D-8-1: Requirements specification of personal link and related application services

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Abbreviations

AMPS - Advanced Mobile Phone Service
API - Application Programming Interface
ASR - Automatic Speech Recognition
BAN - Body Area Network
BTE - Behind The Ear
BW - Body Worn
CEPT - Conference of European Posts and Telecommunications
EDGE - Enhanced Data rates for Global Evolution
ETSI - European Telecommunication Standards Institute
FCC - Federal Communications Commission (US Government)
FDMA - Frequency Division Multiple Access
GPRS - General Packet Radio Service
GSM - Global System for Mobile Communications
HA - Hearing Aid
HSCSD - High Speed Circuit Switched Data
ISM - Industrial, Scientific and Medical (radio bands), defined by ITU
ITC - In The Canal
ITE - In The Ear
ITU - International Telecommunication Union
LAN - Local Area Network
NDA - Non Disclosure Agreement
NTT - Nippon Telephone & Telegraph
PAN - Personal Era Network
PCS - Personal Communication System
PDA - Personal Digital Assistant
QoS - Quality of Service
RF - Radio Frequency
SD-card - Secure Digital card
TACS - Total Access Communication System
TCP - Transmission Control Protocol
TDMA - Time Division Multiple Access
ULP - Ultra Low Power
UMTS - Universal Mobile Telephone Service
UWB - Ultra Wide Band
WAN - Wide Area Network
WIFI - Wireless Fidelity, IEEE standard 802.11b
References

1 Executive Summary

This deliverable covers the requirement specification for a wireless personal communication link (short, medium and/or long range) and its services including its adaptation to the auditory profile for hearing impaired persons as defined in HearCom WP1.

The functional requirements for a wireless personal communication link are evaluated based on investigations with groups of users, professionals and findings from the results of the HearCom Work Package 5, the BlueEar program and standardization (IEC).

Technical specifications are studied with respect to short and long range connectivity, power-budget, source and channel coding, size and performance. Alternative solutions are investigated and compared with respect to performance, flexibility and costs.

Connectivity to mainstream applications is specified (hearing devices, mobile phones, PDA’s, security systems, public address systems, TV sets, etc).

This will include:

- The adaptations of source and channel coding in conformance with the auditory profile HearCom WP1 and the results of HearCom WP4
- Roadmaps and prototype key elements.
- Definition of public and private communication services (e.g. for theatres, public-access systems, television-sets)
- Cooperation with standardisation bodies.

The specification of requirements for the telecommunication technologies that link the different elements of the HearCom solution is based on using mainstream packet OSI 7 layers specification, including TCP/IP telecommunication technologies, and alternatively cellular mobile 2,5G and 3G technologies and WLAN, WPAN, WBAN solutions for the wireless tail.

In addition to the partial conclusions in different aspects of the specification along the document, for a comprehensive overview of the document the most outstanding features are summarized in the section 11 (page 85).
2 Introduction

Acoustic transmission is often not sufficient to ensure receipt of all information for persons in adverse listening conditions. When using hearing devices, assistive devices like magnetic loop-system, infrared system, or FM-systems may be available to assist speech understanding (places of worship, theatres, and classrooms). These systems are one-way, have limited quality and do not always intercommunicate with digital phones, PDA’s and other communication equipment.

Sub-Project SP4 aims at the definition and prototyping of a wireless link that can be used for hearing devices and that will be compatible with mainstream developments (in Particular Mobile 2G, 2,5G and 3G Systems, WIFI, Bluetooth, and others). Secondly SP4 aims at the investigation and prototyping of assistive applications including the definition of a common platform. This work will be covered in a separate work package WP9 including the selected assistive applications that will support speech understanding by rolling text display, speech text conversion and speech processing using hearing devices.

This document will describe in a summarized way the available technologies that could be used in the HearCom project.

HearCom requires a mobile wireless technology to enable users to facilitate access and to move freely while using the application. Currently some of the functionality required by HearCom is provided by a set of fixed and radio technologies.

The proposed evolution is from an analog status represented by the telecoil to a digital status in the form of information packets as favoured by the telecommunication technology world. The technologies proposed are able to provide different degrees of mobility in a digital world.
3 Scenarios and Applications

3.1 General

In many adverse conditions, present-day assistive solutions are insufficient to alleviate the limitations in activities. A number of solutions are available like the use of telecoil and infrared systems, but these systems are very specific, requiring special inductive or line of sight coupling. Also since many years remote microphone systems are available with a direct coupling to a hearing aid; and more recently a dedicated FM one-way directional coupling for microphones has become available.

Nevertheless, the objective is to extend the range of action of aiding solutions, getting a system capable to reach all the aspects of every day life and achieving a global integration of hearing disabled in the communication society.

3.2 Applications/Scenarios

In this section, we expound several scenarios in which users benefit from different applications of the HearCom system. They receive assistance according to the situation – like environmental noise - and their degree of hearing impairment. But not only can the impaired users take advantage of the proposed services, as can be seen in the following paragraphs.

3.2.1 Personal Use

From the very first day that the user got his or her new system, the life became clearly easier. Since long ago there have been hearing aids available for hearing disabled, which helped them to understand the acoustic information that is all around them almost every time. The user has now, nevertheless, a system that adapts the signal to his specific requirements. Hearing the music that plays at the music system, watching TV, or having a talk with other people is now much more comfortable. He just needs to be careful not to forget to carry with him his PCS (Personal Communication System), so it can communicate with the Hearing Aids in the back of his ears. Not harder than it is for any other person to carry his or her smart mobile or a PDA, because, in fact, the system consist exactly of that.

This system helps him or her as well to detect the alarms triggered by several events, from the telephone ring and the door bell to those programmed in new smart home appliances.

The integration of the personal communication system with the mobile telephone nets (GSM, UMTS...) is another advantage. To him or her it is even possible to keep track of the conversation not hearing but reading what the other speaker says. And all this in addition to agenda, internet, computing and other services offered by usual PDA’s and smart mobiles.
3.2.2 Conference Rooms

The system user can attend in his or her everyday life to public events such as theatre performances, religious services, conferences or courses. Sometimes, the intervention of the hearing aids in the back of his/her ears allows him/her to follow the speech with no trouble. But if the acoustic of the room or his hearing ability degrades, the personal communication system in his pocket - that looks just like any other PDA or smart mobile telephone -, will collaborate in adapting the acoustic signal to his needs.

During this situation, he can also extract this device from his pocket to check if there is further information available referring to the act, probably sent by the organizer through a wireless network. In case of a user that cannot hear at all, it is equally possible for him to know at the same time what is being said, since the speech-text converter integrated in the system allows reading it in the format of a rolling display. Exactly the same function that another kind of users finds very useful too: those who try to understand something that is not in their mother language, a situation that is more and more common as it is living and working abroad.

3.2.3 Transport Systems

In the same way as a user can receive additional information during a lecture, this idea can be extended to stations, airports, and subway trains. One or more entities could use some wireless network for transmitting either public information announcements or personalised alerts, usually referring to the departures of trains, busses, flights, arrivals, delays, boarding gates, etc. It could also include some commercial advertisements about the shops in the area, bargains, or other interesting information.

One more time, this service could consist of voice or text messages (like a simple SMS). This is an important detail, because this would allow its integration with the services whose aim is to help the blind people, e.g. in the airports that have suppressed the voice announcements in order to adopt the newly trend of becoming “silent airports”.

As it has been indicated in the previous section, the advantages for non-native speakers are obvious.

3.2.4 Open Air Applications

Given that this system has the capacity of getting connected to several wireless networks, the user can enjoy having access to the enormous amount of information provided.

The simplest application is the reception of radio broadcast, both the analog FM/AM and the digital stations. From there on, the possibilities are enormous: the user can have access to the Internet through different systems including GPRS, UMTS and WiFi, receive location based information, make use of wireless networks installed in university campus, etc.
Data can be read in the display, as well as voice, once it has been converted to text. Depending on the display resolution, video is also a possibility. But maybe the most original option is the opportunity of hearing the audio received by the PCS and then sent to the hearing aids, just as a kind of cordless headphones.
4 Users’ Requirements Research

4.1 Aim

The aim of this section is to understand the users’ requirements for the personal link under development in work package 8, to provide some initial guidance on its development.

4.2 Research Methods

User requirements were obtained by asking end users and professionals to complete a questionnaire. With two separate questionnaires designed, one for each group. All the members of work packages 8 and 9 were involved in the development of the questionnaires.

The user questionnaire asked about users’ experiences of daily life and their experiences with existing technology. Demographic information about respondents was also obtained to allow comparisons to be made between groups of users and against the general population.

The professional questionnaire was distributed to people, such as hearing therapists, who regularly engage with deaf and hard of hearing people. This questionnaire asked the professionals about their views with regards to the needs of users.

Data collection for work packages 8 and 9 was combined and carried out simultaneously; therefore the research methodology and structure of the questionnaires is discussed in greater detail in D9.1. This report will only discuss those findings relevant to the development of a personal link within this work package (work package 8). Data obtained in relation to user requirements relevant to WP9 are discussed in D9.1: Requirements specification of user needs for assistive applications on a common platform.

4.3 Description of Respondents

4.3.1 User questionnaires

The user questionnaire was distributed to 373 deaf and hard of hearing people in the UK that had previously expressed an interest in helping RNID with its research. Of those that were sent the questionnaire 101 people completed and returned it in the freepost envelope that was supplied.

The same questionnaire was translated into Dutch so that it could also be distributed in the Netherlands. The user questionnaire was distributed to 80 deaf and hard of hearing people in the Netherlands. Of these distributed
questionnaires, 15 were given to hard of hearing people while they visited the department of Audiology of the VU University medical centre (Amsterdam) for hearing aid dispensing. Some of them completed the questionnaire during their visit, but most of them returned it in the freepost envelope that was supplied. Of those that were given the questionnaire, 12 returned it. Another 15 deaf and hard of hearing people were given the questionnaire during their visit to a hearing aid dispenser; 10 of them returned it. Another 50 questionnaires were sent to patients of the department of Audiology of the Erasmus medical centre (Rotterdam). Of them, 30 returned it in the freepost envelope that was supplied. Thus, from the 80 distributed questionnaires, 52 were returned.

The questionnaire was also translated into Greek and distributed by several professionals working with hard of hearing people in Athens and elsewhere in Greece. The final modified version of the Questionnaire was distributed electronically to the following groups of respondents:

- The Hellenic Federation for the Deaf (National Federation for the Deaf, Greece-HFD).
- The Greek National Foundation for the Deaf.
- The commercial sector: Epitropou Hearing Aids, Athens.
- Personal contacts willing to help in the distribution of the questionnaires; a researcher specializing in those who are Hard-of-Hearing, a graduate student of the Technical University of Athens and a user of hearing aids.
- Personal communication with elderly hard-of-hearing acquaintances, relatives and citizens contacted in local municipalities of the Athens area.

One hundred printed copies were distributed in addition to the electronically distributed questionnaires. The users contacted covered a wide age range and their occupations also varied widely; students and young professionals (18-30 years of age), full-time professionals (30-60 years of age), and retired citizens (over 60 years of age) were asked to fill in the questionnaire.

Despite the fact that several groups of respondents were contacted, it turned out to be very difficult to obtain answers from the users, at least within the given period of time.

