Supporting Problem Resolution on Construction Sites with Converged Multimedia, Wireless & Mobile Technologies

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ABSTRACT

Construction work is a collaborative effort, with site problems requiring varying levels of attention on an ongoing basis despite the time and effort spent during the planning phase to ensure a smooth build. The project manager or other appropriate personnel such as site engineers would normally attempt to resolve the problem in consultation with the extended project team, whether on the same site or located elsewhere. This process is hindered by difficulties in clearly communicating problems and the tendency to close information links when faced with critical situations.

Research was carried out looking at the role of converged networks to support information flow, in particular the role of voice and multimedia information from the construction site. A survey with nine of the largest international construction companies within the UK was conducted to determine the main problems hindering communication and collaboration within the industry. Voice and verbal instructions/descriptions were considered the most critical when it came to decision-making, with telephones/mobiles being the most common tools used to discuss the problems and agree on a resolution. Difficulties expressed with this method included the ability to clearly express the problem, and the subsequent logging of the agreement and proposed resolution.

This paper presents a prototype solution whereby the PDA is the main communications tool, with software written to allow the exchange, logging, and further dissemination to appropriate parties of voice and/or multimedia information via an onsite wireless network, and VoIP accompanied by various other exchange protocols. Preliminary tests are discussed along with a discussion of the variables involved when deploying such ICT support systems onto the construction site, along with the process required to track any communication involved in a

decision to ensure accountability, and a clearer understanding of the various problems by the different parties onsite.

Keywords: Collaboration, PDA, Wireless Networks, Convergence

INTRODUCTION

There has been a general recognition that the construction industry is slow in adopting change in many areas preventing advancement compared with other industries such as manufacturing. Industry experts (Latham, 1994, Egan 1998, 2002) have consistently highlighted issues such as industry fragmentation, culture and lack of innovation as key factors preventing substantial progress. Amongst the drivers influencing the construction industry within the next 20 years, the knowledge economy and technologies for tomorrow are of key significance (Flanagan, 2004). Research has exposed that despite the extensive planning taking place on any construction project, it is often the case that when work begins on the construction site, all kinds of problems arise which call for immediate attention (Dainty et al., 2006) and where access to up-to-date information is essential. Resolving these frequent problems often requires a lot of communication and collaboration with the project team, be they on or off site resulting in tools to support this collaboration being of upmost importance.

A study of delays in construction projects found causes linked to all parties involved in the project, with the main causes including the inadequacy of sub-contractors, a lack of sufficient resources, incomplete and unclear drawings and deficiencies between consultants and contractors (Noulmanee et al., 1999). The study suggested that delay could be minimized by greater discussion and communication between project members to form greater understanding (ibid). Loosemore (1998) suggests that often the 'crisis situations' which form on the construction site due to unforeseen problems lead to a breakdown of clear and open communication. Project managers must therefore ensure amongst other things that information hoarding (members keeping valuable information between themselves) is minimised, and supporting communication to ensure no bottlenecks (Loosemore, 1998).

Examining ICT within construction Harris and McCaffer (2006) categorise the progression into three stages. The first going up to the late 1970's sees the use of IT to achieve efficiency and cost savings in the processing of information. The second goes from the late 1970's to the late 1980's where the emphasis was to align technology to support the functions of a construction company producing many stand-alone systems from project planning to financial reporting. The last phase which is still evolving is the addressing of the integration of the stand-alone applications and the use of ICT as a communications medium (Harris and McCaffer, 2006).

The emergence of mobile and wireless technologies led to research projects examining applications on the construction site. A variety of applications have emerged with mobile computing, from site diaries and logging of maintenance conditions (Scott and Assadi, 1997, Rojas and Songer, 1997) to the collection of data for defect management (Kim et al., 2008) and site inspections (Kimoto et al., 2005). All the while, the focus has been very much on the collection of data on electronic forms to replace pen and paper, with little focus on examining the use of mobile computing to support general communications such as voice communication with IP telephony (Beyh and Kagioglu, 2004) and further advanced uses. The application of sharing information to improve collaboration is explored in this research.

