Connecting the Unconnected

Bluetooth and 802.11 in harmony

Curtis Sahd
Department of Computer Science
Rhodes University
Grahamstown, South Africa
curtissahd@gmail.com

Hannah Thinyane
Department of Computer Science
Rhodes University
Grahamstown, South Africa
h.thinyane@ru.ac.za

***Abstract*—Many new cell phones on the market come with 802.11 enabled, along with standard Bluetooth functionality. A large percentage of working class people in South Africa typically cannot afford 802.11 enabled cell phones, and thus the most applicable form of wireless data transfer is achieved through the Bluetooth protocol. This paper investigates bridging Bluetooth and 802.11 protocols on low cost wireless routers equipped with a Broadcom chip and a USB port, as well as bridging on high end cell phones. For the router component of this research, the BlueZ protocol stack will be implemented on top of the OpenWrt platform and experiments relating to the feasibility and scalability of SIP voice calls between clients on the Bluetooth network and clients on the wireless mesh network will be investigated. For the cell phone component of this bridging, Java Mobile will be used as the development platform of choice, and a comparison between bridging on the cell phone and on the wireless router will be conducted, with metrics such as latency, scalability, and minimum throughput will be considered. This paper proposes a low cost solution to building community telephone networks in rural South Africa, through the bridging of 802.11 and Bluetooth interfaces.**

Keywords – Wireless; SIP; Community telephone networks; BlueZ.

I. INTRODUCTION

The Bluetooth protocol has been around since 1994, and its primary function is to replace wires and serve as lightweight wireless implementation for data transfer. Even though most high end cell phones are equipped with 802.11, Bluetooth still serves as the primary data transfer protocol between cell phones in South Africa. Based on a survey conducted on the streets of Grahamstown, South Africa, it was discovered that most people called someone in Grahamstown or in the surrounding region on a daily basis. Currently, the only way to make phone calls, whether local or inter-town, is to make use of a fixed landline, which the vast majority of the underprivileged do not have access to, or to make use of the ever increasingly expensive mobile service providers. Paying sky high cellular network rates to make local phone calls places an enormous burden on already financially constrained rural communities. Bluetooth alone cannot be used in a full scale implementation which would enable free local phone calls. However, the combination of Bluetooth and 802.11 mesh networks could, in the context of South African rural communities, create a system which saves rural communities millions of Rand each year. Wireless mesh networks (WMNs) are dynamic, self-configuring networks which are design to span large geographical areas. WMNs could therefore be used to span the geographical area of the rural community, and possibly even connect remote rural communities to one another.

This paper aims to explore inexpensive means to creating low cost community telephone networks with existing technology in rural areas. We propose a system which enables the seamless integration of Bluetooth and 802.11 on the OpenWrt and Java Mobile (JME) platforms. We begin with an introduction to Bluetooth and in particular, Bluetooth networking with piconets and scatternets. We then provide a brief overview of the OpenWrt platform and focus on mesh networking, as well as reviewing related work in this area. Section IV then describes the Mesh Potato, and the possibilities it presents in rural areas. This overview is then followed by an in depth analysis of the proposed infrastructure of the Blue Bridge, and the associated advantages and disadvantages of various implementations. Section VI describes the context of this paper and how the proposed technology can be beneficial to rural communities and coincides with objectives of various social reconstruction programmes. Section VII then concludes this paper.

II. BLUETOOTH PERSONAL AREA NETWORKS

A. Overview

At initial conception Bluetooth was considered the future of Personal Area Networks (PANs), due to it being a lightweight protocol and the inexpensive manufacturing of Bluetooth chips [1]. The Bluetooth specification clearly defines PANs and associated roles of the nodes in the PAN in the case where two devices are communicating directly. The Bluetooth specification also defines the roles of nodes in multi-hop environments, but less research has been conducted in this field [1]. Asthana and Kalofonos [2] have developed a custom protocol which enables the seamless communication of existing Piconets within a Scatternet. Specifically, their research allows for the creation of Ethernet and IP local links on top of scatternets through the use of a standard PAN profile implementation, without the need for ad hoc forwarding protocols [2].

Plenty of research has been done in the field of providing Internet Access to rural communities. There has been little to no research in the field of making use of low cost hardware infrastructure to bridge Bluetooth and 802.11 which enables large scale service provision to local and remote rural communities. Bluetooth Piconets and Scatternets are an important component of bridging Bluetooth and 802.11 mesh networks, as in some cases devices will be able to communicate directly with one another (Piconets) and in other cases devices may only be able to communicate by sending traffic through a number of other nodes before reaching the desired node (more applicable to Scatternets). With that said, many researchers have investigated the formation and limitations of Mobile Ad-hoc Networks (MANETs) with the Bluetooth protocol [1].