One possible explanation for the observed delays or lack of answers may be the fact that the questionnaire was distributed during June and July 2005, during which many people in Greece are on holiday and schools are closed. It should also be noted that in Greece, due to high temperatures in the summertime, a large percentage of the elderly or retired citizens leave the cities during the summer and spend an extended period from June to September in a summer house or in their villages. Due to these reasons only thirty questionnaires were completed and returned.

**UK respondents**

In the UK 48.5% of those that returned the questionnaires were male and 51.5% were female. In the UK 50% of those with a hearing loss are aged 65 or above. In the sample of those that completed the questionnaire in the UK, the distribution of ages was not representative of the general population with only 20.8% being aged 65 or above. Of the remainder of the sample, 49.5% were
aged 46-65 years, 24.8% were aged between 31 and 45 and 5% were aged between 18 and 30 years.

Thirteen percent of respondents did not use hearing aids or a cochlear implant (CI) and 4% had hearing aids but rarely used them. The remainder used aids with 77% having a hearing aid in one or both ears and 6% had a cochlear implant in one ear. In the questionnaire respondents were asked to describe their hearing loss with and without their hearing aids. Responses are summarised in the Figure 1 below. A significant positive correlation was found between descriptions of the level of their hearing loss with and without an aid. More in depth analysis of the demographics of those who return the UK questionnaire can be found in D9.1.

![Figure 1 Descriptions of hearing loss with and without aids for UK respondents](image)

**Dutch respondents**

Of the Dutch respondents, 27 were female and 25 were male. The youngest respondent was 28 years of age, and the oldest respondent was 90 years of age. Most respondents had a hearing aid in both ears (62%) or a hearing aid in one ear (31%). Of the remainder, 2% had a CI, 2% had hearing aids, but rarely used them, and 2% did not have hearing aids or a CI.

The respondents were asked to describe their hearing with and without hearing aids or CI. The described hearing with aids was significantly (p < .05) correlated with the described hearing without aids: r = .52, p < .01, with those participants that reported greater hearing difficulties without their aids or CI, reporting greater difficulties with their aids or CI. Figure 2 presents the description of the hearing (both with and without aids) as given by the respondents.
Greek respondents

Of the 30 Greek respondents, 43% were male and 57% were female. Forty percent of the respondents were 18-30 years of age, 23% were 31-45 years of age, 13% were 46-65 years of age and 23% were 65 years of age or older. Most Greek respondents have hearing aids in both ears (35%) or a hearing aid in one ear (28%). Thirty percent of the respondents do not have a hearing aid or CI. One respondent has a hearing aid but rarely uses it, another respondent has a CI in both ears and one respondent has a hearing aid in one ear and a CI in the other ear. Most respondents indicated that they use lip-reading during conversation.
The Greek respondents were also asked to describe their hearing loss with and without their hearing aids. Responses are summarised in Figure 3 above. In contrast to the results of the UK and the Netherlands, no significant correlation was found between their described hearing with and without hearing aids.

4.3.2 Professional questionnaires

The professional questionnaire was sent to 50 Hearing therapists in the UK, and 21 questionnaires were returned in the freepost envelope provided. All hearing therapists were taken from lists owned by RNID. The length of time had been working in the profession, ranged from 1 year to 28 years with a mean of 13 years. The number of patients seen by each of the hearing therapists was varied with one hearing therapist seeing ‘7-10’ patients in an average week and another seeing ‘at least 60’ patients in an average week, with the most common response being 20 – 30 patients.

The professional questionnaire was sent to five professionals working at the department of Audiology of the VU medical centre (Amsterdam). All distributed questionnaires were returned. Each of the professionals were selected to cover different areas of expertise, with two audiologists, one social worker, one acoepeidist and one psychologist / researcher asked to complete the questionnaire. The number of years that they had worked in their profession ranged from 2 to 39 years. In general, the professionals saw 10 patients a week (the number of patients however ranged from 1 to 40), and most of these patients are younger than 55 years of age.

The professional questionnaire was also distributed to Greek professionals. However, due to the same difficulties that caused the relative low percentage of returned user questionnaires (e.g. holiday season), few professional questionnaires were returned. The low number of completed professional questionnaires does not allow a data analysis.

4.4 Results and Analysis

4.4.1 UK User Questionnaire

4.4.1.1 Daily living

The questionnaire asked respondents about daily living and the level of problems that they encounter in different situations during daily life.

As can be seen in Table 1 below, many respondents encountered problems understanding what is being said whilst in public places. Greater problems appeared to be specifically found in situations that do not allow face-to-face interactions. These problems were also clarified with the qualitative comments made by users about the difficulties encountered when hearing announcements in transport terminals. Qualitative comments included:

‘Every time there is an announcement I ask someone to convey it to me.’
‘How can you lip read a tannoy (loudspeaker)?’

‘Need a third party to tell me what is being said, or I use a visual display.’

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<tbody>
<tr>
<td>When watching sport, e.g. in a stadium</td>
<td>17%</td>
<td>4%</td>
<td>13%</td>
<td>15%</td>
<td>51%</td>
</tr>
<tr>
<td>Face to face conversation in quiet places</td>
<td>26%</td>
<td>65%</td>
<td>7%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>6%</td>
<td>27%</td>
<td>32%</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>Face to face conversation in noisy places</td>
<td>3%</td>
<td>21%</td>
<td>62%</td>
<td>14%</td>
<td>0%</td>
</tr>
<tr>
<td>Communication with others in the vehicle while driving</td>
<td>3%</td>
<td>24%</td>
<td>48%</td>
<td>24%</td>
<td>2%</td>
</tr>
<tr>
<td>Over the telephone</td>
<td>10%</td>
<td>20%</td>
<td>41%</td>
<td>26%</td>
<td>3%</td>
</tr>
<tr>
<td>Lectures or classes</td>
<td>2%</td>
<td>20%</td>
<td>38%</td>
<td>14%</td>
<td>26%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>6%</td>
<td>27%</td>
<td>32%</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>Watching television</td>
<td>20%</td>
<td>30%</td>
<td>32%</td>
<td>17%</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Table 1 Activities of daily living and the percentage of participants that encounter problems**

Respondents also reported frequent problems in lectures and classes, as well as work meetings. With one participant commenting that ‘[work meetings] are ok if one person at a time is speaking… [I] need to see face of person speaking’. Similar problems were found among respondents with regards to communicating over the telephone. All these findings suggest that many people rely on lip reading to help them understand what is being said, causing difficulties in situations where face to face communication is not possible. Problems also seem to be caused in several of the situations by the speakers having a strong accent.

The comments made by respondents also highlight that many of the devices that could assist deaf and hard of hearing people to understand what is being said in public locations, are often not available, not adequate or do not work. These comments included:

‘Even with T switch and amplified phone [I] am totally dependent on having a clear speaker’

‘Unless Stagetext is being used, I usually wouldn’t go’

‘I need subtitles to access the film. I don’t go to the cinema unless subtitles are on’
Respondents were also asked several questions about any difficulties they have of being aware of things happening around them due to their hearing loss. The results to these questions are discussed in D9.1.

4.4.1.2 Personal Wireless Link

To better understand the features users would want in a future personal wireless link, participants were asked a number of questions about the technology that is currently available and used by deaf and hard of hearing people to link audio directly to their hearing aid or cochlear implant. The main technology that is currently used in the UK for this task is inductive loops (t-coil).

In relation to the use of inductive loops (also referred to as the t-setting on aids), it was found that an extremely small number (2%) were not sure whether they had the use of this feature on their hearing aids or cochlear implant. The t-setting appeared to be slightly more popular feature on hearing aids than cochlear implants, with 88% of those who have a hearing aid versus only 60% of those that have a cochlear implant, having the use of the t-setting on their aids. Of the participants who have the t-setting, 34% have an analogue aids, and 61% have a digital aids. Usage of the t-setting was also varied with only 72% of those participants that have the t-setting using it regularly, and 15% who have tried using it, but do not use it on a regular basis.

To understand the situations when loops are used, and the effectiveness of loops in different situations, those participants that had a t-setting on their aids were asked where they used the loop in a number of different situations and how satisfied they usually are with loops in each of those situations. Participants were also able to add additional comments about each situation. The responses to this question are summarised in Table 2 below.

<table>
<thead>
<tr>
<th>Location</th>
<th>Very satisfied</th>
<th>Quite satisfied</th>
<th>Quite dissatisfied</th>
<th>Very dissatisfied</th>
<th>Do not use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Places of Worship</td>
<td>21%</td>
<td>14%</td>
<td>14%</td>
<td>3%</td>
<td>48%</td>
</tr>
<tr>
<td>Watching TV at home</td>
<td>15%</td>
<td>23%</td>
<td>5%</td>
<td>3%</td>
<td>54%</td>
</tr>
<tr>
<td>At home</td>
<td>5%</td>
<td>23%</td>
<td>3%</td>
<td>2%</td>
<td>67%</td>
</tr>
<tr>
<td>Bank, Shop or Post Office counter</td>
<td>3%</td>
<td>22%</td>
<td>19%</td>
<td>16%</td>
<td>40%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>5%</td>
<td>17%</td>
<td>6%</td>
<td>5%</td>
<td>67%</td>
</tr>
<tr>
<td>Theatre</td>
<td>3%</td>
<td>17%</td>
<td>27%</td>
<td>17%</td>
<td>36%</td>
</tr>
<tr>
<td>Ticket offices</td>
<td>2%</td>
<td>19%</td>
<td>21%</td>
<td>11%</td>
<td>47%</td>
</tr>
<tr>
<td>Cinema</td>
<td>5%</td>
<td>18%</td>
<td>19%</td>
<td>17%</td>
<td>41%</td>
</tr>
<tr>
<td>Music concerts</td>
<td>2%</td>
<td>15%</td>
<td>5%</td>
<td>15%</td>
<td>63%</td>
</tr>
</tbody>
</table>

Table 2 Satisfaction when using a loop in different locations for those who have t-setting on their aid

Despite the large number of people that reported using the t-setting on their aid regularly, the table above shows that in many of the situations where people could use an inductive loop, a large percentage of participants do not do so.
Qualitative comments obtained from respondents in relation to each situation give some explanation as to why loops are not used and why users are sometimes dissatisfied with the performance.

Poor sound quality seems to be a major factor in discouraging use and causing people to be dissatisfied with the performance of loops. Participants commented that cinemas’ loops are generally not worth using, as the sound quality is poor, with one participant claiming that, ‘Induction loops at cinemas don’t work’. Similar comments were made about theatres, with the sound quality when using the loop systems being ‘…too poor to be able to enjoy the performance’. Poor sound quality was also stated as a problem in a number of other situations, including loops at music concerts and loop systems installed in rooms and used at work meetings.

As can be seen in Table 2, despite these problems in several situations users are satisfied with the performance of induction loops. Domestic loop systems within the home, that allow high quality sound to be fed directly from devices such as a television straight to their hearing aid were commented on positively by a number of participants, with one respondent stating that ‘[It] definitely makes sounds clearer, less stressful to listen’. Smaller, portable neck loops were also seen as providing better sound quality; ‘I use a personal loop, which is very satisfactory.’ Loop systems in places of worship were also seen as very satisfactory, with users encountering few problems.