Communication during Construction Collaboration

A typical project involves a wide range of professionals coming together for a relatively short period of time. Often these participants are geographically dispersed, with communication and coordination problems affecting project performance and productivity resulting in the acute need for effective information and communication technologies (Li et al., 2000, Anumba et al., 2002). Communication has been defined as the transmission of resources (e.g. information and other meanings including ideas, knowledge, specific skills and technology) from one party to another through the use of shared symbols (Cheng et al., 2001). When it comes to partnering and working with the project team, effective communication has been ranked a priority because partnering requires timely communication of information and the maintenance of open and direct lines of communication among all project team members (Larson, 1995). Problems occurring on site require immediate resolution once they occur (Moore et al., 1992) with effective communication requiring the formation of effective channels to motivate participation and cooperation between the team to produce compatible expectations (Mohr and Spekman, 1994). The UK construction industry has defects which cost at least £20 billion to repair or rebuild (BRE, 2005). Poor communication on construction sites is the cause of some of these defects, with poorly detailed drawings, operatives being given incorrect instruction or technical information not being available. Access to project resources such as team members and project data is increasingly important to cut these losses (Ahsan et al., 2008).

The different communication media available include face-to-face meetings, email, telephone, fax, letter, video conferencing and computer collaboration (Cheng et al., 2001, Morrison and Liu Sheng, 1992), the selection of which depend on four major criteria (Cheng et al., 2001):

1. Amount of information required – different communication channels can convey different amounts of information.
2. Instant information required – telephone and fax are described as the most instant, with email, meeting, teleconferencing, letter and visit becoming less instant respectively.
3. Effective communication required – the accuracy of information transmitted. Two-way communication is the most effective as there are more chances to clarify meanings.
4. Efficient communication required – speed of transmission of messages.

Of the tools used for communication, the telephone, fax, and email consistently come out as the most used (Howard and Peterson, 2001, Forcada et al., 2007, Ahsan et al., 2008). One particular case study showed that non-IT based media was used almost 1.8 times more than IT-based communication media (Howard and Peterson, 2001). Communication amongst project members is crucial to ensure successful project completion and as collaboration partners need to be empowered to locate each other, mobility of context (who, what, why, when and using which resources) are essential facets of any collaborative system (Dustdar and Gall, 2003). Research has revealed that despite the extensive planning that takes place on any construction project, it is often the case that when work begins on the construction site, unexpected problems arise which call for immediate attention (Dainty et al, 2006). With Newton (1998) highlighting that 65% of contractor-rework is attributed to insufficient, inappropriate or conflicting information, it can be argued that the timely collection and dissemination of information to project teams would help reduce and resolve the number of unexpected problems, with computing at the construction site an important factor, problems need to surface and be solved on-site whenever possible (Moore et al. 1992; Sanders and Moore 1992).

Convergence in Construction

An important advancement in ICT is the emergence of convergence in networks and communication, i.e., enabling the merging of voice, video and other types of data in a single system. Converged networks are being used within various industries to incorporate voice into mainstream data networks using Voice over Internet Protocol (VoIP) which brings cost savings by having a unified infrastructure and integrated data system, which can be of benefit to the construction industry (Ahsan et al., 2005; Beyh and Kagioglu, 2006). Research examining the adoption of VoIP within the construction context has identified several issues that require further investigation (Beyh and Kagioglu, 2004; Ahsan et al, 2005):

- the nature of information to be transmitted such as voice, video and other types of data
- data access by various project teams
- reliability, availability and quality of service
- cost of service including network administration, maintenance and upgrade
- availability of terminals and users' devices such as mobile handsets.

When examining the technical issues of introducing the technology, it was established that many of the barriers, such as reliability and security, can be overcome by adopting tried and tested techniques to solve similar problems adopted by other sectors such as manufacturing and IT (Ahsan et al., 2005).

