WIRELESS NETWORK ARCHITECTURE USING SOUND FOR UBIQUITOUS SIGNAL TRANSMISSION

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***Abstract* — The digital divide between urban and rural areas is now attracting active research. There are a host of reasons for this divide and this paper presents the work in progress about one proposed solution to a major technical problem causing this. It has been noted that the high frequency WiFi and similar signals are not well suited for the wilderness type of environment with dense foliage. Additionally, such terrains also impose stringent restriction on computational and electric power as well as in cost. This calls forth the need for a new type of signal that can work efficiently in such environments and a low cost, low bandwidth, low frequency signal that can possibly work is identified in the form of Sound. This paper presents a new network architecture that is designed to work with the low frequency, ubiquitous signals such as sound. The architecture can work in peer-to-peer ad-hoc networks mode, infrastructure mode, broadcast mode (for remote telemetry) etc. using wideband multi-channel transmission. However, since the proposed architecture uses low frequency signal, it is expected to deliver low throughput as well. Using an ubiquitous signal such as sound makes the entire process very cost effective as it eliminates the need of expensive transceivers.**

Keywords—network architecture; low frequency transmission; wireless communication;

I. INTRODUCTION

There is an ever growing technological divide between the urban and rural technological framework. We see the urban front growing in leaps and bounds, fuelled by the large economic resources and wide user base, resulting in improvements in speed, reliability and cost. The rural environment does not have these financial resources, and with some added technological limitations that makes it almost impossible to adopt the urban technologies leaves this front struggling to establish basic minimal connectivity. This divide is not conductive for total economic and social development and progress of the world at large and therefore research in this front is of paramount importance.

The terrain and sparse user base of the jungle type of environment makes it extremely ineffective to set up wired infrastructure for network connectivity and hence the better option in terms of cost effectiveness and reach is using wireless. However, the dense growth of bushes drastically reduces the range of high frequency RF signals used by WiFi, 3G etc. These are also high energy signals, greatly depreciating the usability as the terrains pose serious limitations to the rages of these signals. It is therefore desirous to have a low energy, low frequency, ubiquitous signal. Sound is a good candidate for such requirements, given its ubiquitous presence, low energy and low frequency, allowing it to traverse very well over obstacles. However, the ubiquity of sound also leaves us open to handle a lot of “noise” as well.

The previous studies have analyzed and proven that sound can be used as a carrier signal for wireless data communication [1], studied the noise profiles in various environment to gather idea on efficient signal-to-noise ratios and to aid identification of appropriate channels for communication [2], and a survey to identify sound perception of various frequencies by humans so that the channel used for data transmission causes minimal intrusion to the environment of use [3]. This paper furthers with the architecture for a model designed for the purpose. The ensuing sections of the paper is organized as related works, the proposed signal (sound), the design, its philosophy and application and conclusion and future Works.

II. RELATED WORKS

Use of sound as carrier for low bandwidth, low power communication in the ubiquitous paradigm is discussed in [1]. This paper attempted ubiquitous data communication using existing hardware in smart devices and sound as the signal. Successful data transfer was achieved and future work on furthering this towards practical application was suggested. Mathew et al. presented ambient noise analysis on sound for use in wireless digital transmission [2], in which they discuss the analysis of ambient noise in various environments in order to look for a quieter channel for data transmission and also to look for an appropriate signal-to-noise ratio. Mathew et al. discussed evaluation of sound perception to identify candidate frequency for wireless networking [3] in which a survey of cultural and age neutral population is conducted in order to identify perceivable sound frequency among the general population.

M Weiser, proposed in 1991 pervasive computing as technologies which disappear as they ubiquitously blend into everyday life so that they are indistinguishable [4]. The concepts called tabs, pads and boards were introduced, also opening up the networking challenge the nature of the devices will present. Madhavapeddy A., Scott D., and Tse A. worked on audio networking which was a forgotten technology [5]. They successfully sent and received data and over sound using common computing platforms to do high frequency (ultrasonic) communication. Chen, T. T., & Lee, M submitted a bibliographic study on Ubiquitous Computing looking at inter-relationships among major research themes in ubiquitous [6]. Jurdak, R., Lopes, C. V., & Baldi, P. proposed an acoustic identification scheme for location systems [7] which uses acoustic signals to uniquely identify and locate a user. Madhavapeddy, A., Scott, D., & Sharp, R. presented context aware computing with sound [8]. A number of location aware applications, namely, pickup and drop interface, digital attachments in voice, etc. were analysed. Mandal et. al. discussed indoor positioning with 3D multilateration algorithms using audible sound[9]. It gave accuracy levels of about 2 feet in about 97% times using cheap consumer use hardware.