B. *Piconets and Scatternets*

According to Bisdikian [3] a piconet is simply defined as a collection of Bluetooth devices which can communicate with one another. A piconet consists of one master node and one or more slave nodes, and exists for as long as the master communicates with the slaves. Piconets are formed in an ad-hoc manner, and need a minimum of one master node and maximum of seven active slave nodes. Although only seven active nodes are able to transmit based on coordination of the master node, other nodes are able to connect to the piconet, and are said to be in a parked state [3].

Scatternets are based on piconets and are said to exist when one device is a member of multiple piconets. In the case of scatternets, a node can only serve as the master node for one piconet.

For the purposes of this research it is important to understand the functioning of piconets and scatternets in order to handle the association of clients to the Bluetooth access point.

III. OPENWRT

OpenWrt is defined as Linux for embedded devices [4]. OpenWrt provides a plethora of opportunities for robust application development and service provision on embedded devices, and for the purposes of this research, specifically on wireless routers. In order to grasp the functioning of OpenWrt it is necessary to understand the various components of the software which manages wireless routers and for that matter any embedded device. The software which runs on computer chips or on embedded device chips is known as firmware [5]. The following are a few of the many types of chips which have firmware installed on them: read-only memory (ROM); programmable read-only memory (PROM); erasable programmable read-only memory (EPROM). PROMs and EPROMs are designed to allow firmware updates through a software update [5]. In order to compile custom Linux firmwares on embedded devices, a technique known as cross compiling is used, where a new compiler is produced, which is capable of generating code for a particular platform, and this compiler is then able to compile a linux distribution customized for a particular device [6]. Generally, the cross-compiling process begins with a binary copy of a compiler and basic libraries, rather than the daunting task of creating a compiler from scratch [6]. The remainder of this section describes mesh networking principles and practices on the OpenWrt platform, as well as the state of the art in rural mesh networks.

OpenWrt contains a number of packages which assist with the implementation of mesh networks. Optimized Link State Routing Protocol (OLSR) is an example of a routing protocol developed by Andreas Tønnesen which has been implemented in the form of a package for OpenWrt [7]. Another Open Source mesh networking implementation known as ROBIN (ROuting Batman Inside) has been developed on top of OpenWrt Kamikaze [8]. ROBIN is self-configuring and self-maintaining, which enables the seamless creation of wireless mesh networks. ROBIN requires a minimum of one Digital Subscriber Line (DSL) connection, a Dynamic Host Configuration Protocol (DHCP) enabled router which is connected to the DSL line and serves as the gateway node [4]. Client repeater nodes simply have to be powered on and a mesh network is dynamically configured [4]. With that said, open mesh networking protocols, which simplify the creation and extension of mesh networks, can be utilized in rural communities. Mesh networks thus serve as a low cost alternative to information technology service provision in rural areas, providing significantly more benefits than drawbacks. The benefits of mesh networks in rural communities have been extensively discussed [8] [9]. Reguart et al. [8] suggest that mesh networking technologies in urban areas are often unsuited to rural areas due to the high cost of equipment and maintenance. They proposed and tested Wireless Distribution System (WDS) by making use inexpensive wireless hardware (Linksys WRT54AG and Linksys WRT54G). Through a prototype deployment of their infrastructure they found that inexpensive wireless equipment is capable of providing fourty people with internet access, and at any one point in time there are between fifteen and thirty active clients [8]. The aforementioned implementation performs surprisingly well for sparsely situated rural communities, but would not suffice for the purposes of South African rural communities for the following reasons: Rural communities in South Africa are densely populated; laptops are seldom found in rural areas, as most of the people are living below the breadline and cannot afford such equipment; even if everyone had access to laptops, the use of inexpensive wireless equipment as used above would be overloaded and the end result would most likely be malfunction; also the use of secured outdoor equipment is imperative in the context of South Africa due to crime levels.

IV. THE MESH POTATO

The Mesh Potato is a new device which merges the ideas of current telephony (analog phones) and future technology (reliable wireless communications). The Mesh Potato combines a wireless access point (AP) with an Analog Telephony Adapter (ATA), and thus enables cheap communications using existing technology [17]. Routers by Meraki [18] and OpenMesh [19] are gaining popularity due to their low cost and robustness, but they however lack the functionality contained within the Mesh Potato in terms of integration with existing telephonic infrastructure.