Research Methodology

In order to test the use of convergence within construction and gather requirements for a mobile support tool, two methods were employed: case studies and scenario analysis. A scenario is a description of possible or probable futures (Schwartz, 1991). It is a story about people and their activities (Carroll and Rosson, 1990) that describes human work, human collaboration, or human activity (with or without computers) (Muller, 1999). Muller (1999) identified several uses for scenarios as:

1. Analysis of human work and collaboration with a balance between a focus on technology and a focus on human processes
2. Consumer engagement
3. Design and implementation of systems
4. Usage-guided testing of systems

Rosson and Carroll (2002) note that with respect to scenarios showing interaction with a system or application, user interaction scenarios makes the system's use explicit, and in doing so orients design and analysis towards a broader view of computers. It can help designers and analysts to focus attention on assumptions about people and their tasks. Scenario representations can be elaborated as prototypes, through the use of storyboards, videos, or rapid prototyping tools. For this research, the use of mock screen shots were used (Ahsan et al., 2007) to allow the industry experts to examine the use of mobile technology and to allow the requirements for the user interface to be gathered.

FIGURE 1 MOCK-UP SCREEN SHOTS USED IN THE SCENARIO PROCESS (AHSAN ET AL., 2007)

The formation of the scenario used a mixture of analyst and expert input, with key trends identified in the literature and discussions with ICT industry specialists. The processes which formed the basis of the scenario originated from the methodology within the Chartered Institute of Building (CIOB) manual for project managers (CIOB, 1996). The scenario took a common occurrence of a problem identified by construction workers on site, and on the basis of the procedures from the manual for project managers (CIOB, 1996); several steps were formulated to show the problem resolution process. These processes were then supplemented with the technology displayed in the conceptual model to introduce the concept of unified communications, using the PDA as the main communication and collaboration device on site

The case study is an in-depth investigation which investigates a contemporary phenomenon and in which multiple sources of evidence are used (Yin, 1994). It can employ a mixture of data collection methods, and excels at allowing an understanding of complex issues (Soy, 1996). With respect to construction, it has been found that the case study plays a major role in increasing industry uptake of construction IT solutions (Bloomfield, 1998), and as such is an effective means of identifying correct application of technology. Nine of the largest construction companies within the UK were investigated with site visits examining the problem resolution process, the use of computer technology on site and the views of project managers and site staff with regards to more advanced technologies on site.

After the collection of requirements was complete, a prototype tool was developed and tested. The tests were carried out in a simulated construction environment in order to test the functionality and adherence to requirements. Black-box testing was used to ensure appropriate outputs were produced given a set number of inputs, essentially that the tool would work as it was designed to.

Problem Resolution Process

The scenario explained the problem resolution process according to the CIOB project managers' manual, which was found generally to be true to the process on site; however there were subtle differences in the way problems were handled which had an impact on the communication taking place. These main aspects of the resolution process included:

Role of the Project Manager (PM) – The research found that when it came to problem resolution there were generally two types of managers, the *facilitator* or the *delegator*. The type of role the manager would take would depend on the extent of the problem, with large problems always involving the PM heavily. The facilitator would be involved in the decision process and would act as the intermediary between the experts and the workmen carrying out the jobs. The delegator, though, would assign the engineer on site to speak directly to the expert to come to an acceptable solution.

Role of Project Team –Depending on the problem, the level of involvement from the team varied. One of the companies ensured weekly briefing meetings whereby any problems would be discussed with the project team to ensure maximum awareness.

Documentation – All the sites had official forms to complete due to any cost implications arising from the problem or the resolution (change request, technical query), although these forms were often completed retrospectively with tasks issued verbally using the mobile phone. This did pose a risk of some changes not being documented due to a lack of time, or forgetfulness.

Design Update – Any changes to the design would be agreed upon by the decision makers involved, and since most sites had a document management system in place, updated drawings would be uploaded to the system to ensure staff had the latest copy. Problems included the use of printed drawings, which would be printed out in the morning and used throughout the day. With many changes occurring throughout the day, the printed drawing would often be out of date by the end of the day posing the risk of site staff making mistakes due to incorrect information.