III. SOUND – THE NOISY SIGNAL

After identifying sound as a possible signal, we tested out its feasibility using some smart devices which used the speakers and microphones to send and receive text between the devices [1]. The successful transmission in this was Proof of Concept that the signal can work. However, the ambient noise in the environments were also noticed and it was therefore necessary to identify the noise present in ambient conditions in order to achieve an efficient and effective signal-to-noise ratio to effect successful communication. Hence a second study was carried out to plot the noise profiles in various environments [2] as it provides meaningful insight into the spectrum noise spread and noise levels. Since sound could be used as a signal carrier .it was also necessary to study the human perceptibility of sound frequencies. A gender, age and cultural neutral study [3] was done, which revealed that on average, we usually do not hear sounds less than 35 Hz and more than 14 KHz. This leaves a wide band of frequencies that can be used by the communication channel without being intrusive in its environment of use. Actual performance of sound in each of the frequency bands is still to be studied.

Sound was an obvious choice of a signal, not simply because of its ubiquity, low energy and low frequency, but because it was traditionally a signal used in long-range communications in forest environments long before the advent of technology. Moreover, it was already being used in underwater and terrestrial telemetry and is a good candidate signal that can be extended to many types of urban and rural environments. At the same time, the different nature of Sound signals also necessitates a new network architecture designed to handle all aspects of this signal. This paper is presenting a new design for a communication architecture using low frequency, low energy, wireless signals, capable of operating in peer-to-peer modes, infrastructure modes and broadcast modes in wide-band mult-access methodologies.

IV. DESIGN PHILOSOPHY

A. *The Philosophy*

As the world is becoming more and more aware of the "technology-divide" between the rural and urban generations, research for the reasons for this and ways to bridge this has become one of extreme importance. It is common knowledge that the reasons for this gap extends beyond technological frontiers, onto socio-economic paradigms. This discussion attempts to address one major techno-economical issue that is a bottleneck for the implementation of current urban networked computing systems and architecture in the rural front.

The urban networked computing scenario has been progressing in leaps and bounds, in both the wired and wireless arenas. This has been largely assisted by the high density of urban population which helps in drastically reducing infrastructure cost-per-customer, enabling the service providers to provide faster and newer technologies at a very "affordable" cost. The absence of these contributing factors makes it difficult to provide similar service at a comparable cost, but even if it was provided, "affordable" urban cost might still be too high for the rural economic domain. Therefore attempts need to focus on provision of resources at a much reduced cost, with sustainability as a foremost priority requirement. In the current discussion, we will introduce a low-cost sustainable architecture that is suitable, but not limited to remote rural economic environments. Wired networks are expensive to setup and maintain in the environment under consideration and therefore our quest is towards a sustainable wireless technology.

A technological limitation of the current wireless signals makes is extremely inefficient in rural areas with thick foliage, as in the jungles and rural equatorial, tropical and sub-tropical villages. WiFi, 3G and similar popular high frequency signals fall short of the unique requirements of this environment, as the obstacles in the environment hamper normal operations of these technologies. They are expensive to setup, and with limited users, is not economically viable. The high frequency RF signals generation require high power and most often the remote locations in consideration does not have much power resources available, both in terms of computing power and electricity. Hence a need for some alternative signal and architecture that can work effectively in the environment under consideration is of paramount importance to advancement of research in this paradigm.

Many such requirements point to the need of a new network architecture for such environments. The architecture should be able to address most of the concerns introduced and provide a scheme for sustainable and cost effective network communication. The new architecture will consider using some low frequency signal that will demonstrate better performance with low power requirements at lower cost. The present assumption is that the requirement of the technology is to provide connectivity for use in systems like remote telemetry in the rural framework where the current technologies fail to operate and therefore the scope of this study is limited to achieving workable, sustainable data communication at low bandwidth.

