A Home Automation based Environmental Sound Alert for People experiencing Hearing Loss

Matthias Mielke[1] and Rainer Brück[2]

***Abstract*— Different assistive technologies are available for deaf people (i.e. deaf, deafened, and hard of hearing). Besides the well-known hearing aid, devices for detection of sound events that occur at home or at work (e.g. doorbell, telephone) are available. Despite the technological progress in the last years and resulting new possibilities, the basic functions and concepts of such devices have not changed. The user still needs special assistive technology that is bound to the home or work environment. In this contribution a new concept for awareness of events in buildings is presented. In contrast to state-of-the-art assistive devices, it makes use of modern Information and Communication and home automation technology, and thus offers the prospect of cheap implementation and higher comfort for the user. In this concept events are indicated by notifications that are send over a Bluetooth Low Energy mesh network from a source to the user. The notifications are received by the user's smartwatch and the event is indicated by vibration and an icon representing its source.**

I. Introduction

Degradation or loss of sensory perception can limit the quality of life of an affected person. This is especially the case for people experiencing hearing loss or loss of vision. To provide deaf people (i.e. hard-of-hearing, deaf, deafened) with information about sound, different assistive technologies were developed to support them in various situations and ways. The arguably best-known technologies are hearing aids and cochlear-implants. This kind of assistive technology aims to improve or restore hearing. However, different other devices are available that indicate when an acoustic event has happened.

A selection of such indicating devices (in the following called environmental sound alert) is available at the market-place for many years. But, despite the technological progress in the last years, the basic principles and offered functionality have not changed considerably. They are bound to indoor environments and are targeted to specific events, e.g. the ringing of the doorbell or telephone. For each new sound (we refer to the concept of "everyday listening" introduced in [4]) a new detector has to be bought. Either the detector indicates an event directly, usually by a flashing light, or it sends a message to a receiver using a wireless connection. When receiving the message the receiver indicates the sound by visual signal (flashing light or illuminating an icon) and/or by vibration. Examples of environmental sound alerts can be found in [3] and [1]. Even though these devices are effective, they have several disadvantages: 1. Not every sound can be detected by such a system. Sounds for which no detector is available cannot be indicated. 2. These devices are expensive due to the relatively small clientele. 3. The user has to take care of separate devices; e.g. in case of a portable receiver, she must carry it around with her and has to make sure that the battery is not empty. 4. They are bound to indoor use. New technologies make it possible to rethink this kind of assistive technology. The introduction of new Information and Communication Technology (ICT) and the advent of new technologies like home automation and the Internet of Things provide possibilities for cheaper, enhanced and more convenient assistive technology.

In this contribution we present a concept for an enhanced environmental sound alert, focussing here on the indoor environment. The centre of the system is a smartwatch (alternatively a smartphone), which is complemented by home automation technology to notify the user about sounds. The smartwatch was chosen because of its easy integration into daily routine and of high interest in using smartwatch based technology expressed by deaf people [8].

The rest of the paper is structured as follows: in the next section we provide a brief description of the overall concept, followed by an overview of home automation systems and the description of the proposed approach. A discussion closes the paper.

II. Ubiquitous Sound Awareness through ICT

As mentioned before, the centre of our proposed system is a smartwatch. A smartwatch provides sufficient processing power even for demanding algorithms, therefore can be used for ubiquitous sound awareness. The proposed approach employs two strategies (see Fig. 1): in outdoor or unknown environments the smartwatch runs sound recognition algorithms that are monitoring the acoustic environment for sounds that are of interest to the user [9]. In indoor environments it is also advantageous to exploit the knowledge about the environment by complementing the sound recognition algorithms with sensors for events. To realize the sensors and the communication with the smartwatch we propose the use of home automation technology that communicates with the smartwatch wirelessly. Home automation technology was already successfully used to support people with limited physical or cognitive capabilities [12], [5].

The application can automatically switch to the home environment which allows a seamless and comfortable awareness of environmental sounds.

