How user requirements affect technology choice for wireless hearing instruments

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Abstract

Wireless technology is widespread in our society. However, there are many types and methodologies used for wireless transmission. This paper summarizes the different types of wireless technology available for hearing instrument usage, and explains the rationale behind ReSound's selection of a proprietary system that uses 2.4 GHz technology. After extensive market research, it was found that 2.4 GHz technology could better meet the needs of the hearing instrument end-user. These needs include the elimination of lip synch and echo effects for streaming and the ability to connect to a multitude of audio sources without the need for a body-worn neck loop. In addition, the needs of the fitter were addressed through design of a system to program the hearing instruments without any intermediate cables or body-worn accessories. 2.4 GHz technology then was the clear choice when designing ReSound's wireless hearing instrument line, due to its robust connections to external audio sources and superior audio quality.

The term "wireless" covers a multitude of technologies for transmitting information for many different purposes without the use of electrical conductors (i.e. wires). Hearing instruments have long utilized analog wireless technology in the form of telecoils and FM systems. Use of these technologies can benefit the user by greatly improving the signal-to-noise ratio in certain situations. More recently, hearing instruments have become available that use digital wireless transmission, either to exchange information between right and left devices or to receive information from another source, such as a television or telephone. As with digital hearing instruments, digital wireless transmission enables more possibilities for signal processing than analog. In addition, digital wireless transmission generally has improved signal-to-noise ratio compared to analog and, depending on the particular technology, less susceptibility to interference and encoding for privacy. Digital wireless features in hearing instruments can thus extend and expand on the already established benefits of analog wireless.

"Digital wireless" is also a term that applies to vastly different implementations. Any one of these varying technologies is not inherently superior to others, but it is the case that for any application, some will be better suited to the job than others. This is particularly true for hearing instruments. In selecting the optimum digital wireless technology for use in hearing instruments, it is important to carefully consider both user needs and feasibility of implementing the technology. For example, Bluetooth is a digital wireless technology standard used in many devices, including some that would be convenient for hearing instruments to communicate with, such as cell phones. Thus one would think that Bluetooth might be the best choice for hearing instruments. However, Bluetooth introduces delay to audio signals that may not meet user requirements in many situations. In addition, the exceptionally high power consumption compared to typical hearing instrument battery requirements makes it impractical for this application.

The digital wireless technology selected for ReSound hearing instruments is a proprietary system that operates in the 2.4 GHz ISM (Industry, Scientific, Medical) frequency band. This article will discuss how analysis of hearing instrument user and hearing instrument fitter requirements and practicalities of implementation and design led to this choice.

User requirements narrow the options for wireless technologies

ReSound relied both on published surveys, such as MarkeTrak, as well as thorough market research (Groth & Anthonsen, 2010) in defining user requirements to a hearing instrument system with wireless features. Users were considered to be both the hearing impaired individuals who wear the hearing instruments as well as the professionals who fit the hearing instruments. Because hearing instruments with digital wireless technology have been commercially available for several years, it was also possible to observe and analyze how users interact with existing products, and to use this as a way to further uncover user needs. A team consisting of specialists in Human-Computer Interaction science, software designers and audiologists visited fitters at their practices and studied how they worked with commercially available hearing instruments with wireless features, as well as how they counseled their clients on using these products. The team was able to identify how well these systems supported the fitting and counseling task flow and where breakdowns occurred. For example, one product did not provide a clear connection status during fitting, which resulted in the fitter losing connection without realizing it. Another product required the fitter to interpret blinking lights on the programming interface to know when the hearing instruments could be placed in the client's ears. A general issue for the different systems was that choosing the programming interface was not obvious for the fitter. Considering such issues, it was not surprising that many fitters continue to use cables to fit "wireless" hearing instruments. In Germany, approximately half of 152 hearing care professionals surveyed reported that they almost always used cables to fit products offering wireless fitting.

The most important user needs that emerged from this extensive requirements analysis for both end-users and fitters are listed below. Interestingly, requirements involving communication between hearing instruments were not valued as highly as connectivity to external devices, although hearing instruments with such capabilities are well- known in the market. Fitters in particular expressed the view that wireless communication between bilaterally fit devices had resulted in only marginal if any improvements in hearing for their clients, although some felt strongly that the convenience of changing volume and programs simultaneously was important. Market research carried out in the form of focus groups and formal surveys with hearing care professionals and end-users in Germany, France and the US returned consistent results: using wireless connectivity to achieve better solutions for connecting to phones and TVs were viewed as having the biggest impact on user satisfaction and constituted the most desired improvements for wireless applications. The choice of wireless technology for the ReSound system ultimately was based on how many of these prioritized requirements could be satisfied.