B. *Initial Study Results*

Some initial studies have been carried out and presented in an attempt to identify an appropriate candidate signal for meeting the requirements discussed in the previous section [1][2][3]. The idea was to make use of sound, a low frequency and low energy signal as the carrier signal for network data communication as it was noticed by experience that sound has been used in the past as a communication signal in remote jungles in the form of drum beats, bird calls etc. even before the advent of technology . A brief summary of the results is as follows.

1) *Text Transfer Using sound*

The paper "Ubiquitous Text Transfer Using Sound - A Zero-Infrastructure Alternative for Simple Text Communication" [1] discuss the successful transfer of text data between smart devices using sound as the signal, making use of the built in speaker and microphones as the ubiquitous hardware. The experiment created two Smartphone apps, a sender and a receiver, encoded the data using frequency encoding of ASCII value of each character with a frequency space between each subsequent value. The results show that good transfer is achieved with the frequency gap is at least seven 7 Hz, as we can see from Table 1. This experiment was attempted as a proof of concept to verify data transmission over sound as carrier signal is a possibility and therefore forms the basis for subsequent research in this direction. The results were promising and paved the way to further studies on the possibility of using this as the carrier signal.

TABLE I. TEST CHARACTER TRANSMISSION RESULTS

	% Successful Transmission with freq gaps of:				
Sl No:	***Test Condition***	***3 Hz***	***5 Hz***	***7 Hz***	***10 Hz***
1.	'A', 'E', 'J', 'O', 'T', 'Z'	18%	88%	100%	100%
2.	'0', '5', '9'	33%	100%	100%	100%
3.	'A' to 'Z'	-	98%	100%	100%
4.	'0' to '9'	-	96%	100%	100%
5.	Random characters	-	82%	98%	100%

TABLE II. AMBIENT NOISE PROPERTIES COMPARISON

Scenario	**Noise Properties Comparison**			
	Sigma	***Mu***	***Q (dB)***	***D (dB)***
A.	0.095794	2.3515e-05	12.7382	53.1315
B.	0.036529	5.1988e-05	19.7477	81.3094
C.	0.040365	7.2657e-07	13.0013	75.4303
D.	0.049696	9.7926e-06	15.0469	79.2824
E.	0.028277	7.2574e-06	13.5749	72.9124
F.	0.063095	-4.28e-07	15.0027	81.3116
G.	0.050741	0.018188	12.0411	76.9822
H.	0.060877	3.3152e-06	18.9953	84.9933
I.	0.041024	2.7176e-05	18.35	80.9198
J.	0.21329	-0.00019247	9.3998	86.2883

1) *Ambient Noise Analysis*

After establishing that is possible to transfer data using sound, the further study was intended towards identifying the amount of noise present in various operating environments. This study was carried out in the paper "Ambient noise analysis on sound for use in wireless digital transmission" [2]. This is essential for identifying the minimum signal to noise ratio in order to make a successful transfer. The study also helps us compare the entire frequency range and identify the noise profile and look for an optimal "channel" for the data transmission. We noticed that, though lower frequencies below 500Hz are good for travelling around obstacles because of their longer wavelength, perhaps for the same reason, the ambient noise in this range was also very high. The higher frequency band above the 12,000 Hz was seen to be relatively very quiet, making it a better candidate for data transfer carrier frequency signal. The study covered a good range of environments ranging from woods to roadside to shopping mall etc. The result of the study of ambient noises is presented in Table II and the result of an attempted text transmission is shown in Table III.

TABLE III. DATA TRANSMISSION OVER SOUND

Transmission Text	**Successful Transmission percentages**	
	Success	***Failure***
1. Alphabets	100%	0%
2. Random Characters	99%	1%
3. Digits	100%	0%
4. Short Text	96%	4%

a. Transmission was done with a frequency gap of 10Hz between each character code

Further study needs to be carried out to identify the attenuation of the sound signals of various frequencies in comparison with the high-energy WiFi signals. However, since the signal in consideration is an ubiquitous signal with far less perceived health hazard and limited regulations, the amplitude of the generated signal can be boosted to achieve farther distance of transmission.

2) *Sound Frequency Perception Study*

Though the sound has a very wide frequency range, the accepted norm for audible sound frequencies range from 20Hz to 20,000Hz and transmission in this frequency range is suspected to cause considerable disturbances to individuals present in the transmission domain. However, it was suspected that the actual perceivable range is bit lesser than this range and therefore a survey was conducted to get an indication of what the actual expected range might be. The survey was conducted neutral to culture and age, with participants ranging from different parts of the world and was presented under “Evaluation of Sound Perception to Identify Candidate Frequency for Wireless Networking” [3]. As a result, the lowest perceived frequency was 25 Hz and the highest was 18KHz, with the average range between 30Hz to 14Khz, as seen in Table IV.

