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Wireless Sensor Networks for sound design:

A summary on possibilities and challenges

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ABSTRACT

This article presents opportunities of using Wireless Sensor Networks (WSNs) equipped with acoustic sensors as tools for sound design. We introduce the technology, examples considered as State of the Art and several potential applications involving different profiles of sound design. The importance of adding real-time audio-messages into sound design is considered a main issue in this proposal. Actual technological situation and challenges are here discussed. The usage of WSNs for sound design is plausible, although technological challenges demand strong interaction between sound designers and WSN developers.

1. INTRODUCTION

Sound Design is a technique employed in a variety of disciplines involving audiovisual production, such as filmmaking, television, theatre, sound recording, among others. Lately, its importance is being further recognized among other disciplines such as virtual reality, surveillance, urban planning and healthcare.

Wireless sensor networks (WSNs) are a major step towards a sensing technology. With them, we able to map sensing data, in real-time. For such purposes, a network of sensors is usually deployed in an area where aspects to be measured (think of temperature, humidity, air and noise pollution) have a significant influence on a population. As low-cost solutions for spatiotemporal data acquisition, they offer numerous applications. And they are flexible enough to work in an urban or nature environment, but also on smaller scales, such as a building, a concert hall or an industrial hangar.

Nowadays, there is a considerable amount of research dedicated to develop low-cost sensor nodes [28,29,31]. As such, WSNs equipped with acoustic sensors - such as microphones - have the potential to become an important tool for the process of designing sound. With this technology, signal-processing resources that are currently being dedicated for audio post-production can become part of the pre-production process, permitting the insertion of real-time sonic data into audiovisual formats by means of audio streaming. With upcoming acoustic-sensing technologies, it may be possible to reuse real-time sonic information, transposing and customizing soundscapes virtually from anywhere to everywhere.

2. USING WSNS TECHNOLOGY FOR SOUND DESIGN

Lets imagine that we want to emulate a soundscape of an industrial facility. We can suppose that this soundscape may be composed of different kind of motors sounds, and they could all sum up until becoming a fairly loud background composed by audible noise and vibrations. As shown in Figure 1, by using WSN nodes, it would be possible to capture this soundscape, by allocating different types of microphones depending on the purpose. For example, ultra-directional microphones could register the sound of each motor. Far-field omnidirectional microphones could register the overall background noise. Finally, accelerometers could capture vibrations. Once the soundscape is captured and streamed[1], it would be possible to emulate it somewhere else. For this emulation process, a mirrored implementation can be achieved using a set of speakers, with those combining different polar patterns among existent technologies. Moreover, in this emulation environment it could be possible to adjust levels, customizing the experience for better results.

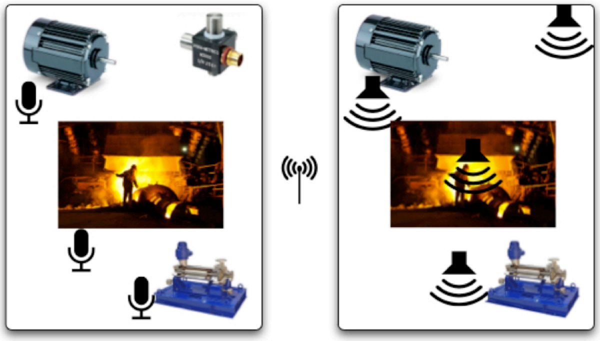

Figure 1. Diagram of the implementation of a WASN set-up, where several nodes equipped with different types of microphones stream real-time audio data from a factory. And at the facility where the streamed data is being received, an electro-acoustic set up is implemented for emulation purposes.

The previously mentioned idea is certainly achievable by means of existent sound recording techniques. But the main feature of WSNs as a tool for sound design is being able to capture and stream real-time information in detail. Therefore, the transcendence of the message evolves and the applications of such technology can be highly demanded.

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[1] When using WSNs, audio is commonly streamed by means of the internet, so the emulation can be made anywhere, worldwide speaking.