Fitter requirements

- No cables, no intermediary devices
- Long range of connection
- Robust connection
- Plug and play
- Easy to use fitting system

Hearing instrument wearer requirements

- Body-worn device not necessary
- Connectivity to television and cell phone
- Long range of connection; stable connection
- Excellent audio quality
- None or limited delay of streamed sound for television (no lip synch problems)
- Simple to set up and use
- Connect to multiple audio devices; multiple users connect to the same audio source

Challenges in meeting requirements

Some of these user requirements immediately led to the disqualification of the digital wireless technology used in most hearing instruments known as NFMI (Near Field Magnetic Induction). While NFMI-based technology would have been the easiest to implement in terms of research and development investment, this technology would not have allowed ReSound to solve the issues most important for users. This is primarily because it was clear that the hearing instruments should be the center of the wireless system, not an intermediary streaming device. With NFMI, a body-worn streamer with an inductive neck loop is the center of the system. This device receives signals from far sources and relays them to the hearing instruments via induction. The range of NFMI is limited to only a few feet, so audio streaming can only occur if the user is in immediate proximity of the streaming device and the hearing instruments must be oriented optimally in relation to the magnetic field, meaning that the streamer must be worn on the body. A third device is required to connect to audio sources to transmit sound to the intermediary device using Bluetooth wireless technology, although audio sources with built-in Bluetooth technology - common in cell phones and some digital music players - can send to the intermediary device directly. The user requirement not to rely on a body-worn device is not met with NFMI-based technology.

It was also clear that Bluetooth was not an optimum solution. Although it operates in the same 2.4 GHz ISM band as ReSound's proprietary technology, Bluetooth is an open standard for wireless communication. It can be used for myriad applications not only encompassing streaming of audio signals but also for such diverse things as wireless computer networks, game controllers, and even programmers for electricity meters. Currently there are nearly 12,000 different products using Bluetooth. Communication protocols for Bluetooth must therefore be broad enough and flexible enough to accommodate these many uses. Because of this, Bluetooth eats up more computational resources and requires much more power to operate than a design for a specific application, such as hearing instruments. Although minimal power consumption did not emerge as an important user requirement, Bluetooth is simply not feasible for direct implementation in hearing instruments.

Because Bluetooth is used to stream audio to the body-worn streamers of NFMI-based hearing wireless hearing instrument systems, it was important to consider the effects of this technology on sound quality. Using Bluetooth for audio streaming introduces a delay that is likely to be unacceptable for television viewing, particularly in the case where direct sound and streamed sound are combined. Bluetooth-based systems that stream audio use a method called A2DP (Advanced Audio Distribution Profile) that describes how Bluetooth enabled devices such as an MP3 player or a microphone can transmit audio to a receiving device such as a wireless headset. The latency for this protocol exceeds 40 milliseconds, and is commonly up to 125 milliseconds depending on the audio compression technique that is used. If the streamed sound combines with sound amplified via the hearing instrument microphones, or with direct sound entering the ear canals in an open fitting, delays of this magnitude are likely to cause the perception of echoes and even lip synch issues when watching television. Even when the delay is small enough not to be consciously perceived, a mismatch between audio and visual signals has a significant negative impact on the television viewing experience (Reeves & Voelker, 1993).

Figure 1 compares delays of audio signals streamed from a home stereo system to three wireless hearing instrument systems. The delay is measured by comparing the arrival of the sound coming from a loudspeaker to the ear of a KEMAR manikin with the arrival of the sound arriving in the ear via the wireless transmission and hearing instrument. The NFMI-based systems that stream from the audio source via Bluetooth introduce very large delays that are likely to be disturbing for listeners. The user requirements for excellent audio quality and no lip synch issues are not met with this technology.

