzoli

Abstract—In this paper we look at the context and design of a distributed web services platform called P2PMW. P2PMW uses P2P principles to automatically build a robust network with flexible routing and practically no administrative overhead in order to share resources between nodes. P2PMW uses open source and widely adopted standards.

Our argument is that the context of rural ICTs is being shaped by high speed wireless networks with limited span that we call "islands" and that the architecture we introduce is a good fit for the context. We further argue that by employing widely adopted open standards and open source software, we can speed the development of effective custom made applications for marginalised rural areas.

P2PMW is built in Java using the Spring framework and JXTA.

***Index Terms*—ICT4D, Marginalised Rural Areas, Middleware, Peer-to-peer.**

I. Introduction

In this paper we present a software application and framework called P2PMW which allows faster development of better integrated applications to be developed for a specific rural African context. The software is expected to assist application developers, who are creating applications specifically for this context, and we also expect it to help the users, who may benefit from integration aspects such as single sign on. P2PMW is being developed at the University of Fort Hare within the Siyakhula Living Lab (SLL)[5], which is a test-bed laboratory based within several adjacent marginalised rural communities in the Mbashe Municipality of the Eastern Cape using a user-centric development paradigm called the Living Lab Methodology [18].

ICTs are a very important factor for development of any impoverished and marginalised society [32]. They are however not a panacea for development problems and need to be introduced in a manner which is adapted to the specific context[14]. The rural African context poses a particular problem for development agencies wishing to introduce ICTs since the low density and wide dispersion of populations generally mean that there is no infrastructure already present there. ICTs cannot cost-effectively be delivered in these areas [3].

Within the SLL, we have observed a phenomenon, which has been anticipated or described by other researchers ([23], [1], [12], [4]): Inexpensive long-distance wireless technologies create rural connectivity islands - high speed wireless networks whose nodes span areas in the order of 10 - 30km in diameter [29]. These islands offer a new form of connectivity: within the island, high-speed links allow advanced forms of bandwidth intensive networked application, such as video-conferencing, while connectivity to the Internet is restricted by the continued high costs. Such islands may be very useful in allowing access to ICTs for rural areas. Within the SLL, researchers are steadily implementing and testing a number of services and applications and especially adapting them to the local context [6]. The applications tested make use of the connectivity within the island, as well as the Internet. [1]

P2PMW was developed within the context described above. Its main aim is to unite efforts of several developers using rapid application development philosophies and having a limited time allotment, to achieve applications that meet the needs of the SLL and are reusable and extendible. A service oriented architecture using web services technologies should fit for the following reasons:

- As yet undreamt of applications would have to be integrated into the system,
- Applications need to access information and resources, which can be encapsulated fittingly using the notion of services,
- And the services can be shared across the high-speed network in an island.

Further owing to the networked nature of the problem and the ownership boundaries of access nodes, a P2P overlay over the island seemed to be good fit [21]. A peer-to-peer model poses an elegant solution to several problems we experienced in setting up the SLL eServices platform.

Section II looks at prior art concerning relevant ICT4D and P2P technologies.

Section III looks at the functional specification of the problem that our solution addresses.

Section IV looks at how we have chosen to implement the solution.

In section V, finally, we outline the direction that this implementation could take in the future and parallel applications of the solution in other problem areas.

II. Previous Work

A. ICT4D

Lessons out of the ICT4D arena for our software came from the following research areas:

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[1] This means solutions are ready for the future as the price of Internet access keeps dropping (e.g. break-even cost of mobile roll-out in rural areas is now below $10 per person per year [17]).

- Telecentres
- Siyakhula Living Lab
- Network technologies for use in developing rural areas

1) Telecentres: Since Telecentres have been rolled out extensively in the past 15 years and also studied in depth, we expected some relevant lessons and background information in this area. Telecentre.org, a network of telecentre activists, operating predominantly in the Americas and South Asia, stress that a network of like-minded people following the same aim have a greater chance of success than if they are operating individually[28], [16]. Allowing local telecentres to network automatically and share resources must thus be a definite improvement.

[10] found in the case of one rural village intervention, that repeatability of service was crucial to sustainability. Customers did not want to come back to the telecentre as their results varied tremendously, arousing skepticism. An integrated platform such as the one being developed at the SLL addresses this problem and introduces integrated solutions and some workflow. Further the following broad categorisation of service types is defined (in order of increasing revenue possibility): Telecentre, DTP, Training and SMME Support.