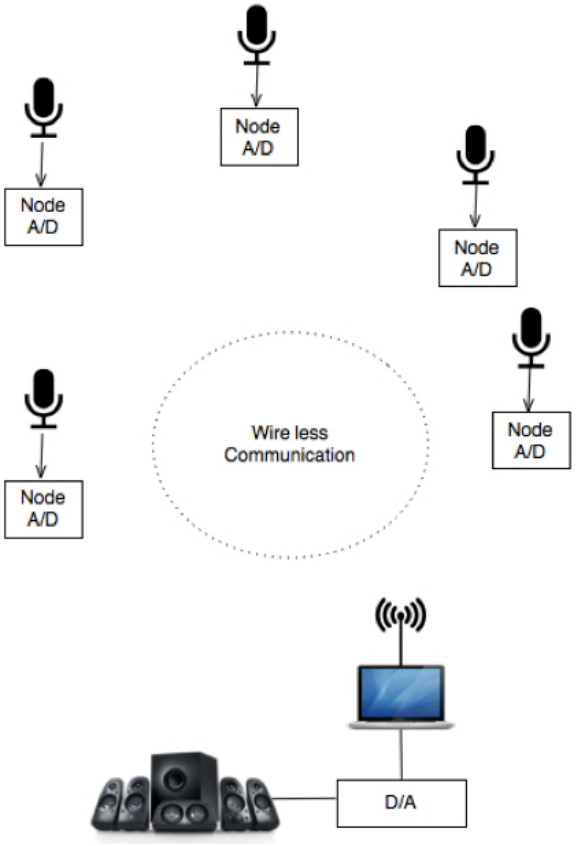

Figure 2. A general diagram exemplifying the AD/DA chain within a WASN setup, followed by audio streaming and emulation.

As shown in Figure 2, wireless communication between nodes permits a flexible configuration of the system. The acoustic sensors attached to the node's DSP can be exchanged. Depending on the need, it is possible to use microphones with different polar patterns and other acoustic-sensors such as accelerometers, hydrophones, etc. The node uses electrical power to feed itself, therefore pre-amplifiers and microphone capsules could also be fed by the same system.

To set-up an electroacoustic workflow using WSNs for sound design tasks, four main implementation steps can be defined:

1. Sound registering: The nodes capture and record sonic data (Analog-to-digital conversion – A/D).
2. DSP: At the node level, several algorithms can be implemented for different tasks, such as compression.
3. Streaming: The processed information is streamed through a wireless link to a collection point that can be a server or any computer. The A/D happens at the node before the information is streamed. Therefore, at the collection point, only digital information is received, from which further data analysis and filtering can be made.
4. Reproducing: From the collection point it is necessary to implement a Digital-to-Analog set-up (D/A) to reproduce the streamed signal. D/A set-ups are usually composed by software processing, a multichannel soundcard and a set of speakers.

As in any electroacoustic chain, the quality of the chain is mostly defined by the sensors, the A/D-D/A conversion and the speakers. Therefore, the first major advantage of working with WSNs is that the sensors, the output sound card and the speakers are fully customizable by the end user. Now, depending on the characteristics of the experience that is going to be implemented, several independent input microphones and independent output channels for connecting speakers may be demanded. Here it is important to mention that, another advantage of this type of configuration is, that the amount of channels will be given by the amount of active nodes and the chosen output soundcard, and not necessarily by the WSN technology. Extensive discussion will be further presented regarding the actual limitations of WSNs technology and how variables such as processing power versus energy consumption could be managed and optimized.

3. STATE OF THE ART

There are not many registered cases where WSNs are applied as tools for sound design. On the other hand, examples using sensor networks to capture motion for audio control are quite recurrent, especially when it comes to live performances. Such applications could also be considered as tools for sound design, although, in this publication, we are focusing on technology able not only to control audio, but to stream and process acquired data as well. Nevertheless, four experiences can be here cited as interesting approaches, where the concepts surrounding them are related to our idea.

3.1 Acoustic-WSNs for emergency purposes

In 2006, Mangharam [16] and his team described a real-time voice stream-capability deployed across a large sensor network of FireFly[2] nodes in an operational coal mine. The experimental deployment was described with a set-up of 42 nodes installed inside the coal mine facility. The platform was used to support 2-way audio streaming with sensing tasks. Even though the main objective of this experience was to use a WSN for quick emergency voice communication without the concern of the resultant low quality of the streamed audio signal, the technology involved is, indeed, real-time audio streaming. For example, a quality upgrade of the same configuration could be used to emulate the mentioned coalmine soundscape, and use it for sound design purposes.

3.2 Acoustic-WSNs and sound art

Since 2004, the research group Locus Sonus[3] has been working on artistic possibilities arising from the intersection of networked audio spaces. The main part of their current investigation concerns the transport of sound and soundscapes, which has led to the construction of streaming systems, as well as sensorial and experimental environments. Their use of streaming technology consists of a network of active microphones continuously transmitting the “unadulterated” sound of the environment in which they are placed. The resultant database is an automated online interface that permits the usage of the information being streamed in several ways, from simple live listening to sound installations, sound spatialization, mixed reality installations using acoustic and virtual spaces, etc.