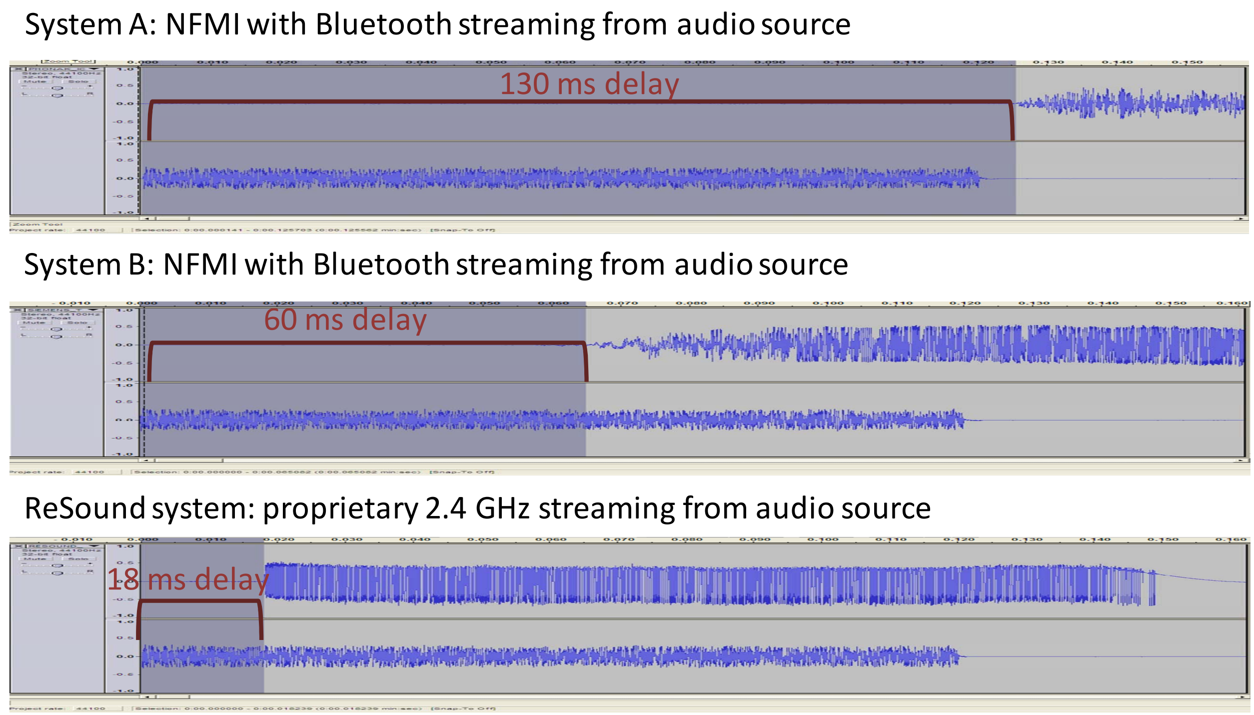

Figure 1.The delay of streamed sound relative to direct acoustic sound for two NFMI-based wireless hearing instrument systems and the ReSound 2.4 GHz wireless system. The NFMI systems stream from the audio source to the body-worn streamer using Bluetooth, which causes large delays. System B likely uses “low density” audio compression, resulting in poor audio quality. The ReSound system uses high density audio compression and keeps delay low for optimum audio quality.

A final issue with NFMI and Bluetooth streaming is that there is a one-to-one relationship between audio sources and the body-worn streamer. This means that a married couple wearing hearing instruments with the same wireless capabilities would not be able to share streaming devices in their home: two separate streaming devices connected to the television would be required, as would two streaming devices connected to the telephone. Likewise, the hearing instrument user with a television in both the living room and the bedroom would not be able to connect to separate streaming devices, but would have to move the same streaming device from room to room. Thus the user requirement to connect to multiple audio devices and for users to share connections is not met.

Taken together, NFMI as well as Bluetooth violate too many of the defined user requirements to wireless hearing instrument features to be acceptable as wireless technology platforms.

Meeting hearing instrument user requirements

Simplicity with no body-worn device

As mentioned previously, NFMI-based systems rely on a body-worn streamer as the center of the wireless hearing instrument system. Other devices that connect televisions or telephones, *and* the hearing instruments themselves are subordinate to the body-worn streamer. The 2.4 GHz technology chosen by ReSound offers more flexibility in designing the system. During the product development process, hearing instrument users evaluated two different concepts to determine which was perceived as most simple. The first concept was somewhat similar to existing NFMI-based systems in that it used a "personal streaming unit" as the center of the system. The difference was that the user would not necessarily be required to wear the device when in use due to a greater range of wireless transmission. This unit contained both 2.4 GHz wireless capabilities as well as a Bluetooth receiver. It would serve as a remote control for the hearing instruments, an interface to cell phones and other Bluetooth-enabled devices as well as a control unit for activating audio streaming.