The UN ICT Task Force reviewed "information kiosks" as far as sustainability is concerned. Their in depth review brings out several major factors sustainability. In addition to networking and sharing resources (as above), they mention the selection of the right person ("social innovator") to drive the telecentre. This is something we cannot as developers influence, although we do have the ability to help this person by making the technology as easy to use as possible. Further, Stoll mentions (pp. 65) that financial sustainability is only achievable if as broad a mixture of services as possible is offered by the telecentre [33]. This also supports our perspective that it must be possible to integrate as yet unknown services into the platform.

The Fostering Digital Inclusion (ADEN) Project of the French Ministry is an international cooperation project, whose website moved to Angola in 2008 and was unavailable at time of writing. The ADEN Pack is a Mandriva Linux based complete solution for telecentre managers. The software is not specifically made for the network islands we presume in our case. Support forums for the telecentre manager are mainly in French.

2) Siyakhula Living Lab (SLL): The SLL is a member of the European Network of Living Labs. The original objective of the precursor rural test-beds project was to develop and field-test the prototype of a simple, cost-effective and robust, integrated e-business/ telecommunication platform for deployment in marginalised communities in South Africa. The test-bed project evolved to include generic communication (Internet, GSM, etc.) based services [29]. The test-bed was distributed in nature from the very beginning. Amalgamation of the original project with the SELF Solar Computer Lab network ([34], [8]) resulted in a network of public access nodes at 8 rural schools, which will ultimately form a single island covering 30km.

Technologies deployed at the SLL, or soon to be deployed include the following:

- An eCommerce application which allows local traders to exhibit and sell their crafts on-line[20];
- An equitable community-based cost management scheme, implemented initially for Internet access, but which is extensible to include other service costs[27];
- An eGovernment platform, which mirrors commonly required home affairs documents, provides a communication transport with home affairs and provides fora for local government initiatives[11];
- BingBee, an unattended kiosk approach, which merges simple and novel hardware HCI elements, with a selection of customised content aimed at promoting logic, literacy and numeracy skills in young children[25].
- GSM and radio channels to deliver information to the community from external and internal sources.
- Agent based service provisioning, which makes available an ontology built from local knowledge to route requests for eServices within the platform [30].

in an effort to provide replicable service to villagers across nodes, a suitable middleware platform could be tremendously beneficial.

3) Wireless and Innovative ICT4D: [2] presents an overview of 17 projects financed by the World Bank in the area of ICT4D. Batchelor raises two relevant points over and above those mentioned in section II-A1: firstly, projects carried out in a rural area often have a greater impact than those carried out in peri-urban areas, and existing technologies (radio, TV and mobile phone) can be used to enhance the impact of ICT4D interventions. The former point illustrates the importance of the current initiative, the latter once again underlines that a wide variety of services must be integrated with the platform to achieve sustainability and maximum benefit for the communities.

Technology and Infrastructure for Emerging Regions (TIER) is a project at the University of California Berkeley which has been investigating innovative technology application in developing areas, including rural developing areas. The TIER WiLDNet (WiFi-based Long Distance (WiLD) networks) sub-project has tested and implemented long-distance wireless networks based on 802.11 technology. They note that current 802.11 standards do not provide good connectivity in WiLDs owing to interference from existing networks, TCP/IP collisions caused by the greater delay and inefficient link-layer recovery. Atmospheric phenomena can also influence the quality of connectivity [23]. Lessons from the WiLDNet research are that the idea of high-connectivity islands in MRAs is feasible and that even with high connectivity wireless networks, bandwidth should never be wasted, as deterioration can occur owing to a number of reasons.

B. P2P

We understand P2P as an application layer technology which constructs mutable overlay networks that have some kind of social significance[2]. It can be used to link nodes of the

[2]Definitions of P2P range from the purely technical architectural perspective (P2P as the opposite of client-server architectures), to an understanding of P2P as socially participative paradigms that are absolved of any particular technological constraints [P2PFoundation.org].

SLL into a cooperating network with certain characteristics, so that message transport within the network occurs in a transparent manner for applications. Defining characteristics of complex networks, in general, are: network resilience, the small-world effect, community structure, network navigation, etc. (for a full list consult [19]). P2P networks are characterised by high resilience (the removal of nodes from the network does not compromise the network), presence of the small world effect (there is a short route between any two nodes) and network navigation (there is a common routing algorithm). Often a community structure (clustering of nodes according to social parameters) evolves with time and usage [21]. All of these characteristics are highly beneficial to the SLL. Network resilience, obvious. Small-world effect implies scalability - ultimately massive network islands in rural areas can be postulated.