3.3 Acoustic-WSNs and environmental monitoring

Donkijote[4] was an experience where a donkey and a real social network become a mobile collective device. Using solar cell panels to power a notebook, video camera, photo camera, GPS, and mobile modem, media content was produced and simultaneously uploaded on the net, developing a digital geomapped-storytelling. It surfed the net as a walking browser that anyone can ride. The complete road was mapped in real time on the net by GPS, and users accessed their position. Part of the acquired and processed data during this experience included concentration of particulate matter and noise levels [9]. Although the technology for wireless audio streaming was available at the used node, Donkijote’s node registered and processed all acquired data at the collection point, sending only sound level values to the mainframe.

Following the idea of environmental monitoring, the widespread of sensors through smartphones has opened a new way of setting-up WSNs. This configuration is commonly referred as mobile crowdsourcing and it is an area of rapid innovation [18,19,14]. For example, D’Hondt proposes in [11] the mapping of urban noise through participatory tasks. From the data gathered by 10 volunteers, her team constructed purely measurement-based noise maps of a target area with error margins of about 5dB, which is comparable to those of official simulation-based noise maps. The same set-up could serve as an audio streaming network, where users equipped with their own handheld devices could behave as audio-recording agents, able to stream real-time sonic data as one sensing collaborative network.

3.4 Acoustic-WSNs and social statements

OKNO is an artist-run organization connecting new media and ecology. In 2013, OKNO has started ALOTOF - A Laboratory On The Open Fields[5], a collaborative exploration into the potential of open-air modes of creation. Their rooftop hosted several interventions, from which “Sonic Illusions” proposed the usage of WSNs as tools for sound design. The

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[2] FireFly is a specific type of Real-Time Wireless Sensor Network platform. Their configurations are composed by several integrated layers including specialized low-cost hardware, a sensor network operating system, a real-time link layer and network scheduling.

[3] http://locusonus.org/tardis/ (Retrieved on November/2015)

[4] http://www.laboralcentrodearte.org/es/recursos/personas/cristian-bettini-a.k.a.-p.ankh (Retrieved on November/2015)

[5] http://okno.be/projects/401 (Retrieved on November/2015)

spectator was stimulated by an emulated soundscape that was acquired in another space but that made sense in the physical context of the spectator, creating the proposed sonic illusion. For this performance, a multi-channel recording was made at the rooftop of the Vrije Universiteit Brussel (VUB) Campus Kaai in Anderlecht, Brussels. These recordings were play backed in loop during the afternoon at OKNO's OpenGreens rooftop event, using a camouflaged multichannel reproduction system. VUB's rooftop has similar environmental characteristics as the OpenGreens' rooftop located at OKNO: both terraces are facing the Brussels Canal and both are between 3-4 floors high. The main idea was to make people believe that the soundscape that they were listening was the original soundscape from OKNO's terrace, while when moving outside the zone of influence of the emulated soundscape, the perceived soundscape changed drastically. This experience was developed by Felipe Reinoso Carvalho, the first author of this publication. Since, for this case recordings, were used instead of real-time audio streaming, this performance can be considered as an example of the potential usage for WSNs in the universe of sound design.

Similar experiences such as "Sonic Illusions" could also be applied as methods for urban retrofitting, improving the quality of degraded urban spaces, "importing" quiet and relaxing soundscapes into busy and stressed urban contexts, without significant investment nor drastic alterations of the existing urban infrastructure.

There are indeed on-the-go interventions in urban soundscapes that could take advantage of WSN technology for sound design purposes. Lavia presents in [2], the results of West Street Story, a 3D immersive outdoor soundscape installation that transformed the atmosphere and ambience in West Street, Brighton / UK. This installation mixed recorded and live sounds, composing them in real time. Also, The Hub[6] is considered the world's first permanent outdoor 3D soundfield. It is presented as an outdoor performance space strategically located where four shopping malls meet - located in Workington Town Centre / UK. It's an immersive sonic experience that can be configured to broadcast any live or recorded sound and it is now being used as a platform for music and soundscape broadcasting.

4. POTENTIAL APPLICATIONS

The following potential applications are related to existing experiences that could take advantage of having access to acoustic-WSNs.