Communication – Almost all the teams relied heavily on the mobile phone to communicate with experts and issue updated tasks. The verbal communication would be supplemented with email and information stored on the project document store but, where possible, face-to-face meetings were desired over the use of telephony and email. Difficulties in explaining problems to the project team were frequent, with time taken in explaining the problem to the wider project team to ensure an adequate resolution.

Duration – Assessing the duration of the problem resolution process was difficult as there are a vast range of problems which can occur on site. In response, average times were stated which ranged from a couple of hours (if it was something which could be sorted out quickly) to weeks or months (if third parties were to be involved and acceptance from the client was requested).

Use of Digital Camera – The digital camera would be used on most sites on a daily basis to document the construction process (which often were saved on a local computer and left). For problem resolution, the digital camera was identified on one site as being used to take an image of the problem which was subsequently emailed to the project team, or placed on the extranet to allow for a more effective resolution.

REQUIREMENTS FOR MOBILE ICT SUPPORT SYSTEM

Examining the findings from the scenario analysis and case studies, the main functions of a support system were identified as:

- Efficient logging and alerting of problems
- Mobility
- Speech recognition
- Use of multimedia content
- Access to latest information

Taking on board the requirements, and leveraging the key technologies of VoIP, speech transcription, mobile devices and multimedia content, a conceptual model and prototype design was developed. The solution, named the Mobile Collaboration Toolkit (MCT), with a deliberately simplified specification list was designed to show that the chosen technologies have a practical application on a construction site. Figure 2 shows the conceptual model of the proposed solution and shows an overview of the various components involved. The MCT makes use of a mobile device to collect information from the site and uses the available network (wireless/GPRS/3G) to send data to a central server where it is published and made available for the rest of the project team to view. The audio is transcribed, allowing data to be collected faster from the site as the construction worker need only record a comment instead of type it into the device. The functionality of VoIP was tested as a separate part of the overall solution and not included as part of the developed prototype. The reason behind this choice was to allow the use of publicly available VoIP tools to allow the investigation of different deployment options.