Although rural areas in South Africa are often on the outskirts of town, plenty of remote and isolated settlements exist, and more often than not, these settlements lack infrastructure such as running water, sewage and waste removal, and electricity. In such cases where electricity is scarce or non-existent, the Mesh Potato is ideal since it can be powered by a 10w solar panel [17].

The Mesh Potato is powered by Open Source firmware (Linux, OpenWrt, B.A.T.M.A.N and Asterisk) which removes vendor lock in and makes the Mesh Potato cost effective and highly configurable [17]. The Mesh Potato enables the seamless connection of analog telephones, as well as wired and wireless IP phones. Cellular technology is the primary form of communication in rural areas in South Africa, and although analog phones are inexpensive and could be subsidized by the government, the Mesh Potato is currently unable to cater for the existing needs of people in rural areas.

V. PROPOSED BRIDGING INFRASTRUCTURE

After extensive literature reviews we found that there is a lack of knowledge in the field of Bluetooth and 802.11 bridging in the context of rural communities in Africa, and as such we propose a system (Blue Bridge) which not only deals with remote access to such communities, but also enables service provision through the use of inexpensive and readily available technology thus connecting the unconnected. The system will be centered around the OpenWrt firmware, which is to be installed on the Ubiquiti AirRouter [10]. The AirRouter will not only serve as an interface for 802.11 connections, but will also become a Bluetooth access point through the use of the BlueZ protocol stack which controls the functioning of the Bluetooth dongle inserted into the USB port of the AirRouter. Asterisk [11] will be installed as a package on the OpenWrt platform, and will serve as the SIP controller. A package will be developed for the OpenWrt platform which will bridge the connections between the 802.11 and Bluetooth interfaces. Fig. 1 shows the proposed infrastructure involving one AirRouter:

Figure 1. Proposed OpenWrt infrastructure for low cost community telephone network.

Any cell phone on the Bluetooth interface of the Blue Bridge should be able to place SIP calls to any other phone on the Bluetooth interface, as well as to any phone on the 802.11 interface. Of course as mentioned in Section B a maximum of seven active connections can exist on the Bluetooth interface, which clearly places limitations on the scalability of the proposed system.

With the aforementioned, the components of the proposed system include the AirRouter (running OpenWrt); the USB Bluetooth dongle; and a JavaME enabled cell phone, which the majority of the surveyed population possesses. The aim of this research is to provide Bluetooth access (via the connected Bluetooth USB dongle) as well as 802.11 access to multiple geographically dispersed routers which in turn enables the creation of community telephone networks, thus connecting the unconnected, and significantly decreasing the burden of expensive cellular calls.

The ideal scenario is the use of minimal equipment, while still maintaining an acceptable level of service provision. This translates to decent quality voice calls, with minimal downtime. In order to achieve this, an understanding of the Bluetooth protocol and its scalability limitations is vitally important. Sahd [12] conducted a study which investigated the real throughput achieved by the Bluetooth protocol on mobile devices. Sahd [12] found that the average transfer speed of the Logical Link Control and Adaptation Protocol (L2CAP) when transferring a 6.6 MB M4A audio file twice between two cell phones is 136.39 KBps [12]. If a maximum of seven clients are connected to the Bluetooth interface each client would be allocated a bandwidth of 19.48 KBps. Based on the assumption that seven simultaneous connections are active on the Bluetooth interface, the minimum accumulated bandwidth for these connections is 27.35 KBps, which would allow a theoretical number of thirty five clients to be connected [13].

This research will also investigate the differences in performance of Blue Bridge implementations on the JME platform and on the OpenWrt platform. Of course the most prominent difference between implementations on the two platforms is the class of Bluetooth device. The OpenWrt platform implementation of the Blue Bridge will make use of a class one Bluetooth device which is capable of a distance of 100m, whereas cell phones typically contain class two Bluetooth chips which enables transmission at distances of 10m. Sahd [12] found that even though the Bluetooth specification states a distance of 10m, transmission is possible at distances as high as 15m.

 ISBN: 978-1-61208-147-2

Fig. 2 shows the proposed Blue Bridge infrastructure on the cell phone:

Figure 2. Proposed cell phone based infrastructure for low cost community telephone network.

From Fig. 2 it can be seen that an external asterisk server would have to substitute the asterisk server contained within the OpenWrt packages. The scalability of the internal asterisk server would have to be researched and compared to that of the external asterisk server. On the other hand, the Nokia N95 8GB could pose to be a severe bottleneck under load.