This variation in where problems are encountered suggests that the problems may not be caused by loops themselves, but rather the way they are installed and maintained. This is supported by comments made about loop systems in public places such cinemas, post offices and banks. Comments included;

‘Most of them [loop systems] don’t work, and the staff has no idea about what they do or should do.’

‘Most loop systems are situated next to computers, which caused interference with sound quality’

‘Often they are not switched on or broken. If they do work the sound quality is very poor.’

One participant also stated that they were less inclined to use a loop, as by doing that they felt that they were highlighting that they were deaf and that doing so would affect their job prospects and highlighting the stigma that is experienced by some people when using assistive technology rather than mainstream products.

Another disadvantage of using loops, highlighted in the comments made by respondents was that when their hearing aid is on the t-setting other noises are inaudible. During activities such as watching television this prevented them from hearing other people in the room, and lead to some participants choosing to use subtitles instead of a loop. Another participant commented that ‘using the t-switch means that I cannot hear anything else, i.e. the doorbell or smoke alarm’, which raises safety concerns. However, one respondent commented on the positive aspects of this feature in that ‘it is great to be able to switch off my wife on occasions!’
Table 3 below shows the features that stop those who have a t-setting on their aid from using inductive loops or bother them when they use them. It is important to note that for the majority of the features, participants have indicated that it does not cause concern for them. However, as participants did not reveal any information why these features didn’t concern them, this result should be interpreted with caution.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Bothers me a little</th>
<th>Bothers me a lot</th>
<th>Puts me off completely</th>
<th>Does not cause me concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems with volume</td>
<td>37%</td>
<td>34%</td>
<td>6%</td>
<td>23%</td>
</tr>
<tr>
<td>Poor sound quality or interference</td>
<td>36%</td>
<td>39%</td>
<td>9%</td>
<td>16%</td>
</tr>
<tr>
<td>I do not know where I can use it</td>
<td>30%</td>
<td>14%</td>
<td>3%</td>
<td>53%</td>
</tr>
<tr>
<td>The need to switch manually</td>
<td>21%</td>
<td>18%</td>
<td>9%</td>
<td>52%</td>
</tr>
<tr>
<td>Difficult to switch manually (small or fiddly switch)</td>
<td>16%</td>
<td>16%</td>
<td>6%</td>
<td>62%</td>
</tr>
<tr>
<td>I do not know how to use it</td>
<td>8%</td>
<td>2%</td>
<td>0%</td>
<td>90%</td>
</tr>
<tr>
<td>It does not connect to other equipment such as telephones, radio, TV</td>
<td>16%</td>
<td>27%</td>
<td>17%</td>
<td>40%</td>
</tr>
<tr>
<td>The need to adjust level and program</td>
<td>18%</td>
<td>27%</td>
<td>8%</td>
<td>48%</td>
</tr>
<tr>
<td>Picking up wrong information, e.g. from another loop nearby</td>
<td>18%</td>
<td>25%</td>
<td>8%</td>
<td>49%</td>
</tr>
<tr>
<td>The need to ask staff to switch their system on</td>
<td>26%</td>
<td>25%</td>
<td>8%</td>
<td>49%</td>
</tr>
<tr>
<td>It does not work with my mobile phone</td>
<td>14%</td>
<td>25%</td>
<td>25%</td>
<td>36%</td>
</tr>
<tr>
<td>The need to connect a magnetic loop round my neck or behind my ear</td>
<td>16%</td>
<td>20%</td>
<td>20%</td>
<td>44%</td>
</tr>
</tbody>
</table>

Table 3 The features that stop those who have the t-setting on their aid from using it or bother them when they use it

As mentioned previously in respondent comments, one of the features of inductive loops that was indicated as bothering and stopping a number of participants from using them at all, was the fact that users need to ask a member of staff to switch their system on in order to use it. Sound quality was also highlighted as a feature that bothered users.

A number of the physical attributes of inductive loops were also highlighted as bothering respondents. As can be seen in Table 3, these included having to wear a loop around their neck or behind their ear, which stops a number of respondents from using a loop completely. Whereas problems such as the need to switch their hearing aids to the t-setting manually and the fact that the switch to do this is small and fiddly bothered some users, however this was not to the level that it put them off using loops completely.

The results also seem to suggest that a number of people who could benefit from loops may use them if they are given the appropriate information. With 44% being bothered by the fact that they do not know where they can use the t-setting and 10% being bothered by not knowing how to use the t-setting.
Infrared systems are sometime used in public venues in the UK as an alternative to inductive loops, especially in cinemas and theatres. They use an invisible infrared light to carry sound to receivers worn by listeners, who can sit anywhere in the area covered by the transmitter. However, due to the nature of infrared, this coverage is confined to the room in which the transmitter is placed. Results showed that only 40% of the respondents that had used Infrared, with only 8% being successful and able to receive sound when using it, and only 15% having used it with partial success.

FM listening systems are another alternative to using infrared and inductive loops, using radio waves to transmit sound to the user’s hearing aid. When the participants were questioned about their usage of FM listening systems 15% of respondents claimed that they had used FM listening systems, with only 7% having used FM listening systems successfully and only 6% having used systems with partial success.

<table>
<thead>
<tr>
<th>Feature Description</th>
<th>Must have this feature</th>
<th>Would like to have this feature</th>
<th>Am indifferent to this feature</th>
<th>Would dislike this feature</th>
<th>Do not understand the feature</th>
<th>This feature is not relevant to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless (has no cables, wires or other connections)</td>
<td>46%</td>
<td>37%</td>
<td>1%</td>
<td>2%</td>
<td>6%</td>
<td>8%</td>
</tr>
<tr>
<td>To help supplement the power of my hearing aid and thus improve the quality of my hearing</td>
<td>45%</td>
<td>37%</td>
<td>2%</td>
<td>2%</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>Incorporated into the size of my current hearing aid – not making it bigger</td>
<td>41%</td>
<td>32%</td>
<td>11%</td>
<td>1%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Light weight</td>
<td>39%</td>
<td>39%</td>
<td>8%</td>
<td>1%</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Ease of operation – easy to use buttons and controls</td>
<td>34%</td>
<td>48%</td>
<td>3%</td>
<td>1%</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>Long battery life</td>
<td>32%</td>
<td>43%</td>
<td>12%</td>
<td>1%</td>
<td>3%</td>
<td>9%</td>
</tr>
<tr>
<td>Can be used with home equipment such as TV, radio and HiFi</td>
<td>39%</td>
<td>42%</td>
<td>5%</td>
<td>1%</td>
<td>3%</td>
<td>10%</td>
</tr>
<tr>
<td>More places where it can be used</td>
<td>40%</td>
<td>41%</td>
<td>3%</td>
<td>1%</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Wireless connection to my mobile phone</td>
<td>26%</td>
<td>41%</td>
<td>10%</td>
<td>2%</td>
<td>7%</td>
<td>14%</td>
</tr>
<tr>
<td>Can connect to a wireless microphone</td>
<td>14%</td>
<td>36%</td>
<td>14%</td>
<td>1%</td>
<td>11%</td>
<td>25%</td>
</tr>
<tr>
<td>Can connect to an array microphone to allow me to tell where sound is coming from</td>
<td>13%</td>
<td>36%</td>
<td>14%</td>
<td>1%</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td>To connect with school FM listening systems without wires</td>
<td>12%</td>
<td>19%</td>
<td>15%</td>
<td>1%</td>
<td>5%</td>
<td>48%</td>
</tr>
<tr>
<td>Automatically switches on when it detects a nearby signal</td>
<td>23%</td>
<td>42%</td>
<td>7%</td>
<td>13%</td>
<td>6%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Table 4 The percentage of participants that would want different features on a future replacement for the t-setting
As well as asking about the problems respondents had encountered with existing systems, the questionnaires also asked questions about the different features respondents would want on a future replacement for the t-setting. Although some respondents did not understand what all the features were especially the different types of microphones, can be seen in Table 4 above, there were only one feature that a number of respondents felt they would dislike. The results indicate that a wireless system would be preferable, however as 13% of respondents felt that they would dislike a system that automatically switches on when it detects a nearby signal, it may be beneficial to give the user the ability to control whether or not this feature is on or off.

The size and weight of the system also appeared to be important features, with users showing preference for a small, lightweight device. Following on from respondents’ comments about the sound quality of existing systems, 82% of respondents stated that any new system should have the ability to supplement their hearing aid and improved the quality of their hearing.

The questionnaires also asked about the situations where they felt a communication link similar to the current t-setting would be useful. Responses to these can be seen in Table 5 below. Despite a large number of respondents stating that being able to use a communication link would be useful in the majority of the situations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Definitely of use to me</th>
<th>Likely to be of use to me</th>
<th>May be of use to me</th>
<th>Not of use to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>At transport terminals to hear announcements</td>
<td>59%</td>
<td>11%</td>
<td>11%</td>
<td>19%</td>
</tr>
<tr>
<td>At home for TV and radio</td>
<td>57%</td>
<td>20%</td>
<td>9%</td>
<td>14%</td>
</tr>
<tr>
<td>Inside public transport vehicles to hear announcements</td>
<td>53%</td>
<td>16%</td>
<td>10%</td>
<td>21%</td>
</tr>
<tr>
<td>At office and in meeting rooms for work</td>
<td>50%</td>
<td>14%</td>
<td>9%</td>
<td>21%</td>
</tr>
<tr>
<td>Cinema</td>
<td>49%</td>
<td>17%</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>Theatres and concert halls</td>
<td>49%</td>
<td>16%</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td>In car, e.g. phone use and listening to radio</td>
<td>47%</td>
<td>20%</td>
<td>10%</td>
<td>23%</td>
</tr>
<tr>
<td>At home for conversation</td>
<td>47%</td>
<td>23%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Lectures or classes, to hear the teacher</td>
<td>44%</td>
<td>12%</td>
<td>17%</td>
<td>27%</td>
</tr>
<tr>
<td>At other work locations, e.g. workshop, hall, outdoors</td>
<td>43%</td>
<td>13%</td>
<td>18%</td>
<td>26%</td>
</tr>
<tr>
<td>At ticket counters</td>
<td>43%</td>
<td>25%</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td>Shops to communicate with assistants</td>
<td>39%</td>
<td>28%</td>
<td>20%</td>
<td>14%</td>
</tr>
<tr>
<td>Places of worship</td>
<td>26%</td>
<td>17%</td>
<td>17%</td>
<td>41%</td>
</tr>
<tr>
<td>In the street to hear traffic lights and warning signals</td>
<td>25%</td>
<td>28%</td>
<td>24%</td>
<td>23%</td>
</tr>
<tr>
<td>While playing sport to hear referee or umpire</td>
<td>7%</td>
<td>10%</td>
<td>14%</td>
<td>68%</td>
</tr>
<tr>
<td>For use with personal stereo or Walkman</td>
<td>23%</td>
<td>14%</td>
<td>17%</td>
<td>46%</td>
</tr>
<tr>
<td>While watching sport to hear commentary</td>
<td>14%</td>
<td>11%</td>
<td>30%</td>
<td>45%</td>
</tr>
</tbody>
</table>

Table 5 The participants’ opinions of locations where a communication link may be useful

A number of respondents also stated that a communication link would not be of use to them in some of the situations. With those situations that respondents
listed earlier as having problems communicating in, being more popular than those where less problems are encountered.