P2P does not presume trusted nodes, nor does it presume a central administrator for the network (as opposed to Grid technologies) [9]. While this does bode dangers, suitable HCI should take care of these (a matter which needs to be tested).

Business cases suggest that where entrepreneurs or divisions within a company wish to keep confidential data to themselves and to maintain control of their systems P2P is a good fit from a technological stand-point and is being used as such in several large global companies[24].

III. API and Framework Requirements

A. Origin

The idea for P2PMW was gained by the author when assisting other Masters candidates with their applications. The lowest common denominator for the applications was the use of Free/Libre Open Source Software (FLOSS) on an Ubuntu platform. This meant that a wide variety of technologies and development methods could be and were used to develop the applications. So although in practice, the candidates generally settled on PHP as a programming language, there was no unity among the PHP frameworks used. One even constructed his own framework. Some candidates had also considered Java (owing to courses they had visited previously). Of 5 applications reviewed by the author, each was written in PHP using a different framework. Several applications re-invented the wheel, solving problems their colleagues had already solved using different methods. E.g. signing into the platform: there was no uniform method for this task, and since it was so elementary, each candidate was forced to solve it. Clearly a middleware framework for the SLL would improve the situation, as candidates could get to grips with the real problems that they were trying to solve. Further, often there were further synergies that could be shared between applications, e.g.

- 3 of the 5 had separate interfaces for users and administrators and the framework which could be grouped to assist users in reaching functionality quickly
- several gathered data useful to other modules, for instance, the billing application and the eCommerce application, or a common messaging application.

B. Developers' Perspective

Since the aim of the P2PMW framework is to help developers develop distributed applications, it must adhere to three basic tenets: simplicity, extensibility and scalability.

- Developers should be able to develop against a a stable public API which is based on accepted industry standards. Standards based APIs tend to come with a host of supporting libraries in many different programming languages, which make implementation of API calls a simple thing. The API should also include interfaces to which the applications themselves have to comply, so that applications can communicate amongst each other. This API should be language neutral and well documented (via samples) so that developers can easily create compliant applications that plug-in to the platform.
- The platform itself should be extensible. Basic network services brokered by the framework, such as single-sign-on (SSO) must also conform to a well-documented interface specification. This allows developers to extend the framework with new services which may be required by new applications and technologies.
- Further, developers should not have to be concerned with the number of applications appearing on the network, or the size and volatility of the network. The services that they call should be structured in such a way as to fail in a manner that protects the functioning of the entire network. Applications that are buggy must be anticipated, and it should not be possible, e.g., that a buggy application perform the equivalent of a Denial-of-Service (DOS) attack on the system.

There are several language neutral technologies available for remote procedure calls (RPC). We considered 3: CORBA, SOAP and REST Web Services. We did not consider XML-RPC as it has been superseded by SOAP. We decided to use Web Services (SOAP), because there is a wide variety of language bindings for the technology, it is stable and standardised already for several years, used extensively in industry and because our communication will presumably need to dodge firewalls [22].

C. Contextual Perspective

The framework specification must fit the context of the SLL. The services listed in section II-A2 must easily be accommodated within the framework. The platform must run on Linux and use free open source software in order to comply with the SLL licensing strategy. This also means that villagers using the software do not need to pay license fees and new nodes joining the network do not incur any software costs.

The system should not require administration of technical and networking issues. New nodes should automatically join the network and administrators should only have to allow or disallow sharing of resources.

eServices should be integrated in such a way that administrators can perform their tasks (allowing and disallowing resource sharing) from the same user interface and they should not have to learn a number of different techniques to run related services on the same platform. Further, application developers should be encouraged to add their application administration front-ends to the same user interface, by exposing this functionality as a service within the application.

IV. Implementation Details

A. Architecture Overview

P2PMW has a service oriented P2P architecture. We found that the loosely coupled design of SOA best suits the heterogeneous programming environment. Additionally, the P2P aspect, allows us to link services that occur at different nodes. Nodes can thus be understood as defining boundaries of ownership of services and the resources underlying them. This is a natural extension of SOA for an environment, where services may not be available all the time and resource sharing can bring great benefit (owing to scarcity) if it is done in a controlled manner so that the owner of the resource can be compensated in some way.

The benefit for programmers, is that new nodes can be added transparently to the applications on the network which can simply start using the services as soon as they require them.