4.1 Sound Design and Society

Social media has been a powerful platform for claim and debate, for example, at civil war events such as the revolutionary wave commonly known as the Arab Spring. Belgian painter Dirk Eelen used civilian-made video-footage from the Syrian revolution as its main source of inspiration for one of his latest expositions, called "Syria as seen on Youtube"[7]. By means of stills from selected video clips, he created a series of oil paintings that capture the spectator's attention due to its powerful message. The way Dirk uses technology as an artistic support is a good example of the potential of WSNs as a platform for similar experiences. If such networks equipped with microphones could be used for real-time audio streaming at urban zones, they could become a tool for communicative installations, where people could get in touch with the sonic reality of war, war that could be happening at the same time as the message is being heard elsewhere, adding tremendous value to the user's experience.

Additionally, audio branding could also take advantage of similar ideas. Advertising campaigns are becoming more sophisticated, always looking into original ways to catch the consumer's attention. WSNs are flexible and discrete enough to be used for example**,** in guerrilla marketing. Since the guerrilla marketing concept involves unusual approaches in public places, such type of campaigns are constantly adopting low-cost unconventional means to get closer to the public. Plus, audio branding has increased significantly its connection with auditory perceptive studies. Charles Spence, Head of the Laboratory of Crossmodal Research at University of Oxford is an important

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[6] http://www.allerdale.gov.uk/default.aspx?Page=1580 (Retrieved on November/2015)

[7] http://dw.de/p/17b9E (Retrieved on November/2015)

researcher into perceptive fields, such as auditory perception and audio branding. According to him in [4], to have a better understanding of auditory cognitive processes, a constant improvement of acoustic and electro-acoustic technologies involved in psychological experiments is constantly requested.

Furthermore, in the scientific community there is strong interest in observing the role of sound made by food. The first author of this publication assesses in [22, 3, 8, 12] the role of sound on taste perception. The main idea here, is to improve ambient auditory stimulation in psychophysical experiments using state-of-the-art techniques in engineering acoustics related to tasting experiences. Part of the proposed methods require the production of customized soundscapes, blending music composition with real restaurant sonic scenes, such as the sound of people eating as background noise merged with sounds of the cooking process. Although these methods don't specify the necessity of real-time audio streaming, both eating and cooking sonic-elements could be easily introduced into customized soundscapes with a WSN implementation. Furthermore, Vanbouche refers in [24] to the significance of how food in prison can become a vehicle of resistance, identity, construction, power, prestige, sociability or other embodiments of food experienced in general society. Considering the difficulty of access to prison facilities, WSNs could be a solution for further investigating the influence of prison's soundscapes on the prisoner's perception.

4.2 Sound design and healthcare

Hildegard Westerkamp [26] defined in 1974 a sound walk as any excursion which main purpose is listening to the environment. And it can be designed in many different ways. No matter what form a sound walk take, its aim is to reactivate our sense of hearing. Nowadays, sound walks are recurrent tools for different types of therapies, facilitating a patient's connection with his/her own memories and it is used as guide through meditative states. Nevertheless, not every therapeutic facility has wide-open spaces where patients can enjoy long sound walks. Immersive technologies can be used for such purposes and WSNs are easily adaptable for similar tasks, providing an infinite spectrum of soundscape libraries. It is important to highlight that a WSN that is installed at a remote natural reserve for environmental monitoring purposes can be used at the same time as a sound design tool, becoming a precious source of natural sonic-environments. Salomé Voegelin is a sound artist who refers to the importance of the ethics of listening [26] and her analysis also comes from sound walks. In her blog, she essays[8] the sonic description of quotidian experiences. The message from her work could be strongly reinforced if supported by WSNs technology, since her research is based on real life experiences.

4.3 Sound design and art

Benjamin Thigpen and Darren Copeland are two sound artists exploring new spatialization methods for live performances. In their Holosonic Music Concert[9], they performed using two hand-held, ultra-directional Audio Spotlight speakers[10]. Manual, moving-speaker spatialization with audio spotlights are combined with a second layer of 24-channel surround spatialization, also performed live. This and other sound art proposals could take advantage of WSN technology to enhance spatialization experiences, bringing real-time soundscaping into live acousmatic performances.

Speaking about Acousmatic sound, Elizabeth Anderson, doctor in philosophy of music, presented in 2012 at the *Visiones Sonoras Festival* in México her octophonic acousmatic work called *Solar Winds*[11]. As she explains in [1], her work is inspired by James Dungey's open magnetospheric model according to which the earth's magnetic field lines are connected to the interplanetary ones carried by solar winds. She had access to NASA magnetic recordings, where a low quality sonic translation of the acquired magnetic information resulted in considerable amount of undistinguished noise. Her musical interpretation is mainly based on theoretical physics and mathematical models that intend

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[8] http://soundwords.tumblr.com/ (Retrieved in November 2015)

[9] http://www.musiques-recherches.be/fr/agenda/item/5460-deux-visages-des-musiques-electroacoustiques (Retrieved in November 2015)

[10] The usage of ultrasonic frequencies in Audio Spotlight speakers [21], allow sound to be projected and reflected in space like a beam of light.