Looking at the situations where a larger proportion of respondents felt that such a link would not be beneficial, these responses may indicate that this response was chosen as users felt they would not encounter such situations. With 21% of the sample being over 65, it is not surprising that the majority of participants indicated that a communication link while playing sport would not be of use to them.

As mentioned previously respondents indicated the importance of the size of a future device. In the development of a replacement technology, users may initially have to carry an additional device. Due to this the questionnaires also investigated users’ opinions to carrying additional devices (this issue is discussed in greater depth in D9.1). Only 6% were not willing to carry an additional portable device if it enhanced their hearing. However, of those who were willing to carry a portable device, 49% claimed that they would want something small enough to be concealed in the palm of the hand or to be able to keep in a pocket or ladies handbag. Thirty nine percent stated that they felt that it would be acceptable for such a device to be visible, for example, something that could be put on a table or held in the hand. However only a minority of participants (6%) felt it would be acceptable for such a device to be in the size of a laptop or a large book.

### 4.4.2 Dutch User Questionnaire

#### 4.4.2.1 Daily living

The same questionnaire given to the UK respondents was translated into Dutch and administered to the deaf and hard of hearing people in the Netherlands. Respondents were asked about daily living and the level of problems that they encounter in different situations. The responses to these questions are summarised in Table 6 below.

<table>
<thead>
<tr>
<th>Situation</th>
<th>No problems</th>
<th>Occasional problems</th>
<th>Frequent problems</th>
<th>Cannot manage in this situation</th>
<th>Do not encounter this situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures or classes</td>
<td>48%</td>
<td>10%</td>
<td>32%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>67%</td>
<td>8%</td>
<td>18%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>At the cinema, to listen to the film</td>
<td>41%</td>
<td>27%</td>
<td>16%</td>
<td>14%</td>
<td>2%</td>
</tr>
<tr>
<td>At the theatre, to hear the performance</td>
<td>39%</td>
<td>18%</td>
<td>22%</td>
<td>18%</td>
<td>4%</td>
</tr>
<tr>
<td>At concerts, to hear the performance</td>
<td>36%</td>
<td>28%</td>
<td>24%</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>When watching sport, e.g. in a stadium</td>
<td>68%</td>
<td>8%</td>
<td>10%</td>
<td>10%</td>
<td>4%</td>
</tr>
<tr>
<td>When playing sport</td>
<td>46%</td>
<td>16%</td>
<td>20%</td>
<td>18%</td>
<td>0%</td>
</tr>
<tr>
<td>Face to face conversation in quiet places</td>
<td>0%</td>
<td>77%</td>
<td>21%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Watching television</td>
<td>4%</td>
<td>37%</td>
<td>37%</td>
<td>20%</td>
<td>2%</td>
</tr>
</tbody>
</table>
### Table 6 Activities of daily living and the percentage of respondents that encounter problems

<table>
<thead>
<tr>
<th>Activity</th>
<th>2%</th>
<th>14%</th>
<th>41%</th>
<th>39%</th>
<th>4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face to face conversation in noisy places</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listening to the radio</td>
<td>8%</td>
<td>33%</td>
<td>39%</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>Communication with staff at shops, banks, etc.</td>
<td>0%</td>
<td>34%</td>
<td>44%</td>
<td>22%</td>
<td>0%</td>
</tr>
<tr>
<td>Over the telephone</td>
<td>0%</td>
<td>38%</td>
<td>40%</td>
<td>18%</td>
<td>4%</td>
</tr>
<tr>
<td>Conversation with others in the vehicle while driving</td>
<td>2%</td>
<td>28%</td>
<td>42%</td>
<td>26%</td>
<td>2%</td>
</tr>
<tr>
<td>Hearing announcements in transport terminals</td>
<td>16%</td>
<td>16%</td>
<td>22%</td>
<td>33%</td>
<td>14%</td>
</tr>
<tr>
<td>Hearing announcements in public transport vehicles</td>
<td>20%</td>
<td>16%</td>
<td>18%</td>
<td>33%</td>
<td>14%</td>
</tr>
</tbody>
</table>

In summary, most respondents cannot hear announcements in public transport vehicles or terminals. Communication in noisy places, such as when talking with staff in shops, over the telephone, while driving and when listening to the radio were problematic for most respondents. Conversation in quiet places and watching television appeared to be less demanding. The other listening situations are not problematic for most respondents, although quite some respondents report frequent problems in lectures or classes. The amount of problems experienced by the respondents depends on the availability of an inductive loop. The frequency with which problems are experienced while watching television and listening to the film at the cinema strongly depends on the availability of subtitles.

### 4.4.2.2 Personal Wireless Link

- 10% of the respondents are not sure if they have t-setting or not
- 88% of those that have a hearing aid in one ear have t-setting
- 71% of those having hearing aids in both ears have t-setting
- One patient reported having a CI; he has use of t-setting
- Of those that have a t-setting, only 37% use it and 24% have tried using it, but do not use it regularly
- Of those that have a t-setting – 8% have analogue aid, 67% have digital aid

### Table 7 Satisfaction when using a loop in different locations for those who have t-setting on their aid

<table>
<thead>
<tr>
<th>Location</th>
<th>Very satisfied</th>
<th>Quite satisfied</th>
<th>Quite dissatisfied</th>
<th>Very dissatisfied</th>
<th>Do not use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Places of Worship</td>
<td>39%</td>
<td>22%</td>
<td>0%</td>
<td>0%</td>
<td>39%</td>
</tr>
<tr>
<td>Theatre</td>
<td>16%</td>
<td>26%</td>
<td>11%</td>
<td>5%</td>
<td>42%</td>
</tr>
<tr>
<td>Music concerts</td>
<td>11%</td>
<td>44%</td>
<td>11%</td>
<td>11%</td>
<td>22%</td>
</tr>
<tr>
<td>Watching TV at home</td>
<td>16%</td>
<td>42%</td>
<td>0%</td>
<td>5%</td>
<td>37%</td>
</tr>
<tr>
<td>Bank, Shop or Post Office counter</td>
<td>0%</td>
<td>21%</td>
<td>11%</td>
<td>0%</td>
<td>68%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>0%</td>
<td>12%</td>
<td>0%</td>
<td>0%</td>
<td>88%</td>
</tr>
<tr>
<td>At home</td>
<td>22%</td>
<td>33%</td>
<td>6%</td>
<td>0%</td>
<td>39%</td>
</tr>
<tr>
<td>Cinema</td>
<td>0%</td>
<td>6%</td>
<td>6%</td>
<td>0%</td>
<td>88%</td>
</tr>
<tr>
<td>Ticket offices</td>
<td>5%</td>
<td>16%</td>
<td>21%</td>
<td>0%</td>
<td>58%</td>
</tr>
</tbody>
</table>
Table 7 above illustrates users’ satisfaction when using inductive loops in different situations. It is important to note that in many of these situations, respondents do not use the loop. Also, many missing responses were observed at this question (about 50%), which limits the generalisations that can be made from the results. The places where the loop is most frequently used are at music concerts, while watching TV at home and at places of worship. Respondents are quite satisfied with the use of the loop at these places.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Does not cause me concern</th>
<th>Bothers me a little</th>
<th>Bothers me a lot</th>
<th>Puts me off completely</th>
</tr>
</thead>
<tbody>
<tr>
<td>The need to switch manually</td>
<td>65%</td>
<td>23%</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>Difficult to switch manually (small or fiddly switch)</td>
<td>52%</td>
<td>33%</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>The need to adjust level and program</td>
<td>42%</td>
<td>32%</td>
<td>16%</td>
<td>11%</td>
</tr>
<tr>
<td>I do not know where I can use it</td>
<td>35%</td>
<td>18%</td>
<td>18%</td>
<td>29%</td>
</tr>
<tr>
<td>I do not know how to use it</td>
<td>56%</td>
<td>19%</td>
<td>19%</td>
<td>6%</td>
</tr>
<tr>
<td>It does not work with my mobile phone</td>
<td>38%</td>
<td>19%</td>
<td>19%</td>
<td>25%</td>
</tr>
<tr>
<td>It does not connect to other equipment such as telephones, radio, TV</td>
<td>47%</td>
<td>11%</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td>The need to connect a magnetic loop round my neck or behind my ear</td>
<td>53%</td>
<td>13%</td>
<td>7%</td>
<td>27%</td>
</tr>
<tr>
<td>Problems with volume</td>
<td>29%</td>
<td>52%</td>
<td>5%</td>
<td>14%</td>
</tr>
<tr>
<td>Poor sound quality or interference</td>
<td>21%</td>
<td>37%</td>
<td>32%</td>
<td>11%</td>
</tr>
<tr>
<td>Picking up wrong information, e.g. from another loop nearby</td>
<td>25%</td>
<td>31%</td>
<td>25%</td>
<td>19%</td>
</tr>
<tr>
<td>There are not enough places where it can be used</td>
<td>11%</td>
<td>39%</td>
<td>28%</td>
<td>22%</td>
</tr>
</tbody>
</table>

Table 8 The features that stop those who have the t-setting on their aid from using it or bother them when they use it

In Table 8 above the features that stop those who have a t-setting on their aid from using it or bother them when they use it, are presented. The colours indicate the response category most frequently chosen by the respondents. It is important to note that quite a few of the respondents that have a t-setting did not complete this question (about 50% missing responses). Thus, results should be interpreted with caution. In general, not many features were reported to be problematic when using the t-setting. Problems with volume, problems with sound quality or interference, the picking up of wrong information and the lack of places where the t-setting can be used were the features that were most frequently reported to bother them a little.

Many of the Dutch respondents stated that they have not used IR and FM listening systems. Only 4 had used IR listening systems, 2 of them having used IR systems with success. Only 2 respondents have used FM listening systems, with only one of them having used FM systems successfully.
Respondents were asked to indicate which features they would want in a future assistive device replacing the t-setting. Results are presented in Table 9. Colours indicate the answer category most frequently chosen by the 80% of the total number of respondents that completed this question. About 30-50% indicated several features that the device must have; the devices have to be small, light of weight and wireless. It also must have a long battery life and must be easy to operate. Furthermore, it has to be usable with home equipment and it finally has to automatically switch on when it detects a nearby signal. Thirty five percent of the respondents also indicated that they would like to have a device with a feature that enables them to use it at more places than the current t coil.