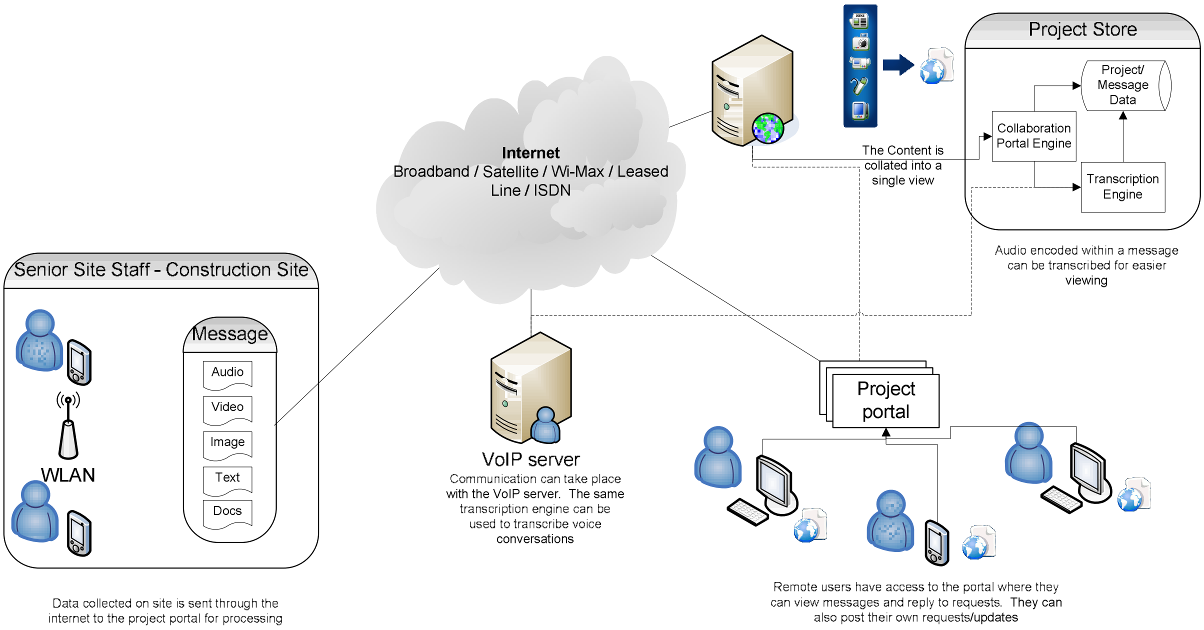

FIGURE 2 OVERVIEW OF PROPOSED SOLUTION (MCT) (AHSAN ET AL., 2007)

Prototype Development

Figure 2 shows the overview of the MCT and indicates two aspects of the MCT, the client where data is collected and the server where the data is processed and distributed. The client server architecture was chosen as it gave a central location for data storage and allowed the much greater processing power of a desktop server to be utilised for processing. A mixture of Microsoft C#.NET for the client and Java 2 Standard Edition (J2SE) for the server was used as it offered a good mix of rapid development on the client and the ability to leverage open source modules on the server.

Client Architecture

Figure 3 shows a breakdown of the client architecture. The processes are separated into three logical layers; the data layer named the data handler which manages all interaction with the database, the business logic layer, named business services, which manages all the processing of data and the presentation layer, named user services, which manages the input and output of data. The resources available to the client include a pocket database, the device file store, the camera and microphone along with network access via any available network connection (3G, GPRS or Wi-Fi).

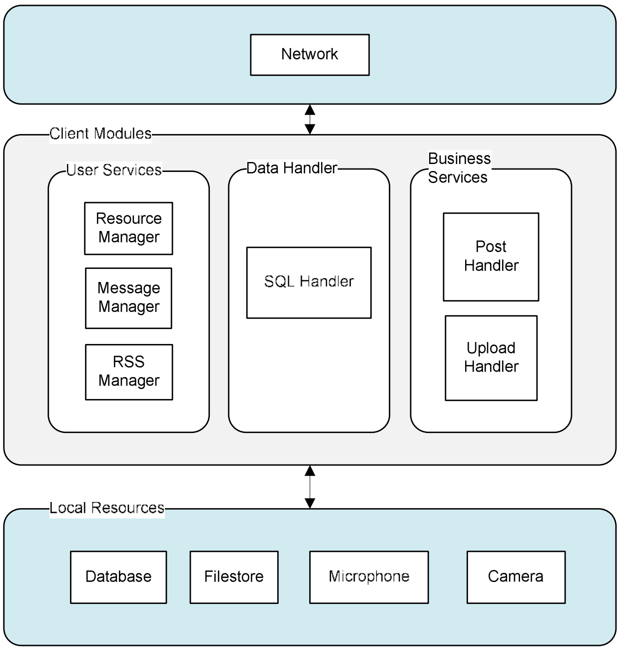

FIGURE 3 MCT CLIENT ARCHITECTURE

Server Architecture

Figure 4 shows the server application architecture, showing four main servlet classes which are responsible for the uploading and handling of messages from the client, speech recognition and the publishing of messages into RSS format. The local resources consist of Microsoft SQL (MSSQL) server Express and the file store. The library includes (apart from the default modules) a JTDS module which allows connection to MSSQL from Java and Sphinx4.0, the speech recognition library.