[11] http://www.cmmas.org/visionessonoras/index.php?ver=2012&lan=es&secc=guests (Retrieved in November 2015)

to model natural phenomena occurring outside our atmosphere. In the - not so near - future such phenomena could be mapped by sensing technologies. Due to actual technological limitations, Elizabeth and many other composers are many times forced to find inspiration only by means of interpretation. In a hypothetic future, the usage of WSNs to emulate extra-terrestrial, underground or underwater streaming should be feasible. This way, it would be possible to add non-accessible soundscapes into public performances.

4.4 Sound design and biology

Biologists are major consumers of WSN technologies, since they struggle with the challenge of gathering real-time data from inhospitable places. Although their main application so far involves environmental monitoring, a few studies have been conducted on the effects of sound and vibrations on plants growth and development [6], although these results are somehow contradictory. Such lack of trustworthiness may be due to absence of technological resources. As an example, from twenty days of recorded data, Lee concluded [13] that all music/spoken word might affect plant growth negatively. But what if we could easily submit a group of plants into different sonic states at the same place? Future research in biology could use WSNs to create custom-made soundscapes involving real sonic scenes from all over the world inside one single laboratory environment.

4.5 Sound design and virtual reality

Since professional interaction is becoming more and more globalized, web conferences are becoming an essential part of our daily lives. Being able to set up a global meeting with the perception that every participant is in the same room is a true desire from the developer's perspective. This perception depends not only on how "real" the surrounding environment can be emulated, but also on the interactive abilities among users. Nowadays, WSNs can be equipped with microphone arrays as input sensors, enabling beamforming algorithms to potentiate a web-conference experience[12]. Such technology is already in use in acoustic cameras, such as the Norsonic Nor848A[13]. This camera provides an accurate "zoom in" of a sound source for any soundscape. The sensation offered by this technology is similar to being able to "focus" on one specific conversation while being in the middle of a group of people having several other conversations, and by doing so, leaving the others as background noise. Let us suppose that, during a meeting, one user chooses to have a 'more intimate' interaction with a group of colleagues from the remote side of the conference, being able to "focus" on listening only to a smaller discussion, leaving the other participants as background noise. This could be achieved by merging WSN nodes equipped with microphone arrays and beamforming algorithms. The user could listen and interact with smaller groups all over the meeting environment without interfering with the progress of the whole.

5. TECHNOLOGICAL CHALLENGES

The acoustic-node implemented in a WSN does not take into consideration the quality of the reproduction chain, as the captured information goes directly to data processing and is often not being 'listened' by human ear. Nevertheless, the nodes by default receive and process sonic data, from which the addition of a reproduction chain to the system could be feasible. From the sound designer's perspective, the main concern should be the compatibility between the WSN configuration and its peripherals, such as microphones and sound cards. From the WSN developer's perspective, further discussion is required focusing on three main aspects: hardware and data processing capabilities, bandwidth available for wireless data streaming and power consumption. The technological challenges here discussed are focusing on the perceptive of the WSN developer.

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[12] http://www.lmsintl.com/acoustic-beamforming (Retrieved in November 2015)

[13] http://www.norsonic.no/en/products/acoustic_camera/Acoustic+Camera+Nor848A.b7C_wtnQYO.ips (Retrieved in November 2015)