Respondents’ description of their hearing with aids was also found to relate to their need for several features. Significant correlations were found, with those who described their hearing loss as more severe, stating that they would like the following features: a) automatically switches on when detecting nearby signals, b) the use of the device with home equipment, c) wireless connection to a mobile phone, d) connection with a wireless microphone.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Must have this feature</th>
<th>Would like to have this feature</th>
<th>Am indifferent to this feature</th>
<th>Would dislike this feature</th>
<th>Do not understand the feature</th>
<th>This feature is not relevant to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorporated into the size of my current hearing aid – not making it bigger</td>
<td>43%</td>
<td>29%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>12%</td>
</tr>
<tr>
<td>Light weight</td>
<td>45%</td>
<td>26%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>12%</td>
</tr>
<tr>
<td>Automatically switches on when it detects a nearby signal</td>
<td>33%</td>
<td>23%</td>
<td>0%</td>
<td>8%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Ease of operation – easy to use buttons and controls</td>
<td>49%</td>
<td>22%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>12%</td>
</tr>
<tr>
<td>Wireless (has no cables, wires or other connections)</td>
<td>52%</td>
<td>21%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>10%</td>
</tr>
<tr>
<td>To help supplement the power of my hearing aid and thus improve the quality of my hearing</td>
<td>50%</td>
<td>26%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>7%</td>
</tr>
<tr>
<td>Long battery life</td>
<td>54%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>12%</td>
</tr>
<tr>
<td>Can be used with home equipment such as TV, radio and HiFi</td>
<td>45%</td>
<td>24%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>14%</td>
</tr>
<tr>
<td>More places where it can be used</td>
<td>30%</td>
<td>35%</td>
<td>0%</td>
<td>0%</td>
<td>28%</td>
<td>7%</td>
</tr>
<tr>
<td>Wireless connection to my mobile phone</td>
<td>27%</td>
<td>27%</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>29%</td>
</tr>
<tr>
<td>To connect with school FM listening systems without wires</td>
<td>18%</td>
<td>23%</td>
<td>0%</td>
<td>0%</td>
<td>18%</td>
<td>41%</td>
</tr>
<tr>
<td>Can connect to a wireless microphone</td>
<td>18%</td>
<td>31%</td>
<td>0%</td>
<td>0%</td>
<td>18%</td>
<td>33%</td>
</tr>
<tr>
<td>Can connect to an array microphone to allow me to tell where sound is coming from</td>
<td>25%</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Table 9 The percentage of respondents that would want different features on a future replacement for the t-setting
Respondents were asked to indicate in which listening situations they would want to use a communication link similar to the current t coil. The results are presented in Table 10. The colours indicate the response categories most frequently chosen by the respondents. Relating the answers to this question with the locations indicated by the respondents as most problematic (see Table 6 – q15-) does not lead to unexpected results. (The results show that the locations that were indicated as problematic by most respondents are also the locations at which a communication link similar to the t coil is most highly needed. Respondents that described their hearing impairment (with the use of aids) as more severe indicate a higher need of the communication link at home for TV and radio. They also indicate a higher need to use it in the street to hear traffic lights and warning signals.

- 19% of the respondents indicated that they are not willing to carry an additional portable device if it enhanced their hearing
- 58% would be willing to carry up to one additional device
- 19% would be willing to carry up to 2 additional devices
- No one would be willing to carry up to 3 additional devices

Of the respondents willing to carry an additional portable device, 62% would want something small enough to be concealed in the palm of hand or keep in a pocket or ladies handbag. 19% felt that it would be acceptable to be visible – to be put on table or held in hands. No one felt it would be acceptable to be the size of a laptop or large book.
4.4.3 Greek User Questionnaire

4.4.3.1 Daily living

The questionnaire was also translated into Greek and distributed to deaf and hard of hearing people in Greece. As described in the sections about the UK and Dutch data, the questionnaire asked respondents about daily living and the level of problems encountered in different situations. The responses to these questions are summarised in Table 11 below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No problems</th>
<th>Occasional problems</th>
<th>Frequent problems</th>
<th>Cannot manage this situation</th>
<th>Do not encounter this situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures or classes</td>
<td>3%</td>
<td>20%</td>
<td>23%</td>
<td>17%</td>
<td>30%</td>
</tr>
<tr>
<td>Work meetings</td>
<td>20%</td>
<td>10%</td>
<td>17%</td>
<td>7%</td>
<td>47%</td>
</tr>
<tr>
<td>Hearing announcements in public transport vehicles</td>
<td>17%</td>
<td>40%</td>
<td>17%</td>
<td>23%</td>
<td>3%</td>
</tr>
<tr>
<td>Hearing announcements in transport terminals</td>
<td>10%</td>
<td>37%</td>
<td>20%</td>
<td>30%</td>
<td>3%</td>
</tr>
<tr>
<td>Face to face conversation in quiet places</td>
<td>33%</td>
<td>50%</td>
<td>10%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Face to face conversation in noisy places</td>
<td>33%</td>
<td>47%</td>
<td>17%</td>
<td>3%</td>
<td>10%</td>
</tr>
<tr>
<td>At the cinema, to listen to the film</td>
<td>23%</td>
<td>57%</td>
<td>3%</td>
<td>33%</td>
<td>7%</td>
</tr>
<tr>
<td>At the theatre, to hear the performance</td>
<td>27%</td>
<td>43%</td>
<td>7%</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>At concerts, to hear the performance</td>
<td>23%</td>
<td>37%</td>
<td>20%</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>When watching sport, e.g. in a stadium</td>
<td>27%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>33%</td>
</tr>
<tr>
<td>When playing sport</td>
<td>23%</td>
<td>20%</td>
<td>0%</td>
<td>7%</td>
<td>40%</td>
</tr>
<tr>
<td>Watching television</td>
<td>60%</td>
<td>17%</td>
<td>10%</td>
<td>13%</td>
<td>0%</td>
</tr>
<tr>
<td>Listening to the radio</td>
<td>17%</td>
<td>33%</td>
<td>23%</td>
<td>27%</td>
<td>0%</td>
</tr>
<tr>
<td>Communication with staff at shops, banks, etc.</td>
<td>27%</td>
<td>50%</td>
<td>17%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Over the telephone</td>
<td>17%</td>
<td>47%</td>
<td>17%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Conversation with others in the vehicle while driving</td>
<td>17%</td>
<td>17%</td>
<td>13%</td>
<td>10%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table 11 Activities of daily living and the percentage of participants that encounter problems

As can be seen in the table above, most Greek respondents frequently have problems with hearing during lectures or classes. The majority of the Greek respondents indicated occasional problems at most of the listed listening situations. Relatively easy listening situations are watching television, watching sports at a stadium, playing sport and work meetings.

Many users commented that they have few or almost no problems during a telephone conversation with friends and family, but may have problems during a conversation with strangers. Also, many respondents commented that the amount of problems that are encountered depend on factors such as distance, intensity of sound and availability of visual stimuli in contexts such as lectures and business meetings.
4.4.3.2 Personal Wireless Link

In Greece, most users are not familiar with T-settings, with 30% being unsure if their aid has a t-setting or not. One-third of the users that have a hearing aid in one ear indicated that their aid has a t-setting, and also one-third of these users indicate that their aid does not have a t-setting. Of the respondents with two hearing aids, 80% reports that their aids have a t-setting and 10% reports that their aids do not have a t-setting. 70% of the respondents that have a hearing aid with a t-setting do use it.

Of the respondents that have a hearing aid with a t-setting, 6 have a digital aid and two have an analogue aid and two respondents do not know whether they have a digital or an analogue aid.

The number of respondents is insufficient to give a representative overview of the places where the t-setting is used and the problems that are encountered when it is used. Both the respondents and the professionals working with hard of hearing people indicated that some questions were too technical. Hence, many questions about technical details were left unanswered. It is important to note that the ability to answer the more technical questions was related to the age and the degree of hearing loss of the respondents; younger respondents that were profoundly deaf from birth were able to answer relatively many questions, whereas older respondents were relatively less familiar with technical details.

Respondents were asked to indicate which features they would want in a future assistive device replacing the t-setting. Results are presented in Table 12. The following features were indicated as necessary features by most respondents: the device must have a long battery life (47%) and it must be incorporated into the size of the hearing aid (40%). Also 40% of the respondents indicated that the device must be light of weight and that they must be able to connect it to home equipment and their mobile phones. 37% of the respondents indicated that the device should help supplement the power of their hearing aid to improve the quality of their hearing and also 37% indicated that it should be possible to connect the device to FM listening systems or an array microphone. Respondents that described their hearing (with the use of aids) as more severe, more often indicate that a feature that allows the device to be incorporated into their current hearing aid should be included.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Definitely of use to me</th>
<th>Likely to be of use to me</th>
<th>May be of use to me</th>
<th>Not of use to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shops to communicate with assistants</td>
<td>40%</td>
<td>7%</td>
<td>7%</td>
<td>13%</td>
</tr>
<tr>
<td>Places of worship</td>
<td>30%</td>
<td>10%</td>
<td>23%</td>
<td>13%</td>
</tr>
<tr>
<td>Theatres and concert halls</td>
<td>43%</td>
<td>10%</td>
<td>17%</td>
<td>7%</td>
</tr>
<tr>
<td>Cinema</td>
<td>37%</td>
<td>10%</td>
<td>23%</td>
<td>7%</td>
</tr>
<tr>
<td>At office and in meeting rooms for work</td>
<td>33%</td>
<td>7%</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>At other work locations, e.g. workshop, hall, outdoors</td>
<td>27%</td>
<td>13%</td>
<td>13%</td>
<td>23%</td>
</tr>
<tr>
<td>In car, e.g. phone use and listening to radio</td>
<td>23%</td>
<td>13%</td>
<td>17%</td>
<td>23%</td>
</tr>
<tr>
<td>At ticket counters</td>
<td>37%</td>
<td>17%</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>At transport terminals to hear announcements</td>
<td>53%</td>
<td>10%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Inside public transport vehicles to hear announcements</td>
<td>47%</td>
<td>10%</td>
<td>17%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 12 The percentage of participants that would want different features on a future replacement for the t-setting

Respondents were asked to indicate in which listening situations they would like to use a communication link similar to the current t-coil. The results are presented in Table 13.

Half of the respondents indicated that a communication link would be helpful at home for conversation, and almost half of the respondents (47%) indicated that a link would be useful inside public transport vehicles to hear announcements, in the street to hear warning signals, and at home for TV and radio. In addition 40% of the respondents would like to use a communication link at shops or during lectures or classes.

Combining these results with the locations that were indicated as problematic by the Greek respondents (see Table 11) does not lead to unexpected results, with respondents who would like to use a communication link at the same locations that were considered previously as problematic.
Table 13 The percentage of Greek respondents that would want to use the new technology in the listed listening situations

Respondents were asked whether they would be willing to carry an extra portable device to help enhance their hearing. Only one Greek respondent indicated that he would not be willing to carry an extra device. The majority of the respondents (66%) would be willing to carry a very small device (small enough to be concealed in the palm of the hand) and 31% would be willing to carry an extra device that could be put on the table or held in hands when sitting. No one would be willing to carry a device with the size of a laptop computer or a large notebook. These results should be interpreted with caution, because when the users are asked how many devices they would be willing to carry if the devices were the size of a mobile phone, more than 45% of the respondents indicated that they would not be willing to carry any device at all. Of the remainder, 48% would be willing to carry one device, while only two Greek respondents would be willing to carry up to two additional devices. It seems that the Greek respondents are only willing to carry very small additional devices – many are not willing to carry a device with the size of a mobile phone.

4.4.4 UK Professional Questionnaire

The results obtained from the professional therapists should be interpreted with caution, as only 21 therapists responded, compared with the 101 users questionnaires that were obtained.
As can be seen in Table 14 above, the responses from the professionals reflected many of the same views as users, with regards to when patients encounter problems communicating. Both sets of responses highlight that more problems are encountered by deaf and hard of hearing people when trying to understand what is being said in public places. Comments made by the professionals also suggested that whether or not patients encountered problems was ‘dependant on lip reading skills’.