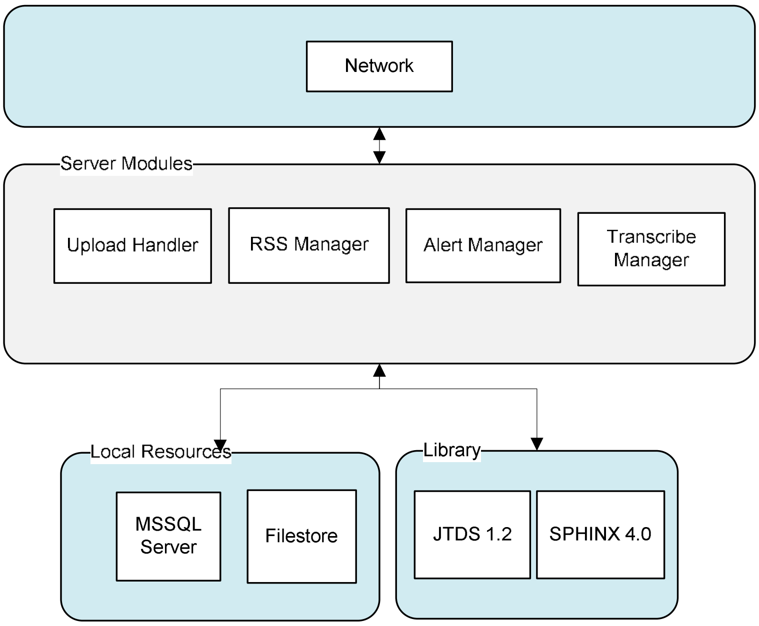

FIGURE 4 SERVER ARCHITECTURE

The HTTP (Hyper Text transfer Protocol) protocol is utilised to push data from the device to the server. The data being sent is a combination of the multimedia data along with meta-data designed to identify the message and subsequent handling options (figure 5). The server application is tasked with separating the content from the meta-data and rebuilding the files.

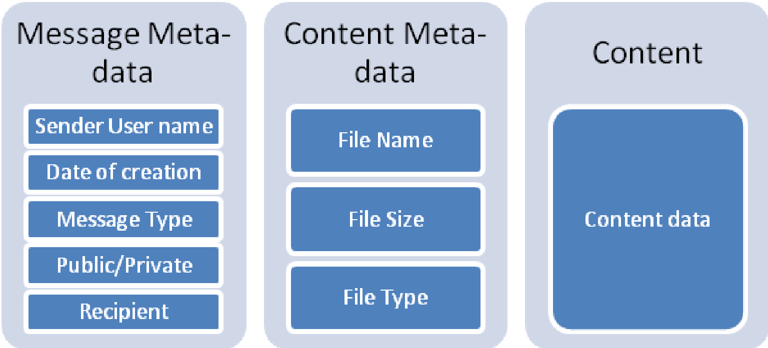

FIGURE 5 COMPONENTS OF A MESSAGE WITHIN MOBILE COLLABORATION TOOLKIT

The processed content is then published in the RSS 2.0 format, which is a dialect of XML and designed by the Berkman Center for Internet & Society at Harvard Law School. The format consists of elements or XML tags which store data. An RSS 2.0 document must contain a '<channel>' element which describes the overall content; in the case of the MCT the project details would be stored within these elements. The channel element may contain any number of '<item>' tags, which represent each message. Table 1 shows a list of elements used within the MCT to store the message contents, including a description and examples.

TABLE 1 ELEMENTS USED TO STORE A MESSAGE IN RSS

Element	Description	Example
title	Title of the message. This also contains the message status	<title>Closed - Status Update</title>
guid	A unique identifier for the message. This requires a URL, however the URL was stripped in the MCT client to give the unique identifier enabling replies to be linked	<guid>http://123.com/46b7bedb-daec-430e-ba7c-cc18f83ec9d2</guid>
link	Link to the message details	<link>http://server/MCT_Alpha_Sphinx/ShowPostList?detail=1&Post_id=46b7bedb-daec-430e-ba7c-cc18f83ec9d2</link>
description	The message contents are stored in HTML	
dc:creator	Author of the message	<dc:creator>Shabbir Ahsan</dc:creator>
pubDate	Date the message was created	<pubDate>Mon, 24 Dec 2007 11:19:00 GMT</pubDate>

Prototype Evaluation

Tests were carried out with two mobile devices being used over two separate sites simulating the collaboration taking place between the construction site and the architect's office. The tool was tested to ensure the basic features were functioning and allowing the transfer of multimedia information using a mobile device and a wireless network. The devices used for the test were the HTC Tytn (figure 6) as it came with Windows Mobile and offered full GSM, GPRS and Wi-Fi 802.11g access.