The second concept configured the system with the hearing instruments as the center, as shown in Figure 2. With this concept, the hearing instruments control all connections, and the user needs only the hearing instruments to be prepared to use wireless features. Using separate streamers for transmission from multiple devices, like the television in one room and home stereo in another, are not regarded as separate solutions, but rather as just another connection handled by the hearing instruments. This turned out to be an easily grasped concept for users, and was preferred over the central controller by the majority of participants. In addition, this solution offers users convenience and mobility not available with other current approaches. Not only can the wearer connect their hearing instruments to multiple devices, they can share wireless accessories with another user. As an example, an individual wearing these devices visiting the home of another owner of this system could connect to their TV streamer to enjoy a football match together.

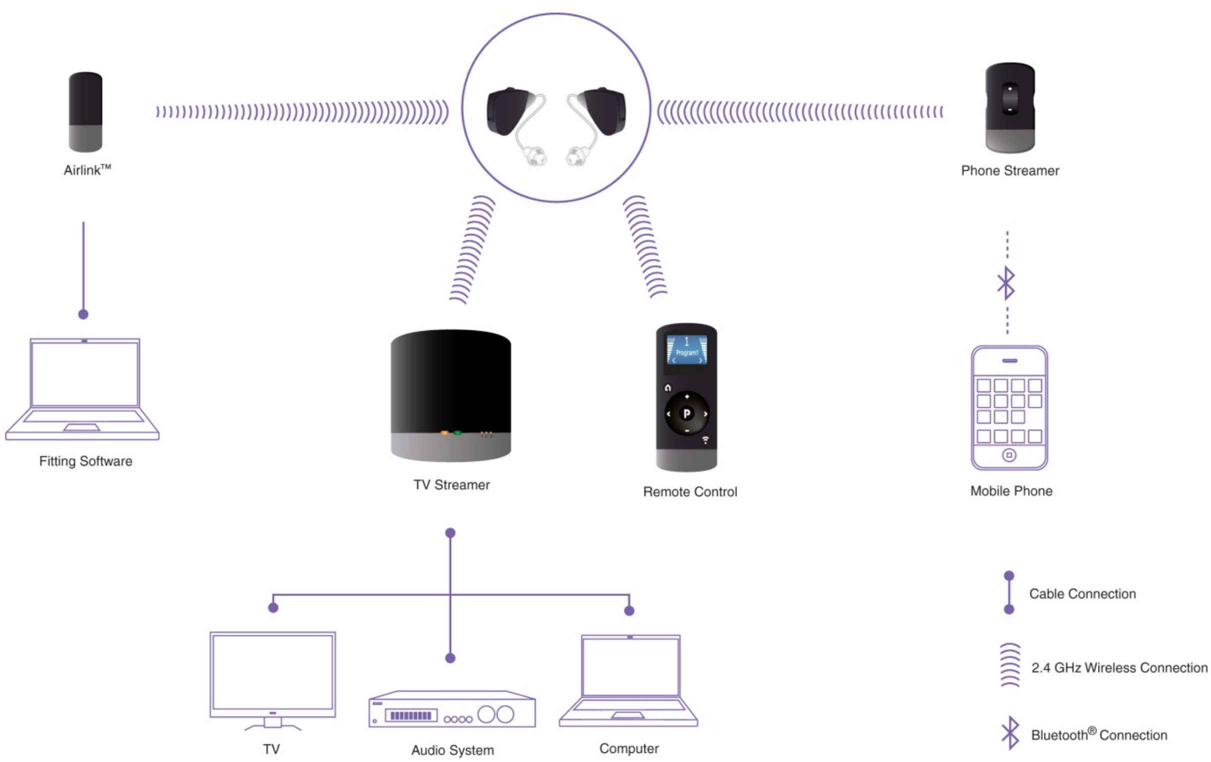

Figure 2. The ReSound wireless hearing instrument system places the hearing instruments in the center. Other technologies require a body-worn streamer to function as the center of the system, in which case the hearing instruments are treated as an accessory.

Stable connections over a long range

The transmission power of the ReSound 2.4 GHz wireless technology is less than 1/100th that of a cell phone, but sufficient to provide connection up to about 7 meters. Providing stable connections was a particular focus of development, as the 2.4 GHz band hosts a large number of wireless devices which could potentially interfere. The ReSound wireless system divides the 2.4 GHz band into 35 channels. If another device transmits in the same channel as the hearing instrument there is a risk that the data packet that is being transmitted is corrupted and therefore has to be discarded. Therefore it is necessary to safeguard the data transmission against such interference.