TABLE IV. RESULTS OF AUDIO PERCEPTION SURVEY

DocN	Geo	AG	Low (Hz)	High (KHz)
JL1325-01	India, Middle/ S. Asia	< 15	25	17
JL1325-02	Indonesia, E. Asia	< 30	30	16
JL1325-03	Malaysia, E. Asia	< 30	50	17
JL1325-04	Australia, Oceania	< 30	35	17
JL1325-05	Netherlands, Europe	< 30	35	16
JL1325-06	Hungary, Europe	< 30	35	14
JL1325-07	Korea, E. Asia	< 55	50	14
JL1326-01	Brazil, S. America	< 30	30	14
JL1326-02	Malaysia, E. Asia	< 30	30	14
JL1329-01	Japan, E. Asia	< 55	25	14
JL1329-02	Switzerland, Europe	< 30	30	14
JL1330-01	Malaysia, E. Asia	< 30	40	18
JL1330-02	England, Europe	< 30	30	17

DocN = Participant Response Document Number (name not included to protect respondent privacy); Geo =Geography/ Country, AG = Age Group; Low = Lowest Perceived Frequency, High = Highest Perceived Frequency

V. THE NEW ARCHITECTURE – PROPOSED

The following sections present the new architecture proposed. This will present the proposed new architecture for network communication using ubiquitous, low frequency signals and will focus on achieving effective communication with minimal overheads so as to further contribute to further cost effectiveness in terms of the computation power required to implement this. The architecture and each individual component is discussed in detail in the following sections.

The individual devices are capable of transmission and reception. They work in both peer to peer and central concentrator based modes. Central concentrators can help to establish long range transmission and relay further towards the end devices whereas the end devices work in low power short range communication.

A. A Communication Architecture

A communication architecture according to the proposal is as follows. The purpose of this model is to establish a wireless communication network in regions that cannot support the WiFi and related high frequency signals due to high rate of attenuation. This is expected to work to provide a low bandwidth communication infrastructure that can support low data rates such as simple text based communication.

B. A Telemetry Architecture

Telemetry architecture is specifically designed for telemetry, and expected to be especially useful in remote jungle type environments where dense vegetative growth which not only attenuates high frequency signals, but also where health monitoring of individual systems deployed in such environment makes it very risky and costly.

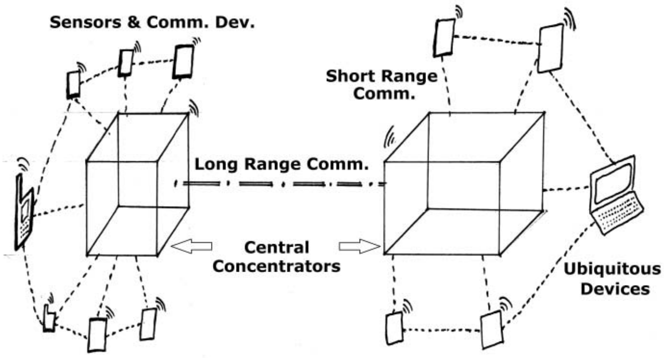

Fig. 1. Simple communication Architecture

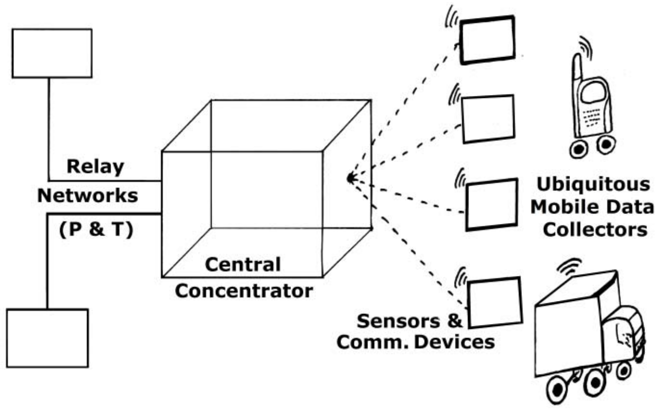

Fig. 2. Telemetry Architecture

In this architecture envisaged, the individual devices can work in both pull and push mode to transmit their health status. This can be extremely data efficient if the systems can send simple health status code. A central concentrator can be installed as data collector. This may be linked to the wired internetwork to provide extended services including web access for monitoring, alarms and many more. Since the signal is wireless and ubiquitous, data can be collected by individual wireless handheld devices or drive-by vehicles. This will be very helpful for diagnosis and repair. In extreme critical cases, a fly-by drone equipped with a mobile device that can collect data in extremely difficult to access locations.