FIGURE 6 HTC TYTN

The functionality tests included:

Collection of multimedia information - This entailed the collection of videos, pictures, audio and text. The multimedia information was collected in real-time when messages were being created simulating the use of the application when on site in a problem situation and recording information to allow other team members to fully understand the problem.

Sending of data from location of problem – Wireless networks were established at both sites enabling the users to send messages direct from their locations. The option of creating messages and storing for later sending was also tested. Messages sent were immediately visible to the user of the second device on the second site allowing the messages to be viewed and appropriate action to be taken.

Viewing of data – New messages were visible using the MCT application on the mobile devices as well as using Microsoft Outlook or a web browser. Viewing the messages on the device allowed the user the option to download the multimedia information in order to view it, thereby allowing information to be reviewed by team members whenever they wished.

Voice over IP Trials

The MCT deployment did not include VoIP functionality as part of the application, but in order to test VoIP, commercially available tools were used. In a review of the commercially available IP telephony PBX (Private Branch Exchange) solutions, the open source software-based PBX called Asterisk was chosen. Asterisk is capable of handling the common PBX functionality including voice mail, conference calling, interactive voice response, and call distribution, as well as the more advanced functions of video conferencing (using a high grade H.264 codec), and call logging and recording. Many versions of Asterisk were available for evaluation, due to the software being an open source model. The version provided by Trixbox (www.trixbox.org) was chosen as it gave access to a greater set of modules built by the open source community and included a web GUI for simple administration. The purpose of evaluating the open source IP PBX was to understand the capabilities and application within the construction sector, focussing on the capability to create an audit trail for communication occurring on site. The testing involved creating three users with different devices to represent the different modes of working which would exist on the construction environment, which are as follows (figure 7):

1) Desk-based IP phone – the trial used a Grandstream GXV-3000 video phone as it supports both the SIP and H264 standards. This phone was used to represent the type of phone which would sit on the desk of the project manager or architect and hardwired to the network.
2) Soft phone – The RE used a freely available piece of software developed by Counterpath, who also develop enterprise IP software. The application used was X-Lite and had advanced features such as call recording, video conferencing (although the free version only accepted the older and more clumsy H263 codec), automatic conference and 2 lines.
3) Mobile Soft phone – To represent the mobile user, a freely available SIP client for Windows Mobile called Fring was used. The clients available for mobile devices were not as advanced as those available on PC, offering only basic calling functionality.

FIGURE 7 GRANDSTREAM GVX-3000, XLITE SOFT PHONE, FRING MOBILE SOFT PHONE (LEFT TO RIGHT)

To establish the functionality of the VoIP deployment, a scenario of a problem occurring on site and the following discussion to work out a resolution was used. The test took place within a lab environment. The scenario had three actors:

Bill:– the site engineer out on site, using the mobile soft client

Tom: – the architect at his office, using the desk-based IP phone

David: – the project manager at his computer, using the PC soft phone

The narrative for the test was:

"Whilst on site Bill got a call from one of the workers as they had come across a problem on site. The workmen found that the piping in the ground was laid differently than what was previously thought. Bill immediately called David using his mobile VoIP client. David was at his desk attending to his emails when he saw the call come in from Bill. Using his wireless headset he accepted the call. Bill explained the problem to David who promptly called Tom on his second line. Tom was in his office

and took the call using his desk-based IP phone. David introduced the problem, then placed Bill on the call via the conferencing facility to discuss options. David placed his call on the speaker and invited his colleagues to join in the discussion. After a quick discussion it was discovered that a small change was required to the drawing, and the go-ahead was given to adjust the task. All three agreed and the call was ended."