For the ReSound wireless system, data is transmitted as so-called packets, which are tiny digitally coded portions of information. ReSound uses two methods to protect against interference of wireless transmission of these data packets. The first is time division. The rules governing operation in the 2.4 GHz band specify that no device must transmit for more than 0.4 seconds at a time on a given channel. This means that even in heavily congested channels small time slots appear where the channel is free. To exploit this, ReSound sends very short data packets – only between 160 and 500 microseconds (or 0.00016 to 0.0005 second) long. Such a short packet has a high chance of getting through simply because of its length.

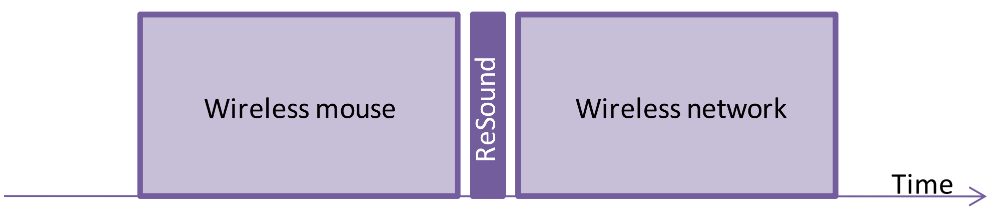

Figure 3. ReSound transmits data in exceedingly small time intervals to avoid conflict with other transmitting devices operating in the 2.4 GHz band.

The second line of defense is called frequency hopping. Basically that means that each time a new piece of data is to be sent a new channel out of the 35 possible channels is picked for the transmission. The hearing instrument mutually agrees with the wireless accessory on which channel to send the next data packet. As all the different devices in the band use a different selection strategy they virtually always steer clear of each other.

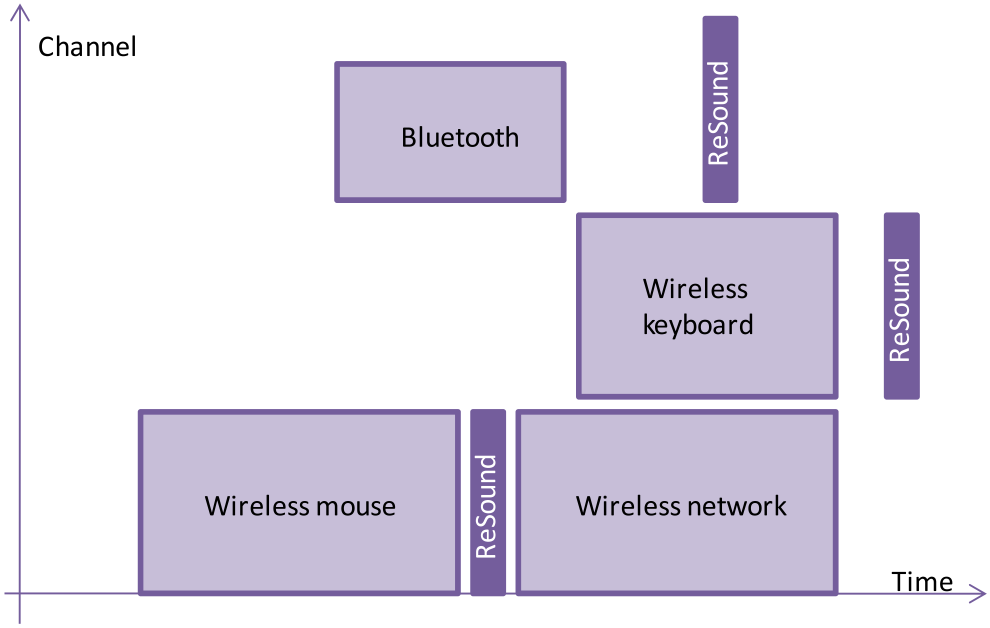

Figure 4. In addition to transmitting in very short time intervals (as indicated by the horizontal axis), ReSound technology makes use of 35 different channels (vertical axis) in the 2.4 GHz band to avoid disturbance from other wireless devices. This graph gives an impression of how other types of wireless device transmissions are distributed relative to ReSound technology.