5.1 Hardware and Data Processing

Acoustic WSNs are still technology in development, especially when it comes to continuous data streaming. In 2008 Satyajayant presented [23] a survey of multimedia streaming in WSNs, with a classification of the mechanisms proposed for streaming at each layer of the stack. It is stated that the possibility of real-time multimedia streaming opens to WSNs a whole new range of applications. The mentioned publication reviews cross-layer approaches and proposes several cross-layer solutions that combine the best approaches available at each of the layers, while optimizing the set-up for particular multimedia streaming applications. For the potential applications presented in the aforementioned survey, low-cost nodes are believed to suit best, using as many input channels as demanded. As discussed before, as long as the provided AD/DA conversion fulfils minimum requirements, the quality of an electroacoustic chain will mainly be defined by the transducers (microphones and speakers). Pioneers such as the IDEA project are constantly working at the development of low-cost acoustic nodes [7, 20]. Nowadays there are nodes built for less than 100 euros and research is striving for better performance at cheaper price. Vrije Universiteit Brussel (VUB) is directly involved in the development of WSN hardware and software applied for noise monitoring and has a clear perspective of what is expected regarding its technological advance in the near-mid future, especially when it comes to multiple simultaneous signals of transparent sound streaming (or at least within low-compressed audio formats). Two PhD candidates from the department of Electronics at VUB evaluated[14] the feasibility of implementing an application example. The example consisted of setting up a WSN composed of 50 nodes, each equipped with a microphone within 100 m radius area. Processing resources to implement each node are easy and affordable to acquire in nowadays market. With less than 50 dollars it would be possible to implement a Wi-Fi node with enough memory (512 Mbytes, 1 GHz CPU) to perform basic processing. If we are talking about dozens of channels to be streamed, more processing power should be added for the implementation of compression algorithms, so the information to be streamed could be downgraded into, for example, mp3 format (e.g. 192/320 Kbps). By doing so, the amount of data to be transmitted will be significantly reduced when compared with uncompressed formats. Furthermore, several solutions for multimedia streaming based on Raspberry Pi boards are already available[15].

5.2 Bandwidth for Data Streaming

Following the example above, if thinking about streaming 50 channels simultaneously through a closed WSN into a main hub, Wi-Fi protocol can support up to 50 Mbps bandwidth, leaving enough band for the required need without compromising its performance[5]. Wi-Fi within 100 m radius area is plausible if working at open field and considering two key factors. First, having physical obstacles in the working area will always limit the bandwidth behaviour. Second, the biggest limitation of bandwidth relies on working at a clear frequency band, meaning that other devices working at the same chosen frequency band can reduce the performance of our network transmission significantly. If working indoors, for the same network configuration the acting radius should be reduced at approximately 20 m^2. Wi-Fi repeaters are commonly used to achieve longer distances such as the Netgear range extenders[16]. After concentrating all streamed channels at one main hub, an Internet connection can be attached for transferring all the collected data. An Internet connection able to transmit with the requested bandwidth can be found for enterprise clients. Nowadays, commercialized home connections can't provide the necessary bandwidth in the upload channel.

One advantage of working with WSN nodes could also become a disadvantage. The option of using the node as a power source for microphones means that the node is being powered externally, i.e. by means of a continuous powering (Ethernet, plug) or a limited lifetime battery. Such feature could constrain the freedom of positioning nodes at any desired place, although WSN developers

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[14] Personal Interview between the author and both PhD candidates: Jelmer Tiete, Federico Dominguez (July, 2013).

[15] http://www.raspberrypi.org/ (Retrieved in November 2015)

[16] http://www.netgear.com/home/products/wireless-range-extenders/wn3000rp.aspx (Retrieved on November 2015)

are aware of the limitation and an objective to be constantly improved is the implementation of low-energy consumption tasks, progressively optimizing the necessary energy allocation. In this case, an important issue to be aware while choosing microphones is their consumption characteristics. Another way to manage energy consumption of networks is by the choice of the network protocol**.** The usage of IEEE 802.11 family protocol (basis for products using Wi-Fi brand[17]) is advised when it comes to robust data streaming, such as raw audio data. Due to its robustness, it demands considerate amount of power. For audio streaming applications, IEEE 802.11aa sub-family is considered as the ideal protocol [10]. One disadvantage of this protocol family is that it can only work within star network topologies. If comparing with Wi-Fi standards, IEEE 802.15.4 family protocol (from which ZigBee is a common denomination) offers much lower consumption and multi-hop for communication topologies is included in its higher layers (peer-to-peer)[18]. This protocol is quite limited when it comes to robust-constant data streaming, but when raw data and constant streaming is not mandatory, it can be adapted for highly compressed formats, enabling periodic streaming. Brunelli is a researcher that visualized the potential of audio streaming using multi-hop networks, proposing in 2008 the improvement of audio streaming over multihop Zigbee Networks [5]. He presents a Push-to-Talk application, which allows the investigation of the capability of Zigbee protocols for low-rate voice streaming and the trade-off between audio quality and power consumption comparing different compression algorithms. Zigbee Networks allow the exchange of information between nodes - control signals, trigger signals, etc. For example, one node could only stream when another is capturing signals below 90 dBs, and so on. Also, the peer-to-peer feature permits that the signal of one far-away node can be transmitted through other nodes creating a transmission chain, avoiding signal loss and allowing nodes to go further away from the gateway (gateways are similar to Wi-Fi repeaters). Depending on necessities and limitations, Wi-Fi and Zigbee protocols can be combined admitting the implementation of a powerful, flexible and more affordable multi-channel audio-streaming network. In order to obtain data reduction, Molina presents in [17] a new configuration of Heterogeneous Networks consisting of a collaborative processing configuration composed by multimedia and non-multimedia nodes. By multimedia nodes we are referring to nodes equipped with sensors; non-multimedia nodes are the ones used only for data streaming support or controlling purposes. Here, it is important to consider that, when working with transmission channels composed by several nodes, if all the information coming from a different transmission channel has to arrive at the same time, latency compensation must be applied. Being able to combine different network configurations could also help optimizing and reducing the amount of data to be transmitted. Figure 3 shows the option of having wired networks for small distances interconnected by Wi-Fi Hubs, from which a star wireless network could emerge, being able to achieve longer radius ranges. In this case, wireless transmission is only used when the distance demands, therefore reducing costs, optimizing components and energy consumption. Also, if necessary, multihop nodes could be used as complementary add-ons for interaction features between nodes. For example, future transmitters could switch frequency channels on the fly supported by multihop technology, being able to handle heavier and heavier data ranges while allowing dynamic changes in the WSN topology.