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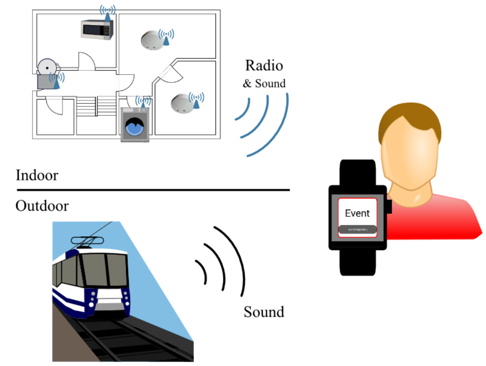

Fig. 1. Concept for ubiquitous sound awareness using ICT.

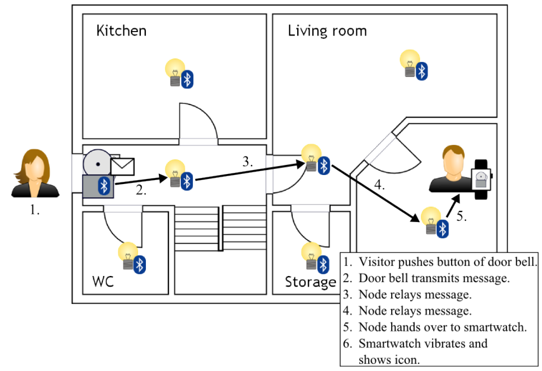

Fig. 2. Example use case of the proposed system.

III. Home Automation

The idea behind home automation is to increase the quality of life through technology. Home automation promises energy savings, improved security and occupant safety, comfortable and convenient living solutions, reduced equipment maintenance and operational costs, increased lifetime of the equipment, as well as positive environmental effects [13]. A variety of network technologies – both wired and wireless – has been used for home automation. Wireless technologies have the advantage that no rewiring is necessary when installing a home automation system. Currently, different wireless technologies are competing for the home [13].

Among the numerous wireless home automation systems reported in literature are systems basing on Bluetooth and Bluetooth Low Energy [2], [14], [10], [11]. Bluetooth (Low Energy) is a widespread standard designed for low power applications and is supported by current ICT, i.e. almost all current smartphones, -watches, and tablet computers. Its widespread support by commercial products allows easy integration of them into Bluetooth based home automation systems. All of the above cited systems have in common that they are using a standard Bluetooth network with one central master, i.e. either a PC [2], [14] or a smartphone [10], [11], and sensor- and actor-devices that act as slaves. Even though a centralized, single-hop network of devices is the standard configuration of Bluetooth, the Bluetooth Special Interest Group recently announced the standardization of a Bluetooth based mesh network[1] to build multi-hop networks. In a mesh network all devices (called nodes) are interconnected. A message is transmitted by forwarding it from one node to the next. Each node acts as relay stations for messages.

IV. Home Automation based Sound Awareness

As explained before sensors are used in the home environment beside sound recognition to improve reliability. Home automation provides the opportunity to notify deaf people about sounds in a house. The concept and the prototype that was implemented to show the feasibility of the proposed approach are presented in the next sections. We build upon a Bluetooth based mesh network, because it is a promising approach to implement home automation systems.

A. Concept

The basic idea of the concept is that the devices generating sound which is of interest to the user will be equipped with a transmitter. When the sound is generated, a notification is sent through the mesh network to the end device (smartphone or smartwatch) of the user. The mesh network is formed by home automation technology (e.g. for controlling the lights). This approach offers more convenience for the user, because she does not need to take care of an extra notification device.

The proposed system consists of nodes that implement different roles. Three roles were identified for the nodes:

1) *Source*: A source is the sender of a sound event. It can employ different methods to detect such an event. E.g. a doorbell can be detected either acoustically or electrically through the push button.
2) *Network Nodes*: These nodes form the mesh network. Their task is to relay the data packets in the network.
3) *Sink*: a sink is a device that implements an actual user interface and indicates the detection of a sound. In relation to mobility a sink can be realized in one of two formings:
    a) *Stationary sink*: A stationary sink is an output device that is bound to one place and thus not moving. An example is a light fixed near the doorbell that flashes when it rings.
    b) *Mobile sink*: A mobile sink is a mobile output device, i.e. a portable device carried around by the user. E.g. a smartwatch or -phone.