It thus has the attributes of a regular service oriented architecture (SOA) with additional P2P communication facilities. The P2PMW architecture may also be seen as a P2P communication bus, which is accessed by programs which wish to either provide or consume services. The functionality provided by P2PMW is thus dependent on the services (service providers) and applications (service consumers) that are available on the network. The communication bus is itself a P2P overlay network on top of a physical network.

Initially the network has no specific topology and ultimately a fully connected network arises, as peers exchange the contents of their node caches upon joining the network and cache peers they discover through any queries. Temporarily, however, new nodes may only see a portion of the network (as depicted in figure 1).

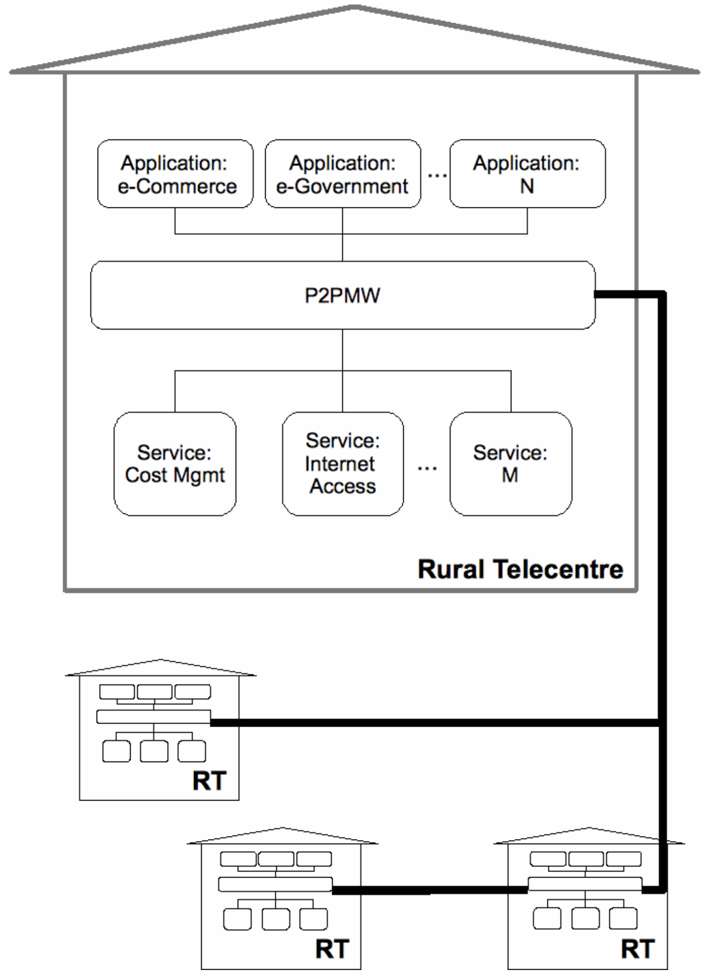

Figure 1. Example network and node architecture of P2PMW, showing 4 rural telecentres (nodes) within a single network. The network is not fully connected, the bottom right node forwards messages transparently via the P2P layer to its neighbour on the left. Within a node, one sees that P2PMW is the communications medium for applications, services and other middleware installations. Examples of potential applications and services are networked transparently across telecentres by the middleware.

B. Implementation

P2PMW is implemented in Java and Java Server Pages. It uses the Spring framework, which is a widely used framework that introduces light weight inversion of control, and allows developers to concentrate on creating business logic using plain old Java objects [13], [26]. The technology was chosen, because Java EE (Java Enterprise Edition) technology is widely used, stable technology designed for deployment of server software such as platforms, which run on application servers (in our case Apache Tomcat). Interaction with the platform is performed via Web Services. An XML Schema document describes the possible interactions with the platform. These are then published in WSDL (Web Services Description Language) by the Spring Web Services framework, and may be used by any client software to access the platform functionality. For instance, PHP client code documents how this can be done for PHP applications. Spring Web Services were chosen over Apache Axis, because of their tight integration with the Spring Framework and their lightweight nature.

Platform to platform connectivity and resource brokering is performed with the established JXTA protocols and Java implementation. This decision was spurred by several factors: UDDI resource brokering introduces a central aspect which like DNS requires administration and which introduces a single point of failure in a context with high peer churn (network volatility); JXTA 2.5 provides a simple API and simple methods to create a P2P network; JXTA 2.5 is the distribution layer for Sun's Glassfish application server and is thus more robust and efficient than previous versions[7]. JXTA by default creates a dynamic super-peer network, which is formed according to performance of nodes. It can be reconfigured to allow other topologies. JXTA nodes discover the network using the following methods: broadcast (which may work well on simply configured islands), seeding nodes available on other subnets, public nodes in the Internet (not relevant to us) and an address cache (for nodes that have already been connected to the network) [31].