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[17] http://standards.ieee.org/about/get/802/802.11.html (Retrieved on November 2015)

[18] http://www.zigbee.org/About/UnderstandingZigBee.aspx (Retrieved on November 2015)

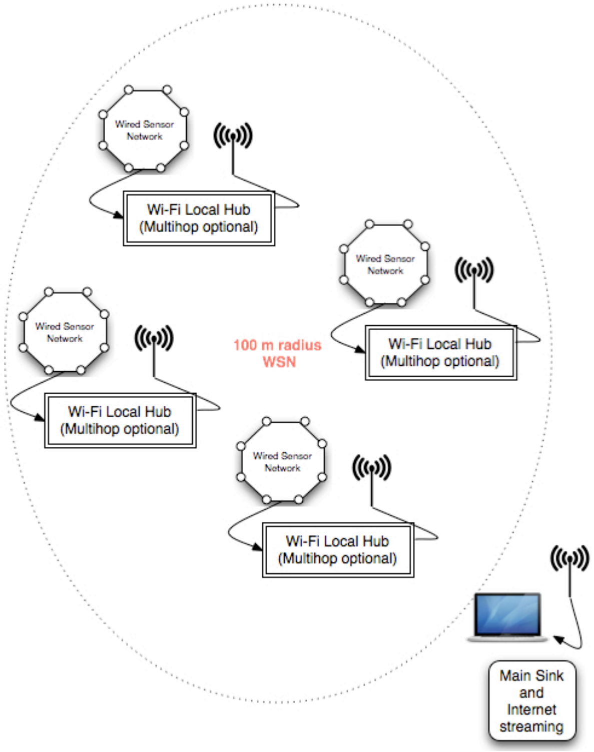

Figure 3. Example of different combination of network configurations. The flexibility provided by WSNs can help optimizing resources, reducing the amount of data to be transmitted.

5.3 Power consumption of a WSN system and energy harvesting possibilities

The necessary technology to develop a WSN set-up capable of processing and transmitting the desired data exists. But there is still the key issue of powering every node via battery and this is an important limitation of this technology for a full independent wireless-streaming experience. Data streaming and audio compression demands a considerable amount of processing, therefore strong energy consumption. Even if we manage to keep each node running for a day without recharging it, eventually each battery on each node will have to be replaced by a charged one. So, what was supposed to be an autonomous user-friendly solution becomes a logistic challenge. Fortunately, the technology involved in WSNs is the same used in the handheld devices industry. And, since we are talking about one of the most profitable and growing existent markets, huge amount of resources are constantly being allocated into balancing the progressive need for computational performance improvements versus lowering the price/size of components and developing new ways to extend batteries' lifetime. Furthermore, research on the abilities of charging them using natural resources such as sun and kinetics is a recurrent approach, especially when it comes to small batteries, such as the ones used by WSN nodes. Nowadays, it is possible to create a full autonomous system using components that are commercially available, whether the system is just a blinking LED or an FPGA demanding heavy signal processing. In other words, if you redesign a system, so that it consumes twice as much power, you can always make your solar panel surface twice as big, although there are several factors that will influence the power management of any system [30]. For example, with a large enough solar panel it is possible to power a Pentium 4 at 2.4 GHz [25]. Although it is easy to find power supplies providing constant 100 Watts (the equivalent of a laptop adapter), there are essential factors to have in mind when it comes to set-up a system for energy harvesting, such as: where the system will be deployed; the amount of sunlight available in such place; types of ambient energy available (thermal gradients, vibrations, mechanical energy); size constraints to the complete system; the acceptance of replacing batteries if their maximum amount of charge-discharge cycles have been reached; etc. The fact is that infinite autonomy is available. Constraints will be cost and size, common variables being constantly managed and updated by the industry. Yannick Verbelen proposes in [25] a novel model for parameterization of ambient energy harvesters, showing that physical and electrical properties of generators can be expressed as a maximum power and an environment dependent efficiency. The minimum size of any generator could be calculated for a combination of system requirements, and the target environment of the system, using a straightforward design methodology. He also presents that the efficiency parameter can quickly be obtained by normalized benchmarking of the target environment [25].