In order to determine which platform will serve as the basis for a community telephone network, a number of metrics would have to be compared. These metrics can be seen in Table I:

TABLE I. KNOWN METRICS OF PROPOSED BLUE BRIDGE PLATFORMS

Metrics	**OpenWrt**	**Blue Bridge on cell phone**
Cost	Cheap	More expensive
Compactness	Average	Very compact
Complexity	High	Medium
Platform	Linux	Java Mobile

Based on the information currently available, assumptions from the data in Table I could lead one to believe that the Blue Bridge on the cell phone would be the better alternative as a whole. However, metrics such as performance under load, scalability, and multi-hop capability can only be determined once the implementation and necessary research has been completed.

With the above overview of the equipment needed for the implementation of the Blue Bridge, subsection A provides information regarding the costs involved, and a means for funding the Blue Bridge.

A. *Costs and implementation considerations*

There are two important factors to consider when determining the cost, and the number of units necessary for the implementation of community telephone networks: the geographical area and the proposed number of connected clients. The geographical area plays a large role in determining the strength of the devices needed to transmit a good quality signal. Mountains, trees, buildings, and other obstructions have to be considered. The number of connected clients dictates the scalability of the system, and thus the overall cost of implementation. Table II provides an overview of the costs involved:

TABLE II. KNOWN METRICS OF PROPOSED BLUE BRIDGE PLATFORMS

Device	**Cost**	**Means of funding**
AirRouter 150Mbps WiFi Router	R313.50	Government
Mecer Class 1 USB Bluetooth (ENUBT-C1EM)	R169.00	Government
Basic machine for Asterisk server (1.8 GHz, 2GB RAM, 500GB HD)	R2700.00	Government

Based on the costs in Table II, the maximum total cost for a prototype system catering for seven connected nodes will come to a total of R3182.50. This value is of course inclusive of the Asterisk server machine, which would not be necessary if the Asterisk server were to be implemented on the AirRouter itself.

The average voice call from the Vodacom cellular network to another network costs R2.75 per minute [20]. Based on the assumption that seven people spend five minutes on the phone each day for one month, the total cost incurred is R2983.75. Even though the Bluetooth protocol only permits seven active clients, more than seven people could connect to one AirRouter, due to the unlikeliness of everyone placing calls simultaneously. With that said, it can be seen that in just one month, the costs incurred by impoverished communities can be drastically reduced. This rate is the highest rate per minute rate on the Vodacom prepaid plan, and was chosen to estimate the maximum amount of money spent on cell phone calls.

Section VI provides an overview of government initiatives to introduce equality in impoverished areas, as such all equipment and implementation costs would be government subsidized.

VI. CONTEXT

The reconstruction and development program (RDP) of South Africa is a program implemented by the African National Congress (ANC) which addresses socioeconomic problems which exist as a result of the Apartheid regime [14]. The RDP program is of great benefit to all South Africans and in particular, South Africans living in rural areas without basic necessities such as adequate housing, water and electricity. Traditionally RDP housing was built on plots of 250m^2 which placed tremendous strain on the fair land distribution due to special constraints [15]. Recently,

 ISBN: 978-1-61208-147-2

there has been a movement from traditional RDP housing to more cost effective multi-storey RDP housing which reduces plot sizes from $250m^2$ to $80m^2$ [15][16]. With that said this poses as an ideal situation for the successful implementation of the Blue Bridge, as signal penetration will be higher and this type of RDP housing would prove more effective from a point of view of device mounting as well as line of sight access for surrounding residents. The Blue Bridge will benefit such communities immensely in terms of cost savings, and possible expansions could include educational resources and Internet access.

VII. Conclusion and Future work

In this paper, we proposed an inexpensive means to creating a community telephone network, which utilizes existing technology and infrastructure. We demonstrated an innovative approach to merging two independent technologies to achieve maximum penetration in all spheres of society. We proposed an infrastructure for the implementation of the Blue Bridge on the OpenWrt platform, as well as on the JME platform, and determined the metrics necessary for large scale implementation. This paper demonstrated an understanding of the social inequality and the effects of overpriced communications on impoverished communities.

The Mesh Potato lacks functionality which caters for the existing needs of people in rural areas. Similarly, the Blue Bridge lacks the functionality of providing an analog telephony interface, which is still widely used. As such, future work which adds functionality to the OpenWrt component of the Blue Bridge could involve connecting the Mesh Potato to the AirRouter via cable, and ensuring that both devices are on the same subnet, thus enabling the utilization of the analog interface of the Mesh Potato. In terms of the cell phone component of the Blue Bridge, the Mesh Potato could be connected to the cell phone via the wireless interface.