Excellent audio quality and no lip synch issues

As discussed, Bluetooth transmission from sources such as televisions and other audio sources are of too poor quality to meet user requirements. ReSound designed a proprietary method for transmitting audio that does not have the sound quality drawbacks associated with the A2DP protocol. As demonstrated in Figure 1, the latency associated with this method is very short, providing a natural-sounding listening experience and completely avoiding any asynchrony of audio and visual input. In addition to handling such issues, it is also possible for the fitter to make individual adjustments to the frequency response for the audio streaming, and the user has flexible options to adjust the volume of the both the audio streaming and the hearing instrument amplification.

Meeting fitter requirements

The requirements for professionals fitting the hearing instruments are mainly related to the actual fitting process. Although nearly all hearing instrument manufacturers' products are compatible with standardized programming interfaces, fitters have still had to battle with a tangle of fitting cables and connectors for nearly two decades. The first "wireless" fitting solution was the industry standard NOAHlink, which is only wireless from the PC to the programming interface: programming cables, programming boots and programming pills are still required. The NFMI-based wireless hearing instruments also feature wireless programming. Like the NOAHlink, they require an intermediate device to be worn by the patient that communicates with the PC via Bluetooth. They have the advantage of eliminating the physical connectors from the body-worn programming interface to the hearing instruments. While this is a small step in the right direction, it does not completely meet the user requirement for a wireless fitting in that clients must still wear an intermediary device. One such device actually incorporates the bulky NOAHlink medallion with a rather intimidating hook housing an induction coil for the NFMI-based communication. Clients are required to wear the hook around their necks during programming.

Direct connection, long range, and "plug and play"

The ReSound 2.4 GHz solution has the capability to send directly from a small USB device similar to a memory stick directly to the hearing instruments over a range of approximately 3 meters with no intermediate device. This USB device is called an AirLink. Once the fitting software is installed, the fitter need only insert the AirLink into a USB port on the PC, and clients do not need to wear other devices than the hearing instruments themselves. This meets not only the "plug and play" requirement, but also the goals of direct connection and long transmission range.

Inherent in the concept of "plug and play" is an assumption of ease of use. While the ease of inserting a small device into a USB is more or less self-evident, the entire fitting system must be easy for the fitter to navigate. To ensure this, wireless fitting and handling of wireless accessories was included as an integral part of a new fitting software design rather than as an add-on to existing software. This design was based on observation and analyses of the tasks that must be carried out in a fitting and the order in which the tasks typically are done. Extensive, iterative usability testing was also carried out at various stages during development. This type of testing examines how easily users are able to use the tools/devices to accomplish their goals. For example, if a fitter cannot quickly and intuitively figure out how to connect to a hearing instrument wirelessly when a fitting is begun, usability fails on this task, and the functionality must be altered and retested.

Robust connection

Establishing and maintaining robust connections were also important requirements for hearing instrument fitters. In a conventional programmable hearing instrument fitting, the device is wired to the computer via a programming interface, such as a HiPro or proprietary interface, and it can safely be assumed that the data sent into the cable will 1) arrive at a specific hearing instrument in the other end of the cable, and 2) arrive at the same instrument every time data is sent. This sounds obvious, but the assumption does not hold for wireless fitting. When a wireless programming device sends data packets with information about the fitting (e.g. gain settings), any device in the vicinity can and will receive this data providing that it is listening in the correct way.

Because all hearing instruments will receive all data, they need to filter the data received. For that reason all ReSound wireless products are factory equipped with a globally unique identifier (or address). This identifier must match the information about destination in the data packet, otherwise the packet is rejected as not belonging to this specific hearing instrument.

Using this address system, a private link between the wireless programming device and a hearing instrument can be created, as only the hearing instrument with the correct address will receive data sent to that address. This ensures that hearing aids can be fitted reliably even in clinics where several AirLinks are active at the same time. This is illustrated in Figure 5 – even though both instrument A and B receive the packet, it is only processed in hearing instrument A.