6. ETHICS INVOLVING AUDIO STREAMING

When talking about independent computational entities performing information streaming, ethics comes as an essential part of the discussion. One of the latest examples on how sensing technologies applied into surveillance can have multiple reactions is PRISM (National electronic surveillance program operated by the United States National Security Agency). Edward Snowden discloses in 2013[19] how PRISM applies sensing algorithms to patrol U.S. and worldwide citizens through social networks and e-mail accounts by collecting, analysing and recording personal - and supposedly private - information without individual authorizations. While the North American government justifies such actions by explaining that their intention is to target specific persons - like foreign politicians or terrorist suspects - they end up collecting everyone's information simply because it is easier, more valuable, and more effective. And here is where the conflict lies. After further specific analysis, it is always possible to go back in time on anyone's archived data. And since decisions on how to proceed regarding such information are still made by humans, the entire 'on-line' population is submitted to judgment mistakes of a few 'powerful' strategists. How this applies to WSNs? If you consider your e-mail, Facebook or Twitter accounts as nodes from an immense network, PRISM central server works as the sensing core of the network, recording and processing all your - and everyone's - data.

Locus Sonus proposals (3.2) could also have had ethical implications if not understood correctly. These experiments are being conducted through an evolving network of permanently open microphones producing multiple audio streams, relayed by the Internet and by a programmed server. Such open microphones are spread around the globe and maintained by a large number of collaborators providing live sound material for subsidiary projects. Potential collaborators for such experiences should be aware that all messages being streamed by the system are travelling through the Internet and the correct usage of 'white data' is a recurrent discussion in today's society. In this case, the information being streamed has the objective to provide sound material for subsidiary artistic projects, projects that will have the liberty to manipulate the original message and playback any possible results.

7. CONCLUSION

Acoustic-WSNs are presented here as breakthrough technology for sound design. Such networks can mainly add value to the message by means of providing opportunities to sum real-time audio information into soundscaping. And such usage could go even further. It could, for example, help on-field audiovisual producers to identify ideal locations and time frames for future high-quality on-location sound recordings.

This article mainly refers to the usage of wireless sensing technologies equipped with acoustic sensors. But what happens when the challenge is to create new sounds and new atmospheres? Other interesting applications could involve different type of sensors, such as particle sensors, humidity, temperature, etc. From which it would be possible to transform different forms of data into sonic data, a more and more recurrent sonification task among sound designers and music composers.

It is plausible that the main limitations regarding the usage of WSNs as a tool for sound design are related to the novelty of the technology and its ability to adapt for such purpose. Therefore, a good relationship between sound designers and WSN developers must be cultivated from the beginning of the process. The sound designer should be involved preferably from the moment that the technology is being customized, so he/she can participate during technical decisions that could affect drastically its performance. An extra interest from developers on how the network is going to be used is always a plus and can help optimizing the final hardware architecture. From this point of view, the fact that most WSN developers are still located at research and academic facilities could be interesting. Multidisciplinary interaction usually leads to new ideas and prototyping. At the speed technology is evolving, most of the challenges here discussed may overcome in the next years. Since this manuscript is being submitted to an audio conference, it is intended to summarize the challenges behind WSN design and development in

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[19] http://www.guardian.co.uk/world/video/2013/jun/09/nsa-whistleblower-edward-snowden-interview-video (Retrieved in 2015)

friendly way, in order to nourish and inspire sound designers, and researchers in the general field of sound engineering.

Going back into the ethical issues involving real-time audio streaming, history has shown more than once that not every scientific discovery has been used for the greater good of society. Ideas such as this one aim to bring science and technology closer to art and communication. However, the usage of sensing technologies is expanding rapidly through different paths and it is up to us, researchers, to define its historical transcendence, proposing innovative and useful applications.

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