Another proposal for future work regarding this research could involve the use of low cost, high powered wireless equipment which could solve the need for large numbers of AirRouters or similar devices, since one device could provide access to a larger area. Future implementations of the aforementioned could involve connecting powerful wireless equipment to the AirRouter via the LAN interface, and in the case of the cell phone based Blue Bridge, via the wireless interface. The proposed expansion of the original infrastructure can be seen in Fig. 3.

Fig. 3(a) shows the expansion of the OpenWrt based infrastructure through the use of an external high powered wireless device, which is connected to the AirRouter via cable. This device then expands the wireless network, which then enables a larger number of clients to connect to the mesh and reap the benefits of a community telephone network. Of course the AirRouter will still serve as an access point for nearby 802.11 and Bluetooth clients.

Fig. 3(b) depicts the expansion of the cell phone based infrastructure for the Blue Bridge. Since the cell phone is unable to connect to the external wireless device via LAN cable, a connection needs to be made wirelessly. As such, the external high powered wireless device will transmit signal over a greater distance accomplished by the cell phone and will serve as the primary AP for 802.11 based clients.

Acknowledgment

I would like to thank my sponsors, the Telkom Centre of Excellence at Rhodes University, funded by Telkom SA, Business Connexion, Verso Technologies, THRIP, Stortech, Tellabs and the National Research Foundation.

References

[1] Zaruba, G.V., Basagni, S., and Chlamtac, I., “Bluetrees-Scatternet formation to enable Bluetooth-based ad hoc networks,” IEEE International Conference on Communications, ICC 2001, vol. 1, 2001, pp. 273-277.

[2] Asthana, S. and Kalofonos, D., “Secure ad-hoc group collaboration over bluetooth scatternets,” Applications and Services in Wireless Networks, 2004. ASWN 2004. 2004 4th Workshop, pp. 199-124.

[3] Bisdikian, C., “An overview of the Bluetooth wireless technology,” IEEE Communications Magazine, vol. 39, 2001, pp. 86–94.

[4] OpenWrt. Available at: http://openwrt.org, 2011. [Accessed 04-04-2011].

[5] Apple. What is Firmware?. Available at: http://support.apple.com/kb/ht1471, 2008. [Accessed 01-04-2011].

[6] Fainelli, F., “The OpenWrt embedded development framework,” 2008.

[7] OpenWrt. Available at: http://wiki.openwrt.org/inbox/mesh.olsr, 2011. [Accessed 06-04-2011].

[8] Reguart, A., Cano, J.C., Calafate, C.T., and Manzoni, P., “Providing Internet Access in Rural Areas: A Practical Case Based on Wireless Networks,” The 2006 IFIP WG 6.9 Workshop on Wireless Communications and Information Technology in Developing Countries (WCIT 2006), 20-25 August 2006, Santiago, Chile.

[9] Parikh, T.S., and Lazowska, E.D., “an architecture for delivering mobile information services to the rural developing world,” Proceedings of the 15th international conference on World Wide Web, 2006, pp. 791-800.

[10] UBNT. Available at: http://ubnt.com, 2011. [Accessed 04-04-2011].

[11] Asterisk. Available at: http://asterisk.org, 2011. [Accessed 07-04-2011].

[12] Sahd, C., “Bluetooth Audio and Video Streaming on the J2ME Platform,” 2010.

[13] AsteriskGuru. Available at: http://www.asteriskguru.com/tools/bandwidth_calculator.php, 2011. [Accessed 09-04-2011].

[14] Metagora. Reconstruction and Development Programme (RDP) of South Africa. Available at: http://www.metagora.org/training/encyclopedia/rdp.html, 2006. [Accessed 10-04-2011].

[15] Alexandra. Another RDP first from the Alexandra Renewal Project. Available at: http://www.alexandra.co.za/05_housing/article_0610_rdp_housing.htm, 2006. [Accessed 09-04-2011].

[16] Joshco. Sol Plaatje. Available at: http://www.joshco.co.za/solplaatje.html, 2011. [Accessed 10-04-2011].

[17] VillageTelco. Mesh Potato. Available at: http://www.villagetelco.org/mesh-potato/, 2011. [Accessed 11-04-2011].

[18] Meraki. Meraki. Available at: http://meraki.com/, 2011. [Accessed 11-04-2011].

[19] Open-Mesh. Open-Mesh. Available at: http://www.open-mesh.com/, 2011. [Accessed 11-04-2011].

[20] Vodacom. 4U Prepaid. Available at: http://www.vodacom.co.za/vodacom/Deals/Prepaid/Prepaid+Price+Plans/4U+Prepaid, 2011. [Accessed 23-05-2011].

Figure 3. (a) Proposed wireless expansion of OpenWrt based Blue Bridge (b) Proposed wireless expansion of cell phone based Blue Bridge