Figure 2 below shows the relation to each other of the technologies explained above.

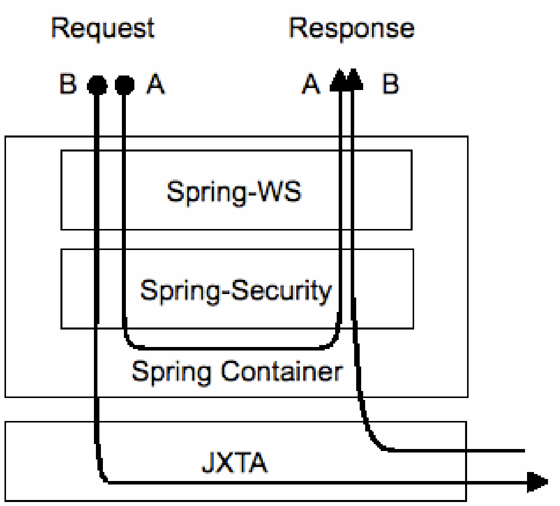

Figure 2. Web services stack implemented in P2PMW for the use case of authenticating to the platform. The figure shows how two requests are treated by the stack and result in responses: Request A is handled locally, while Request B is answered remotely.

C. Use Cases

The use cases described in this section illustrate the core functionality of P2PMW and what it actually does to meet the requirements set out in section III. Each use case ultimately translates to a SOAP method, which may be invoked on the P2PMW platform.

- System Registers a New Service: Is a local or a remote service being registered?
  - If it is local, create an advertisement for it (including the WSDL definition) and, if it is shared, circulate the advertisement to known peers. Register the service with the security subsystem for immediate use. The administrator can change the sharing status of the service from shred to not shared, or vice versa.
  - If it is remote, register the service with the security subsystem as a blocked service. The administrator has to unblock the service, after which it may be used.
  - In both cases: note whether the service requires user certification (underlies cost management) or whether it is public.
- A User Accesses a Service: First the users session certificate is checked. Search cache of service advertisements, if the service cannot be found propagate search to peers. Return a Web Services address that can be called to access the service functionality. In each case, the user can call the service name returned and get the WSDL definition of the web service, in order to dynamically use or explore new services.
- Service Dependency is Unfulfilled: an application or a service dependent on a further service, must be able to handle the possibility the further service is unavailable - e.g. the email application depends on the Internet service, which is unavailable; perhaps the user can compose emails in an offline mode.

Example services that can be offered as built-in modules single-sign-on functionality, disk storage (P2P disk storage such as Oceanstore) and a logging module, which could provide the basis for the cost management service.

V. Future Work

A. Empirical

The platform has not yet been deployed in the SLL. Once the platform offers useful functionality it should be installed within the SLL. We expect that a field trial will yield important information and insights into the feasibility of a distributed rural telecentre approach. An interesting question, e.g., is whether the design of the system can compensate for the lack of a central administration as far as security is concerned.

Further more empirical work needs to be done on the categorisation and identification of various islands of connectivity in marginalised rural areas. Perhaps and analysis of individual case studies could show how one can best utilise the phenomenon.

B. Development

The following interesting design and architecture issues should be addressed for future versions of P2PMW.

Investigate Glassfish as the application server. Since JXTA is already integrated as the distribution component of Glassfish, and since Glassfish integrates with Spring, these open source free technologies might make P2PMW more efficient and homogenise the communication stack and architecture in general.

Define a class of SOA applications which use P2P principles to distribute functionality: Base use cases for this class of applications should be defined. Others are already investigating the use of web services in distributed networking environments like Grids[15]. Grids and P2P domains of research overlap and thus we could pursue this matter and make comparisons. This approach can also be contrasted with the agent based provisioning approach being developed within our group and mentioned in section II-A2.

Other application areas: Distributed, resource sharing in a community setting is an application that does not only apply to rural telecentres. As a generic application we expect to find other areas in which the software can assist collaborative behaviour, including in very large networks.

VI. Conclusion

The software described in this paper tries to make development of distributed applications for rural development easier. The software walks a fine line between prescription of interfaces and processes, and usefulness to developers of future applications, who require a measure of freedom. By employing a Service Oriented P2P Architecture a good balance can be struck between organisation and flexibility, while providing the overall distributed system robustness required by the context.

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