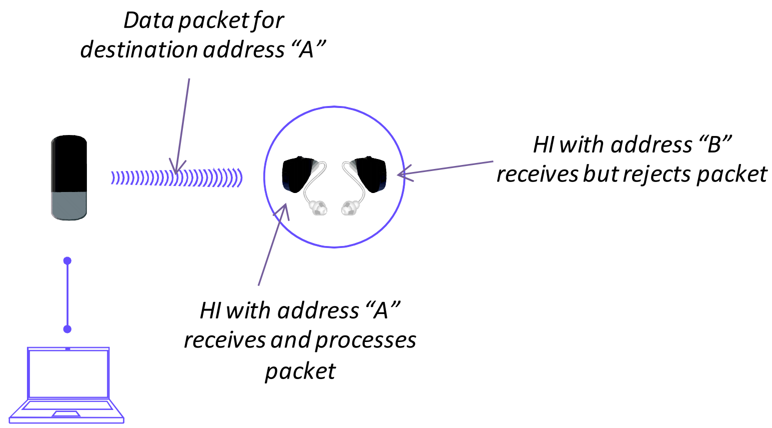

Figure 5. The wireless programming interface is able to establish private communication with individual hearing instruments and reliably exchange data with them by use of unique addresses assigned to the hearing instruments at the factory. Hearing instruments receive, but ignore, data that is not addressed specifically to them.

This creates a new problem: How does the wireless programming device (the AirLink) know the address of the hearing instrument with which it should communicate? When all addresses are unique (and there are more than 4 billion possible addresses), a mechanism is needed to discover devices in the vicinity. For that purpose one of the addresses has been picked to be used for the "discovery" process. For the first 2 minutes after being turned on, the hearing instrument will transmit a little bit of data on this globally shared address basically saying "I can be found on address X if you need me". When discovery is started in the fitting software, the wireless programming device will listen for this information and thereby learn the addresses of the devices that can be communicated with. All of the hearing instruments that are discovered are displayed in the fitting software, and the fitter can assign the appropriate ones to right and left ear for the fitting, as shown in Figure 6. Once the user picks one or two devices for fitting, the private communication is started.

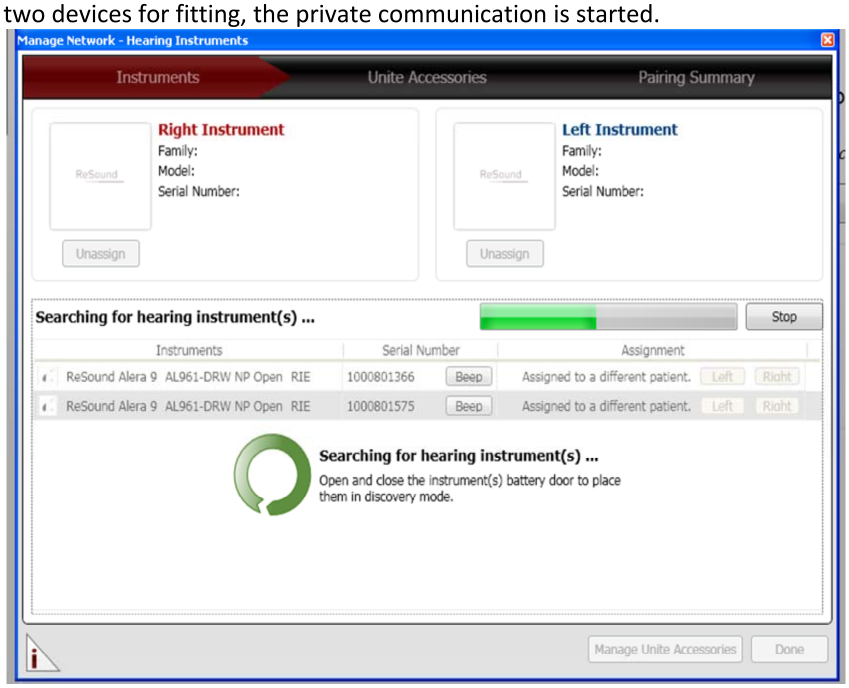

Figure 6. During "discovery" the wireless programming device searches for all hearing instruments within range and displays them. A private connection to the appropriate hearing instruments is established when the fitter assigns them to the right and left ears.

Summary

Resound’s choice of a proprietary 2.4 GHz-based system for its wireless hearing instruments is a first in the industry and an impressive technological feat. However, it is not technology for the sake of technology. The selection of this approach was the result of a systematic analysis of prioritized user needs, careful consideration of how these needs could be met, and rigorous investigation of possible technical solutions. This article reviewed what user requirements were identified, and how these influenced design of the wireless hearing instrument system. Of primary concern for users was a simple, hearing instrument-driven solution that could be used for robust connections to external sources with the best audio quality. The 2.4 GHz wireless technology is currently the optimum solution to satisfy these requirements.

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