<table>
<thead>
<tr>
<th>Activity</th>
<th>A little worrying</th>
<th>Quite worrying</th>
<th>Very off-putting</th>
<th>Not a problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>The need to switch manually</td>
<td>81%</td>
<td>14%</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>Poor sound quality or interference</td>
<td>55%</td>
<td>20%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Problems with volume</td>
<td>50%</td>
<td>25%</td>
<td>-</td>
<td>25%</td>
</tr>
<tr>
<td>Picking up wrong information, e.g. from another loop nearby</td>
<td>45%</td>
<td>15%</td>
<td>5%</td>
<td>35%</td>
</tr>
<tr>
<td>It does not work with their mobile phone</td>
<td>45%</td>
<td>35%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>The need to adjust level and program</td>
<td>43%</td>
<td>29%</td>
<td>5%</td>
<td>24%</td>
</tr>
<tr>
<td>Not knowing where to use it</td>
<td>43%</td>
<td>24%</td>
<td>19%</td>
<td>14%</td>
</tr>
<tr>
<td>It does not connect to other equipment such as telephones, radio, TV</td>
<td>42%</td>
<td>11%</td>
<td>10%</td>
<td>37%</td>
</tr>
<tr>
<td>The need to connect a magnetic loop round the neck or behind the ear</td>
<td>38%</td>
<td>14%</td>
<td>29%</td>
<td>19%</td>
</tr>
<tr>
<td>Not knowing how to use</td>
<td>33%</td>
<td>24%</td>
<td>29%</td>
<td>14%</td>
</tr>
<tr>
<td>Difficulty switching manually (small switch)</td>
<td>33%</td>
<td>48%</td>
<td>14%</td>
<td>5%</td>
</tr>
<tr>
<td>There are not enough places where it can be used</td>
<td>20%</td>
<td>45%</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>The need to ask staff to switch their system on</td>
<td>14%</td>
<td>24%</td>
<td>57%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 15 Hearing therapists’ opinions of the features of loops and the how much it puts their patients off using them

Professionals’ responses seemed to agree with those of the users with the inconvenience of having to ask staff to switch their system being one of the main reasons that stops patients using loops. One difference between the responses of
users and professionals was that the professionals appear to see fewer features as not causing a problem. However, the professionals were responding in relation to a number of patients with different needs. This supports the suggestion mentioned earlier, that when the users answered the same questions, they were responding in relation to the situations they personally encounter and therefore stated that many of the features did not cause them concern.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Very important – key feature</th>
<th>Quite important</th>
<th>Neither important nor unimportant</th>
<th>Unimportant</th>
<th>Very unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorporated into the size of current hearing aid – not making it bigger</td>
<td>76%</td>
<td>14%</td>
<td>5%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Wireless – has no cables, wires or other connections</td>
<td>67%</td>
<td>29%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>To help supplement the power of a hearing aid, thus improve the quality</td>
<td>65%</td>
<td>20%</td>
<td>10%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Light weight</td>
<td>62%</td>
<td>29%</td>
<td>5%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Ease of operation – easy to use buttons and controls</td>
<td>57%</td>
<td>38%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>More places where it can be used</td>
<td>48%</td>
<td>43%</td>
<td>5%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Can be used with home equipment, such as TV, radio and HiFi</td>
<td>48%</td>
<td>48%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Wireless connection to mobile phone</td>
<td>43%</td>
<td>43%</td>
<td>10%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Connect to an array microphone to help people tell where sound is from</td>
<td>19%</td>
<td>57%</td>
<td>19%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Automatically switches on when it detects a nearby signal</td>
<td>15%</td>
<td>50%</td>
<td>20%</td>
<td>15%</td>
<td>-</td>
</tr>
<tr>
<td>Can connect to a wireless microphone</td>
<td>38%</td>
<td>48%</td>
<td>10%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Can connect to school FM listening systems without wires</td>
<td>29%</td>
<td>43%</td>
<td>14%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Long battery life</td>
<td>33%</td>
<td>24%</td>
<td>38%</td>
<td>-</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 16 Hearing therapists’ opinions of the importance of different features on a future replacement for the t-setting

The findings from Table 16 above show the professionals views of the different features that they felt would be important on a future replacement for the t-setting. When compared with users responses one can see that they are very similar with only marginal differences. With preference being towards a small, lightweight, wireless system.
<table>
<thead>
<tr>
<th></th>
<th>Very important</th>
<th>Quite important</th>
<th>Neither important nor important</th>
<th>Unimportant</th>
<th>Very unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>At office and in meeting rooms for work</td>
<td>76%</td>
<td>14%</td>
<td>-</td>
<td>-</td>
<td>10%</td>
</tr>
<tr>
<td>At home for TV and radio</td>
<td>76%</td>
<td>19%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Lectures or classes to hear the teacher</td>
<td>72%</td>
<td>14%</td>
<td>-</td>
<td>-</td>
<td>14%</td>
</tr>
<tr>
<td>Inside public transport vehicles to hear announcements</td>
<td>67%</td>
<td>19%</td>
<td>10%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>At transport terminals to hear announcements</td>
<td>67%</td>
<td>29%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Places of worship</td>
<td>67%</td>
<td>29%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>At ticket counters</td>
<td>67%</td>
<td>24%</td>
<td>5%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>At other work locations, e.g. workshop, hall, outdoors</td>
<td>62%</td>
<td>24%</td>
<td>10%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Theatres and concert halls</td>
<td>57%</td>
<td>38%</td>
<td>-</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>In car, e.g. phone use and listening to radio</td>
<td>52%</td>
<td>29%</td>
<td>14%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Shops to communicate with assistants</td>
<td>52%</td>
<td>38%</td>
<td>5%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>At home for conversation</td>
<td>48%</td>
<td>38%</td>
<td>10%</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>In the street to hear traffic lights and warning signals</td>
<td>38%</td>
<td>38%</td>
<td>14%</td>
<td>-</td>
<td>10%</td>
</tr>
<tr>
<td>While playing sport to hear referee or umpire</td>
<td>38%</td>
<td>38%</td>
<td>19%</td>
<td>-</td>
<td>5%</td>
</tr>
<tr>
<td>Cinema</td>
<td>33%</td>
<td>43%</td>
<td>14%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>For use with personal stereo or Walkman</td>
<td>29%</td>
<td>43%</td>
<td>19%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>While watching sport to hear commentary</td>
<td>33%</td>
<td>38%</td>
<td>19%</td>
<td>10%</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 17 Hearing therapist’s opinions of locations where a communication link may be useful for those with a hearing loss

Again the professionals responses were very similar to users when asked where they felt a communication link may help patients. With professionals indicated that it was very important that a communication link was available in all locations.

4.4.5 Dutch Professional Questionnaire

The professional questionnaire was completed by five professionals working at the department of Audiology of the VU medical centre (Amsterdam). Due to the small size of this sample the results should be interpreted with caution.

Professionals were asked to indicate in which situations the hearing of their patients is not sufficient to understand what people are saying. In Table 18, the results are presented. The colours indicate the answer category most frequently chosen for each listed location or listening situation. The professionals commented that the severity of problems encountered by their patients strongly depends on the availability of an induction loop (especially at locations like the cinema and the theatre) and other characteristics of the environment, such as the opportunity to lip-read the speaker.
Face to face, quiet
Waking up – alarm clock
Awareness events around vehicle
Cinema
Playing sports
Watching TV
Communication staff at shops noisy
Conversation while driving
Awareness someone is at the door
Awareness that baby / child requires attention
Awareness incoming call
Lectures or classes
Work meetings
Announcements in transport vehicles
Announcements in transport terminals
Face to face, noisy
Theatre
Concert halls
Watching sport
Radio
Over the telephone

Table 18 The number of patients that experience hearing problems in different listening situations. The colors indicate the answer category that was most frequently chosen by the professionals.

Difficult to switch manually
Need to ask staff to switch system on
Picking up wrong information
Need to switch manually
Problems with volume
Poor sound quality / interference
Need to adjust level / program
Do not know where to use
Do not know how to use
Not enough places where it can be used
Does not work with mobile phone
Does not connect with other equipment
Need to connect magnetic loop

Table 19 The problems encountered by hard of hearing patients (as described by professionals) when using an inductive loop. The colours indicate the answer category that was most frequently chosen by the professionals.

Professionals were asked at which location their patients would mostly need an additional portable device. They found it very difficult to answer this question, because they think it strongly depends on the individual situation of the hearing impaired person. For example, a retired person does not need the device at work, but for the working hard of hearing people, the need for an assistive device might be substantial.

Finally, professionals were asked to rate the importance of several additional features that could be included in the assistive device. According to them, the device must have a feature that improves the ability to hear speech when
surrounded with many persons. Also of importance is a feature that improves the ability to hear speech in reverberant or echoey places and a feature that would improve the ability to hear speech and improve the listening comfort in noisy situations. The ability to connect the device to the doorbell is also rated as important. Less important features are the ability to connect the device to a mobile phone, smoke detectors or the Internet.

4.4.6 Greek professionals questionnaire

Due to the reasons mentioned in section 4.3.2, Analysis of the Greek professional data was not possible.

4.5 Conclusions

The sample of users was very varied and included a mix of ages and levels of hearing loss. It is therefore assumed that the results obtained are representative of the views of this population, unless otherwise stated. The numbers of people in each age group did not match the distribution of the general population in the UK; however, as all age groups were represented it was not felt that this affects the validity of the data. This assumption is also supported by the fact that the opinions obtained by the professional questionnaire were very similar to those of the users.

These results highlighted that the problems encountered by individuals vary greatly. Depending on factors such as the level of their loss, the aids they use, their age and the support (assistive devices) that are available in different situations. Despite this, the problems encountered all tended to be in public and noisy locations, with problems also being affected by the availability of visual stimuli, such as being able to see the other person to lip-read.

To define what features deaf and hard of hearing people wanted from a future personal wireless link, they questionnaires initially asked about existing systems. Inductive loops were the most commonly used system in all three countries, with Infra-red and FM systems also used by a small number of people in some locations in the UK and the Netherlands.

Inductive loops require a t-setting on the aid, for users to connect to the system. This feature was more common on hearing aids than cochlear implants, and more so on digital rather than analogue aids. Not everyone who had the ability to use inductive loops did use them, and a large number of those who had used inductive loops had been unsatisfied with the performance.

The results highlighted many of the problems that users encounter when using existing inductive loops. Many of the reasons related to the installation and maintenance of the loop systems, with users encountering poor sound quality, interference, and having to ask staff to turn the system on. Comments by users also stated that they were unsatisfied with the physical aspects of existing loop systems. With respondents stating that they disliked having to wear a visible technology such as neck loops and encountering difficulties connecting to devices such as mobile phones. Several users also commented on disliking the fact that
they had to use assistive devices, which they felt had a stigma attached to them. A number comments also suggested that adequate information is often not provided, leaving users unaware of how and where they can use the t-setting and the benefits of using such devices.

The reasons as to why inductive loops are not used by all, was unclear from the data obtained. However, opinions were split over whether the fact that users are unable to hear sounds around them when using the t-setting was an advantage or a disadvantage. Some users stated that they liked the fact that they could block out background noises, whereas other disliked the fact that they were unable to hear doorbells and alarms. The fact that individuals have very diverse needs is highlighted.

Comments made by the few people that had used IR and FM systems, were very similar to those made about inductive loops. As with loops, a large proportion of users had been unable to use such systems successfully with poor sound quality and the way such systems are managed and maintained being criticised.