The scenario may be possible to enact, in-part, without the use of IP phones, and instead using traditional PBX systems and mobile phones, but the successful enactment of the scenario with IP devices shows that there is conformance among IP devices for what may be considered more advanced functionality such as conferencing and that audio and video communication can occur over infrastructure that is self-established (i.e. the construction companies can have wider choice over communication infrastructure).

With the three devices being placed on a separate LAN infrastructure and behind security firewalls, initial connection proved difficult. This problem was overcome with the use of a STUN (Simple Traversal of UDP through NATs (Network Address Translation)) server, which enabled the connection to get past the firewalls whilst maintaining network integrity. With the problem resolved, the narrative was simple to act out. The devices connected and the call was established with no difficulties. Figure 8 shows a screenshot of the soft client on the PC and the mobile client. The soft client (X-lite) clearly shows that both lines are active and in fact in a conference, with the mobile client connected through Wi-Fi.

FIGURE 8 TEST CONFERENCE CALL

When the accounts were setup, the option to record calls was set to true, and as such all calls going through the IP PBX would therefore be recorded. Trixbox included a simple interface to allow users to log in and track the calls. The test showed the call was recorded (fig 9), and all three audio streams from the three users in the call were also saved.

FIGURE 9 CALL LOGGING AND RECORDING

Running the usability test with the VoIP deployment the following was discovered:

Fast and efficient setup – The test deployment was setup in a short period of time, but it is obvious for a large construction firm, the time to deploy will be much longer and more thought would have to be taken in planning the configuration. The management of the system is achieved through a web interface, offering the in-house IT staff the ability to setup and maintain the application after some training.

Call Logging – The server logged all calls in a database. Using the concept of distributed systems, this information would be available to be used within a unified view of the project whereby data from the various distributed systems would be shared.

Call Recording – The system was setup to record all calls in the WAV format. Trixbox included a web application allowing users to view their own call history and play back files, along with access for admin to view all activity and playback files.

Firewall – The firewall was identified as a problem early on in the trial as it prevented connection. The STUN server was a way of bypassing the problem allowing the network to maintain integrity when running the VoIP server.

Multi-Client – The tests showed a number of different clients in use which highlights the diversity available for the IP market. The Wi-Fi client did have problems with standby mode. When the Tytn handset would go into standby after being idle for some time, the wireless connection would be dropped therefore disconnecting the phone. This would cause problems if these wireless handsets were to be used on site as difficulties in connection would cause engineers to resort to the mobile phone. This can be overcome by preventing the handset from going into standby mode, but the implication is shorter battery life.

CONCLUSION

Examining the process of resolving problems occurring on site it was clear that communicating as much information about the problem played an important part in achieving an effective solution. Initial use of multimedia information in the form of digital images was found to be used on some construction sites, but with the prototype tool, the process of capturing and disseminating this information was streamlined allowing a larger set of multimedia information to be collected and disseminated direct from the problem location. The ability to send a large degree of multimedia information would resolve any ambiguity surrounding a problem, and with information stored in a central location, access to the information would always be available to the project team.

Another important consideration was the tracking of communication and decisions made. The research identified delays in the logging of problems and their subsequent resolutions leading to a risk of changes going undocumented. The use of VoIP and call logging /recording was presented as a possible solution to help keep track of verbal communications and subsequently the decisions being made surrounding problem resolution. The tests showed that calls could be recorded and stored for auditing purposes, and with further improvements in speech recognition, be available to immediate review.

The research presented novel uses of technology linking the various aspects of mobile communications, multimedia content, speech recognition and call logging to enhance the flow of information in order to support the decision-making process and ensure shared understanding amongst the project team. The tests showed that functional support was achievable, with the prototype tools functioning according to their specifications. The tests were carried out in simulated environments, but in order to improve the tool and the processes on site, further tests would have to be carried out in real life situations to ensure adherence to industry requirements.

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