It has to be noted, that one device can implement different roles. A source can also act as a network node and relay incoming messages, as well as a network node can be a sink too (e.g. a stationary power plug with a flashing light). All devices that are part of the system and implement one or more of the roles described above are equipped with a Bluetooth Low Energy module to transmit and receive messages. An example use case is shown in Fig. 2. Here the user (right in Fig. 2) is notified of the ringing of the doorbell. A notification message is send by the doorbell (acting as source) through the mesh network to the sink, the

[1] Press release available online: `https://www.bluetooth.com/news/pressreleases/2015/11/11/bluetooth-technology-to-gain-longer-rangefaster-speedand-mesh-networking-in-2016` (accessed 05/17/2016)

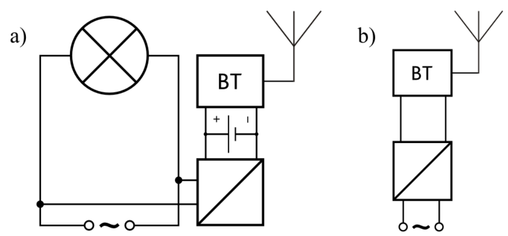

Fig. 3. Block diagrams of the battery buffered ceiling lamp configuration a) and power plug configuration b).

smartwatch of the user. The network nodes are composed by Bluetooth enabled lamps in the house. However, a realistic system would consist of many source nodes and can consist of more than one sink node.

B. Prototype Implementation

The prototype was realized with Bluetooth Low Energy modules (BLE Nano from RedBearLab[2]) basing on Nordic Semiconductor's nRF51 chip series. The modules were chosen because they readily integrate RF and an ARM Cortex M0 microcontroller. A Bluetooth stack and free development software facilitate implementation and integration of own application code directly on the module, eliminating the need for a dedicated application controller. Our prototype realizes the use case shown in Fig. 2. We implemented the sink using an Android Wear smartwatch, and designed some hardware for the source and network nodes. The source is a node equipped with a push button to simulate the doorbell, but can be used to simulate other devices as well. A network node can be implemented in different ways and we decided to implement two designs:

1) *Ceiling lamp configuration* (Fig. 3 a): Here the mesh node is integrated in a ceiling lamp. Ceiling lamps are usually positioned in a way to provide good illumination in the room, often in the centre without obstructions nearby. This positioning is also ideal for RF signals. The prototype is equipped with a battery to allow operation when the lamp is switched off.
2) *Power plug configuration* (Fig. 3 b): The node is implemented in a power plug. The advantages are simple installation and continuous power availability, while the disadvantages are the blocking of a power outlet and the position near the wall, which is not optimal for RF signals.

On the software side, we make use of the open source Bluetooth mesh network implementation FruityMesh[3] [7] for the prototype. FruityMesh was designed with low power in mind to support battery powered network nodes with a reasonable runtime and is based on the Bluetooth standard v4.1, so that current ICT can connect to the network. The network is self-healing in case of node failures. FruityMesh

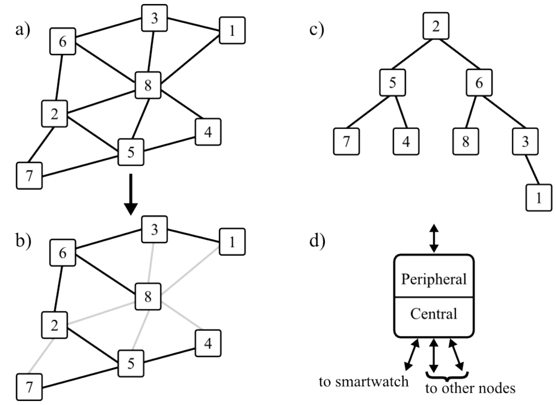

Fig. 4. Generation of a mesh network. a) Initial Situation. b) Resulting Network. c) The resulting network as tree. d) Connections of a node in the implementation.