All these findings highlight that the needs of users are individual and diverse, influenced by lifestyle and circumstance, as well as the environment where systems are used. When asked about a future wireless system, every feature was wanted; however some features were more important to different groups of individuals, depending on their needs.

As opinion was split over whether users wanted a system that automatically switches on when a signal is detected, care needs to be taken over when selecting what features are added to any future system. The results also highlighted that although some users were willing to carry more than one or a larger additional device, a device that is small, wireless and lightweight with good sound quality seemed to be preferred option for the majority of respondents.

4.6 Recommendations

It is clear from this research that existing communication links are not effective and are often not used by deaf and hard of hearing people. Supporting the development of a new personal wireless link is the proposal of this work package; however, this research also shows that care needs to be taken during the development of any replacement system ensuring that any future system will meet the needs of deaf and hard of hearing users.

Due to the number of problems that users encountered with existing systems care needs to be taken during the design and development of the Personal Wireless Link, especially with regards to the man-machine interface. It is important that a future system is intuitive and easy to use. It is therefore recommended that users are involved at regular intervals during the development process to test and refine new design ideas.

Users stated that they wanted a large number of features on a future system. Attention also has to be paid to ensure that any future device carries out its main
purpose of providing users with a good high quality sound, through a system that is reliable, which with the wide variety of potential users with different individual needs, will be a delicate issue.

Many of the problems that this research has highlighted are related to the fact that inductive loops are a niche technology developed to assist those with a hearing loss. What is needed in any future system is better integration with the world and other systems and technology. This research highlighted the importance of awareness: ensuring that information is provided so that people are aware of any new system, whether they are a user, an operator or the provider.

One possible solution would be to resolve this problem with a mainstream product, rather than an assistive device. If a system could be developed that enhanced listening in difficult situations, such as public places and noisy locations, it would not only be deaf and hard of hearing people that would benefit. Such a system would also be used by those without a hearing loss, which also has further benefits for deaf and hard of hearing people as such a system is more likely to be installed and maintained to a higher standard, than an assistive technology with fewer users.

If these recommendations are not considered then it is likely that users will be dissatisfied with performance or deterred from using any future system. However if users are involved throughout this processes as suggested, the personal wireless link proposed will hopefully improve the lives of many deaf and hard of hearing people.
5 Functional Requirements

5.1 User Interface Requirements

5.1.1 Delay Requirements

In the hearing-aid context we can distinguish two types of delays: processing delay and relative delay. Processing delay is introduced by the signal processing in the hearing aid and should be kept as low as possible. The relative delay is the difference in processing delay between the left and right hearing aids and should also be kept low. Note that when the sound source is located to the side of the listener there is a natural delay between the time instant the wavefront hits the left and right ear respectively. This natural delay (among other aspects) enables us to locate sounds spatially. If the relative delay is non-zero the spatial image is distorted.

5.1.1.1 Processing Delay

The processing delay is introduced in the signal processing chain between the microphone of the hearing aid via signal processing to the hearing aid loudspeaker and is the sum of algorithmic delays (delay that is inherent, to the signal processing algorithms used), propagation delays (due to transmission to and from PCS), and hardware related delays (e.g., data buffering associated with scheduling of the processing task). The tolerable processing delay varies considerably depending on which aspect is tested, e.g.:

- annoyance when speaking and listening to own voice through hearing aid and still hearing the “direct path” via bone conduction and leakage around the earmold;
- echo when listening to external sounds;
- conversational problems due to large delay (speakers start talking at the same time);
- out of synch visual impression (e.g. lip movements, TV image...);
- type of hearing aid (partial/total occlusion of ear canal, monaural/binaural);
- level/type of hearing loss.

The annoyance due to processing delay when listening to ones own voice was studied by [6] for a set of simulated hearing losses and for completely occluding binaural hearing aids. They demonstrated that the delay becomes annoying if it exceeds 20ms. The delay may be slightly less annoying if the hearing loss is more severe. In [7] they study the annoyance for normal hearing people, and arrive at essentially the same conclusion. They argue that the annoyance due to delay can mainly be attributed to the case when listening to ones own voice and further conclude that the permissible delay in this case is significantly shorter than for audio-visual synchronization; audio-visual synchronization requires a delay lower than 150ms. In [8] they study the same aspect, annoyance when listening to ones own voice, but with test subjects with
real hearing losses. Depending on the type of hearing loss the “just acceptable” delay ranged between 14 and 30 ms.

The annoyance when listening to external sounds was examined for non-occluding hearing aids by [9]. They investigated delays up to 10ms and report that the disturbance levels were low and acceptable for their application.

The problem of delays during conversations has been extensively studied in speech coding. It is recommended to keep the one-way delay below 150 ms [10]. This is well above the limit when considering listening to owns voice while speaking. However, any processing delay in the HA/PCS system is added to the total delay in a conversation.

To summarize, there is no implementable, fixed level of delay below which there is no perceived loss of quality. Instead, there is a continuous monotone increase of annoyance with increasing delay. Moreover, the tolerable delay varies, but only moderately so, with the level of hearing loss (the more severe the loss the less sensitive to delay), and the type of HA (the more occluding the less sensitive to delay). The tolerable delay is also a trade-off between the annoyance due to the delay and what can be achieved with the signal processing that is made possible with the delay.

The previous discussion indicates that the selection of a maximum processing delay is a trade-off between delay-induced quality loss and the facilitation of signal processing. As a reasonable compromise, the maximum processing delay allowed for the HearCom project is set to:

- 15ms for situations in which the transmitted signal is heard together with the own voice
- 150ms in case of 2—way conversations in which the own voice is not heard back via the transmission system
- up to a few hundred ms for 1-way transmission (e.g. for entertainment services like radio)

5.1.1.2 Relative Delay

A quick calculation provides the order of magnitude of the tolerable relative delay. The distance between the ears is approximately 25 cm. If the sound source is located to the side of the listener the wavefront reaches the closest ear approximately 1ms before the other ear. Thus, the time difference cue, or interaural time difference (ITD), for spatial localization varies between 0 and 1ms. To preserve the spatial image the relative delay should be a small fraction of a millisecond. In [11], it was observed that an ITD change of just a few microseconds can be detected by normal hearing people. In [12], human subjects were exposed to artificial delays between 0.17 to 0.68 ms in one ear. The test subjects (normal hearing) immediately suffered from a displacement of perceived sound location. After some time the test subjects adapted to the delay and the displacement was reduced. For a (typical) HA user who switches between wearing the HAs and not using them, a relative delay of 0.1 ms and repeated adaptation to that will be annoying.
Note that in the case of monaural use of HAs the relative delay will be equal to the processing delay. This puts a very severe (unrealistic) constraint on the processing delay if the spatial image is to be preserved. Therefore, for monaural use, no requirement on relative delay is formulated. For binaural use, a relative delay of 0.05 ms is deemed tolerable for the HA/PCS system.

5.1.2 Signal Quality Requirements

The quality degradations discussed in this section should not be confused with the degradation due to background acoustic, additive noise. The degradations we discuss here are incurred in the wireless radio link between the HAs and the PCS. Further, we separate the requirements on signal quality into two cases:

1) degradations in the coding of “one-way” streaming audio for transmission from PCS to HAs, i.e., communication mode 3 as defined in Section 5, and
2) degradations in the coding in the “two-way” wireless link (from HA to PCS and back to HA), i.e., communication mode 2

Quality will be measured using both objective tests, i.e., tests done by a machine involving no human listeners, and subjective tests requiring human listeners. Objective quality will be measured using PEAQ [13] for general audio and PESQ [14] for speech. Subjective quality will be measured using the MUSHRA test [15]. In the following we will talk about transparent processing. Informally, a signal processing operation is transparent if the output of the processing is perceptually equivalent to the input, i.e., the output and the input cannot be distinguished. In terms of the objective measures, we will say that the output is transparent if the PEAQ and PESQ measures of the output are at most 0.25 and 0.1 units lower than the PEAQ and PESQ measures of the input respectively. In terms of the subjective tests, transparent processing is achieved if the MUSHRA score of the output is at most 10 units lower than the score of the input.

5.1.2.1 Quality Requirements of One-Way Streaming Radio Link

The one-way link must interface to audio played back at a wide range of sampling frequencies, from 8 kHz narrowband telephony to 44.1 kHz mainstream audio. It is assumed that the external audio is re-sampled to a sampling frequency of 32 kHz, and that the subsequent processing is done at this sampling rate.

When audio is subjected to several encoding and decoding stages - so-called transcoding -, additional distortion may be incurred (more than the sum of the distortions from the separate coding stages). As can be seen in the proposed architecture in Section 6.1.2 (page 52), the external audio that is decoded in the generic audio receiver of the Personal Communication System (PCS), is input to the source and channel encoder of the Body Area Network (BAN) interface for streaming to the HAs. This last encoding and decoding in the BAN interface should be transparent with respect to the decoded audio in the PCS generic audio receiver. Transcoding will be tested with the GSM and 3rd generation mobile telephony codecs as well as with hi-fidelity audio codecs.
The influence of bit errors in the wireless transmission on the audio quality is discussed in the next section. The quality requirements in this aspect are the same for the one-way streaming link and the two-way link.

5.1.2.2 Quality Requirements of Two-Way Link

Three main sources of degradations and corresponding requirements are discussed in this section:

1) the audio bandwidth of the system,
2) the source encoding and decoding, and
3) the influence of channel errors from the wireless transmission.

The required audio bandwidth is related to the level/type of hearing loss and the type of audio material. To cover the whole range of losses and hi-fidelity audio, the system should use a bandwidth of 16 KHz, i.e., a sampling frequency of 32 kHz.

By encoding, it is meant, in the following, the cascaded operations of source encoding and channel encoding, analogously for decoding. In the two-way communication mode of the system, the complete audio processing chain is as follows: encoding in the HA, wireless transmission to the PCS, decoding in the PCS, processing by the advanced signal processing unit, encoding in the PCS, transmission to the HA, and decoding in the HA.

For an error free channel, and an all-pass advanced signal processing unit, the above processing should be transparent: the encoding and decoding prior to, and the encoding and decoding after the advanced signal processing should not introduce any perceptible modification of the audio. I.e., we are comparing the output of the advanced signal processing unit when undistorted audio is input to the unit to the output of the complete processing chain. This will be tested for three typical set-ups of the advanced signal processing unit.

Channel errors can cause impulse-like distortions that are very annoying to a listener and can interfere with subsequent signal processing. Explicit error control by channel coding and careful choice of the source coding method can reduce the effects of channel errors. Channel coding methods can only reduce the average error rate but will not affect how a channel error that passes the channel decoder uncorrected influences the output audio quality (at least not in a predictable way). The choice of source coding method is crucial in this respect as source codecs can be designed to be inherently robust to channel errors. Unequal channel error protection can improve the robustness as for adaptive transform coders [16] for example. The channel error rates depend on the transmission method. Evaluation of the error rates of the wireless link will provide the guidelines for the amount of channel error protection needed in the communication. If the bit error rate is high it may be necessary to employ explicit error correction techniques. If the error rate is lower it may suffice to employ an audio codec that is inherently robust to bit errors.