C. The Architecture Sub-systems

The individual sub-systems of the communication architecture envisaged are shown in fig. 3. A brief description of each individual component of the system is as follows.

1) Transmitter

The transmitter is the low energy, low frequency signal generator. This is an analog device that is responsible for converting the electrical signal from the A/D to the transmission signal. In our consideration, we look at sound as a possible signal, in which case the transmitter is a simple speaker that can generate signals of the specific frequency used by the system.

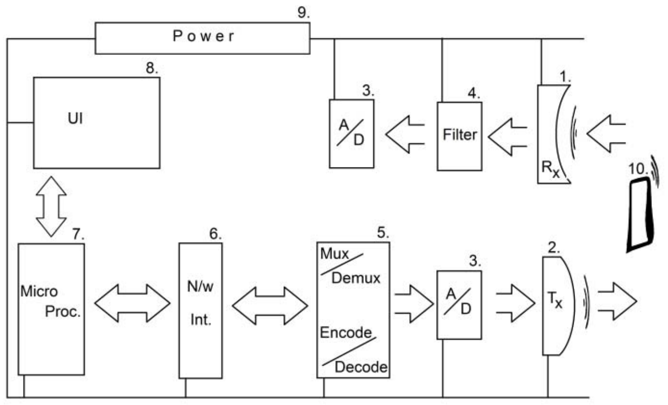

Fig. 3. Componant subsystems in the architecture envisaged

2) Receiver

The receiver is responsible for receiving the signal sent out by the transmitter and convert it into electrical signals. This device is an analog device, which is capable of receiving analog signals and converting them into analog electrical signals. When considering sound as the network signal, a simple microphone that can respond to the specific transmission frequencies can act as the receiver.

3) A/D

The actual signal being transmitted may be analog. This obviously calls for the need of an Analog to Digital Converter. This device is responsible for converting the digital pulses to analog electrical signals that can be handled by the transmitter and also to translate the analog signals read by the receiver into corresponding digital pulses. The ADC will work before the actual signal transmission in the case of sending data and after the filter in the case of receiving data.

4) Filter

The signal is expected to use a frequency band from a wide spectrum of available frequencies. Hence, for efficiency, it is desirous that the unwanted frequencies are filtered out since they directly translate as noise. If this noise is allowed to propagate, it will consume resources and therefore, for better efficiency and resource utilization, it is best that the noise is eliminated as early as possible in the system. Hence the noise filter is introduced soon after the signal is captured and before it is fed into the ADC.

5) MUX/ DEMUX

A Multiplexer/ De-multiplexer block is responsible for decoding the data encoded in the signal. In the transmission process, the MUX will receive the data from the network interface, generate the audio signal, and encode the signal using the agreed protocols. In the reception process, the DEMUX will receive the digital signal from the ADC and use the same protocols applied during the signal encoding and extract the data from the signal, which is passed on to the network interface for further processing.

6) N/W Interface

This simplified interface module block is responsible for acting as the intermediate between the transmission device and the signal transmission and reception mechanism. The block also allow for modularity of the system design, allowing interoperability between different signaling methods and allow the higher levels to integrate seamlessly with different possible signal types that may evolve in future. For the scope of the current study, we will look at one such possible signal, sound. If the transmission mechanism for the terrain is found to perform better using light instead of sound, this block will allow the communication mechanism to work with changing only the signaling mechanism as this layer insulates the underlying details from the users.

7) Microprocessor (Signal Processing)

The microprocessor is seen as a multi-capable software driven system This system will control the entire communication operation including interacting with the UI device subsystems, managing data representation, transmission protocols, error handling, and any other functions required for the optimal running of the system.

8) UI

The User Interface mechanism is responsible for interacting with the user. The most popular UI will usually comprise of a display device and some display-feedback driven mechanism for the user to input data. Older days computing had restricted systems where a CRT screen would display the output and a special purpose device called the keyboard would be used to enter only character based devices. The advent of touch-screen devices has revolutionized this concept and has brought in a number of innovations in area. The modular design should help this system to interact with any UI type of user preference.