transmits messages through connections between the nodes. A connection is a bidirectional communication channel for exchanging messages between two Bluetooth devices. It can only be established between one device acting as *central* and a second acting as *peripheral*. Connections are scheduled in intervals (*connInterval*) and in between the devices go into sleep mode to save energy [6]. Since the number of available connections is limited through the resources of the nodes (in case of the used Bluetooth stack three central and one peripheral connection (Fig. 4 d)), the algorithm has to decide which devices establish a connection. For a given set of nodes (Fig. 4 a)) the FruityMesh algorithm forms a spanning tree (Fig. 4 c)) that determines which nodes connect (Fig. 4 b)). The tree is formed by local decisions in the individual nodes basing on information about the neighbours. When starting forming the network, each node is the only member of its own cluster and broadcasts its parameters (i.a. the unique node id, cluster id and size, and number of free connections) to the nodes in range. After a specified time, each node evaluates all received data with a score function to determine the next action, that is either to connect to another node for expanding the own cluster or to leave the own cluster to join one of larger size (or, in the first round, a cluster with smaller id). Afterwards the nodes broadcast packets with updated information. This process is repeated several times and terminates after a fixed time. An extensive description of the algorithm is found in [7, p.44ff.].

This algorithm is problematic when a mobile sink serves as network node in the mesh network. When the sink moves, it may be necessary to rebuild the mesh; an energy hungry process that would sacrifice the run time of battery powered nodes. To prevent this, a mobile sink may not act as a network node and may only be integrated as a leave node in the tree. Connectivity is ensured by reserving one central connection of a node for sinks (Fig. 4 d)). Therefore, the mobile sink has to act as a peripheral to connect to the network. When acting as a peripheral, the sink advertises its presence to the mesh network by broadcasting advertising packets. These are received by the nodes in range, which reply with a connection request packet. The sink checks the

[2]Documentation online `http://www.redbearlab.com/blenano/` (accessed 05/17/2016)

[3]FruityMesh is available at `https://github.com/mwaylabs/fruitymesh` (accessed 05/17/2016).

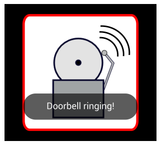

Fig. 5. Notification screen icon to indicate the ringing of the doorbell. A Toast provides a textual representation of the event.

received signal strength (RSSI) of the packets and connects to the node which sent the packet with the highest RSSI, assuming that it is the nearest node of the network. This network node now becomes the *handler* of the sink. Its task is to relay event messages from the network to the sink. When it receives an event message, it transmits the message that consists of a field identifying the type of the sender and the type of event to the sink. The sink decodes it and issues a notification to the user. On the smartwatch, a notification consists of a vibration to draw the user's attention to it, and an icon that shows the source of the event (Fig. 5). The screen is turned on so that the user does not have to interact with the watch to see the notification. Despite the connection to the handler node, the smartwatch still advertises its presence. When a node with higher RSSI becomes available, it terminates the old connection and establishes a connection to the new node that thereon becomes the handler.

V. Discussion

The presented approach showed good performance in the laboratory and it provides several advantages compared to up-to-date assistive systems. These are:

- The approach can be expanded in two ways: like traditional systems a sound source can be detected by specialized detectors. By way of standardisation they would be interoperable. Or by generic sound detectors that are trained to detect a sound.
- The approach has to be seen in the context of home automation that aims to connect home appliances. Viewed from this point, the costs for the system are relativised when various devices will be equipped with the wireless connectivity. Already today several connected systems are available (e.g. lamps and smoke detectors). Additionally, we expect that a notification system would also be of interest to other users and should be implemented in a "Design for all" fashion. The proposed approach is therefore a building block of a home automation system.
- The use of smartwatch and smartphone makes the integration into the daily routine simple [8].
- The combination of strategies allows ubiquitous awareness of environmental sounds inside and outside the house.

But there are still obstacles for the use in the actual home, which should be discussed here. Even though we envisioned the use of battery powered or backed nodes, this is not achieved easily. To achieve low energy consumption Bluetooth Low Energy makes use of scheduled connection events in which data is exchanged. This introduces a delay for relaying a packet from one node to the next which equals *connInterval* in the worst case. The total worst case delay of a message is given by the number of hops *n* between sender and receiver and *connInterval*: $t_{delay} \leq n \times connInterval$. The longest delay in the network is determined through the longest path in the spanning tree. So there are contradicting requirements: a fast transmission for low reaction times requires a small value for *connInterval*, which in return would result in a high energy consumption [6]. A good trade-off has to be chosen between latency and energy consumption with network size in mind.

Another disadvantage is the short range of Bluetooth Low Energy which makes it necessary to equip a house with a sufficient number of nodes for comprehensive coverage. A dedicated system would be of high cost that can only be relativised when viewed in the context of general home automation (see above).

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