9) Power

The power supply module will supply power to all working subsystems in the design components. The environment of use for this technology envisaged demands frugal use of power and a sustainable model. The scope of this study does not cover the specifics of the power module. This module, for the purpose of this study will be seen as a black box that is able to provide sustainable power to each of the subsystems, most likely a combination of battery energy and some type of renewable energy such as solar (photovoltaic) energy.

10) Measurement Devices

The measurement devices play an important role in this domain. Each of these devices are expected to be low-tech devices with minimal computing hardware resources and is expected to have full communication capability using this protocol. This implies that each measuring device will have full block of each of the aforesaid blocks and capabilities. The devices will record their measurement and encode the data in accordance with the applicable protocol. The device will then transmit the data using the signal in consideration.

VI. CONCLUSION AND FUTURE WORK

The need for a different kind of signal that will work in difficult terrains, like that one in consideration, namely the jungle terrain with thick vegetative growth also necessitates a new architecture specifically designed for this. This signal will be low power, low frequency and therefore expected to provide sustainable longer distance connectivity, at the cost of bandwidth. This paper proposes a new architecture designed to work with low-frequency, low-energy signals and presents a modular design. The modular design allows this to be extended to work with different possible signal alternatives at the signal level and different UI types at the user level and even interconnect them allowing seamless interoperability. The current architecture presented makes use of sound as the signal, though any other type like optical, low freq RF or any other signal type can be introduced. The user may choose to view the data using different types of devices including, but not limited to smart hand-held devices, plain old computers, database and service driven applications, the web and many more.

This architecture needs to be implemented in a “proof of concept” in order to verify and confirm its adequacy and efficiency improvement in the terrains of interest. Measurements need to be taken in the actual target environment in order to establish that this model is a definite improvement and practical in terms of cost and complexity in exact measured parameter values.

REFERENCES

[1] Mathew, K. and Issac, B. (2012, December). Ubiquitous Text Transfer Using Sound - A Zero-Infrastructure Alternative for Simple Text Communication. Proceedings of the International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering (CISSE 2012) – International Conference on Telecommunications and Networking (TeNe 2012), USA, Springer.

[2] Mathew, K, Issac, B., and Tan, C. E. "Ambient noise analysis on sound for use in wireless digital transmission," Information Technology in Asia (CITA), 2013 8th International Conference on , vol., no., July 2013, pp.1,4, 1-4.

[3] Mathew, K., C.E Tan and Issac, B. (2013, December). Evaluation of Sound Perception to Identify Candidate Frequency for Wireless Networking. Proceedings of the International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering (CISSE 2012) – International Conference on Telecommunications and Networking (TeNe 2012), USA, Springer.

[4] Weiser, M. (2002). The computer for the 21st Century. IEEE Pervasive Computing, 99(1), 19–25.

[5] Madhavapeddy, A.; Sharp, R.; Scott, D.; Tse, A.; , Audio networking: the forgotten wireless technology, Pervasive Computing, IEEE , vol.4, no.3, July-Sept. 2005, pp. 55- 60.

[6] Chen, T. T., & Lee, M. (2008). Ubiquitous Computing in Prospect: A Bibliographic Study. 2008 International Symposium on Ubiquitous Multimedia Computing, 57–62.

[7] Jurdak, R., Lopes, C. V., & Baldi, P. (n.d.). An acoustic identification scheme for location systems. The IEEE/ACS International Conference on Pervasive Services, 2004. ICPS 2004. Proceedings., 61–70.

[8] Madhavapeddy, A, Scott, D, & Sharp, R. (2003). Context-aware computing with sound. … 2003: In the proceedings of The Fifth International Conference on Ubiquitous Computing, October 2003, 315–332.

[9] Mandal, A., Lopes, C.V., Givargis, T., Haghighat, A., Jurdak, R., Baldi, P., , Beep: 3D indoor positioning using audible sound, Consumer Communications and Networking Conference, 2005. CCNC. 2005 Second IEEE , vol., no., 3-6 Jan. 2005, pp. 348- 353.

[10] Free Sound library of sound clips. [online] Available at: < http://www.freesound.org> [Accessed 22 April 2013.