For the requirements with respect to channel error robustness we distinguish between random errors and burst errors [17]. With random errors the probability of having a bit error is independent of the previous errors; with burst errors, the channel errors typically occur in longer sequences of bits that are all in error. The
channel decoder must provide a bit stream with an error rate lower than 0.0001 in order for a transform coder to output “tolerable” quality at the decoder [16]. Also, the degradation for higher error rates should be graceful. For burst errors (and also for random errors) it is required that channel errors do not produce distortions that are perceived as uncomfortable by the user.

5.1.3 Physical Requirements

The physical requirements of the system components include requirements on the following properties:

- Power consumption (approximately the same as current technology)
- Size of the HAs (not bigger than current HAs)
- Size of the PCS (not bigger than a typical PDA)

The survey that is being conducted may provide additional properties and will provide a basis for a more precise specification of physical requirements.

5.2 Radio Link Requirements

5.2.1 Introduction

This section gives an overview of the requirements for the radio link related to some aspects like traffic, security, etc. The information gathered does not include an extensive degree of detail, given that, on the one hand, we are going to use (and therefore we will have to adapt to) mainstream technologies. And, on the other hand, more specific data will be agreed along the development of the HearCom SP4 prototype, and the subsequent adjustment of parameters.

The HearCom application is based on the availability of continuous mobile communication of the user with a series of peripherals, terminals and servers where information or the application logic is used or originated. We can distinguish different legs of this communication link scenario (Figure 5, page 52).

A personal communication device (PCS) is central to the operation and is the clearing house of all user communications.

<table>
<thead>
<tr>
<th><strong>WAN: Wide Area Network</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mobile Networks</strong></td>
</tr>
<tr>
<td>o Long range link: Public area’s: 1 to 20 km; Public</td>
</tr>
<tr>
<td>o GSM, GPRS, UMTS</td>
</tr>
<tr>
<td>o High complexity, medium size, medium power, data, audio, video</td>
</tr>
<tr>
<td><strong>WLAN</strong></td>
</tr>
<tr>
<td>o Medium range link: Office: 10-100 meter; Public</td>
</tr>
<tr>
<td>o WiFi</td>
</tr>
<tr>
<td>o Mainly Data</td>
</tr>
</tbody>
</table>

**PAN: Personal Area Network**
Medium range link: Home/personal area: max 5 to 50 meter; Private
- Bluetooth, WiFi
- Medium complexity, small/medium size, medium power, data, audio, video

**BAN: Body Area Network**
- Short range link: Body: max 0.3 to 1.5 meter; Private
- Low complexity, miniature, low-power, data, audio
- Collaborating with or replacing existing telecoil. Possibility of including this link interface in new ultra low power devices (like Coolflux [4][5])

<table>
<thead>
<tr>
<th>Table 20 Communication link scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.2.1.1 WAN (Wide Area Network link)</strong></td>
</tr>
</tbody>
</table>

- Communication of the user PCS to other users and servers via **Mobile networks**:

  This type of communication provides the service that will be available with a higher guarantee of quality and continuity. The service is provided via GSM, GPRS, EDGE or 3G UMTS networks with data transmission speed ranging from low to medium.

  The service provided is, phone voice service, messaging and data IP communication.

  The limitations are the relative low speed achieved and the cost involved.

  The big advantage is the availability everywhere and the guaranteed quality and continuity of service during movements.

- Communication of the user PCS to other users and servers via **local area wireless networks**

  Wireless local area networks are installed in specific hot spots by companies and institutions.

  The service they provide is local and no guarantee of service is provided as in every typical IP environment. This network can be used to distribute high data bandwidth with internet service. Via internet HearCom users can have access to local services including public distribution of information and announcements together with connection to HearCom Server for specific HearCom services like speech-to-text conversion.

  PCS can be used to translate other local network specifically for the hearing impaired like the "telecoil", an analog technology that is presently used to distribute content and announcements in a public environment or to connect to the personal phone.

| **5.2.1.2 PAN (Personal Area Network link)** |

Thin link provides connection to the PCS of the user to the different personal domestic equipments via Bluetooth.
5.2.1.3 BAN (Body Area Network link)

Communication of the user PCS to peripheral equipment like hearing aids or audio equipment via body area networks.

This service is provided via low speed low power radio link.

5.2.2 Traffic and User Limitation

The most important limitation for wireless devices and wireless communications is the capabilities of air interface. The data rate (the amount of data per second that can be exchanged) is the main restriction within these capabilities. And the more users are connected, the lower data rate is available for each of them.

In general the user and traffic limitations can be expressed by the Quality of Service (QoS) available in a wireless network. The characteristics of the QoS are for example the guarantee of specific bandwidth, the limitation of delay and delay variation (jitter), the limitation of transmission loss (bit error rate, frame loss...).

Each wireless network has specific mechanisms (marking flows; admission control; priority scheduling; buffer management; constrained routing; mechanisms for signalling) to improve and to achieve suitable QoS depending on user requirements.

Before developing a wireless network, it is crucial to define very precisely technical requirements and targeted QoS to achieve high level of efficiency and achievability.

5.2.3 Security

Each wireless network has specific mechanisms, to protect transmission or exchange of data, which can be enabled at different levels (from the applicative layer to the physical layer). We can say that the optimal security is achieved when the end-to-end secure communication is assured.

The three most important security requirements are:

- the integrity: the ability to verify that the content of a message has not been modified;
- the non-repudiation: the verifiability of the origin of a message;
- the accountability: the unique traceability to an entity.

The security risks in wireless include those risks of wired networks, as well as the new risks introduced by weaknesses in wireless protocols. It is important, in fact, to adapt the level of protection to the end-user application, e.g. for a face-to-face conversation employing the PCS for TTS conversion, it is just necessary to guarantee a certain level of confidentiality, whereas for a telephone conversation with the bank, using also TTS, it would be desirable a higher degree of security, providing mechanisms for authentication.
5.2.4 Confidentiality

In the same way, wireless networks provide different levels of protection to assure the confidentiality of a transmission enabled at different layers (from the applicative layer to the physical layer). For example, the Bluetooth specifications provide confidentiality mechanisms at the physical layer.

As well as the security, the most important is to adapt the level of confidentiality to the end-user requirement. The targeted application has not specific requirement, so it can also be seen as a standard public use for the confidentiality issue.

5.2.5 Power Autonomy

The goal of HearCom is to provide a system capable to assist the users in their everyday life, and it means, at least, all the day long. From this standpoint, there is a severe restriction in having a comfortable, always available system.

As it is explained in section 5, there will be different models of operation for the system, some of the including communication between the PCS and external systems of between the PCS and the HAs. Thus, the restrictions are determined by two elements in the system: the PCS and the HAs. This feature is expected to keep on improving in the following years.

Besides the user preferences and habits –such as the use of mobile phone-, the power autonomy required depends on the degree of disability of each user since it conditions the necessity of resorting to the services offered and the different modes of operation of the system.

5.3 Hardware Requirements

The hardware requirements for the PCS are summarized in the following table. This is in fact based on the specifications of the PDA HP iPAQ PocketPC h6340, which represents a good example of the needed features for the PCS.

It has enough processing capabilities and memory and an acceptable autonomy taking into account the current state of technology. This proposed solution follows an approach that wants to make stress on the mobility possibilities for the user. It incorporates wireless connectivity through GSM/GPRS, WLAN (802.11b) and Bluetooth, as required, and has an adequate size and weight.

However, some of the considered applications requiring heavy processing and memory capabilities (e.g. for advanced audio enhancement) will be have to be put aside, waiting for the improvement of the available technology. Something equivalent applies to the power autonomy, which we expect to improve considerably along the carrying out of the project.

Besides, there are other interesting characteristics available in this device, such as visual indicators of state and phone call notification by visual or vibration alerts.
<table>
<thead>
<tr>
<th>Processor</th>
<th>Texas Instruments OMAP 1510, running at 200MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>128 MB total memory (64 MB ROM and 64 MB SDRAM), up to 55 MB user available memory including 20 MB iPAQ File Store Up to 1GB with optional SD Card</td>
</tr>
<tr>
<td>Expansion Slots</td>
<td><strong>SD Slot</strong>: supports 1-bit SDIO and 4-bit SD/MMC type memory standard</td>
</tr>
<tr>
<td>Power</td>
<td><strong>Battery</strong> - Removable/Rechargeable 1800 mAh Lithium-Ion. Optional extended 3600 mAh  (Note: Battery run time varies based on the usage pattern of an individual user and the configuration of the handheld. Use of some internal wireless capabilities and backlight will significantly decrease battery run time)  <strong>Requirements</strong> - AC Power - AC Input: 100~240 Vac, 50/60 Hz, AC Input current: 0.3 Aac max - Output Voltage: 5Vdc (typical), Output Current: 2A (typical)</td>
</tr>
<tr>
<td>Autonomy</td>
<td>220 hours on standby, 5 hours on talk time</td>
</tr>
<tr>
<td>Wireless Technologies</td>
<td>Integrated quad band GSM/GPRS, WiFi 802.11b, Bluetooth 1.1, IrDA</td>
</tr>
<tr>
<td>I/O ports</td>
<td>1 charging/communications port, 1 headset connector, IrDA and USB</td>
</tr>
<tr>
<td>Indicators</td>
<td><strong>Power Button</strong>: Charge and Notify indicators  <strong>LED 1</strong>: GSM/GPRS  <strong>LED 2</strong>: Bluetooth  <strong>LED 3</strong>: WiFi  <strong>Phone Notification</strong>: Vibrate, Audible, Visible message on the display</td>
</tr>
<tr>
<td>Display</td>
<td>3.5-in diagonal, 240 x 320, 16-bit 64K colours transflective TFT colour with LED backlight</td>
</tr>
<tr>
<td>Audio</td>
<td>Integrated microphone, receiver, speaker and one 3.5 mm stereo headphone jack, MP3 stereo (through audio jack and speaker)</td>
</tr>
<tr>
<td>Pointing device and keyboard</td>
<td>Touch Screen and Stylus  <strong>Keyboard</strong>: Removable 26 alpha-numeric keys with 2 application buttons, and send/end buttons</td>
</tr>
<tr>
<td>Dimensions and Weight</td>
<td>75 x 18.7 x 119 mm  190 g</td>
</tr>
</tbody>
</table>

**Table 21 Hardware Requirements**
6 Technologies

6.1 Architecture

6.1.1 Current Architecture

Current HA systems aim at giving the hearing disabled the same abilities to function in an acoustic environment as the normal hearing person. However, these systems do not take into account the plethora of information and multimedia sources that are emerging, e.g. mobile phones, music players (home stereo, mobile players) and home cinema systems, and they do not provide an interface to these sources. The functionality provided is limited to modification of audio from the acoustic environment to fit the particular needs of the user. The telecoil technique, see Figure 4, does give access to audio from radio, TV, and in cinemas but the main limitation is that it requires a costly installation wherever it is needed. It is desirable to have a system that does not need any specialized infrastructure.

When designing an audio enhancement system for the hearing impaired we wish to maximize battery life, maximize signal processing capacity, maximize flexibility for the user, and facilitate access to the many audio sources that are/will be available. In most contemporary hearing aid systems all functionality is built into the devices that are worn behind or in the ear. The advantage with an “all-in-the-ear” (or behind-the-ear) device is that the user has only one piece of equipment to keep track of (or two, if a binaural hearing loss). The disadvantages are:

- Complicated user interface (for the user and/or the system designer).
- The HA will be expensive or have limited enhancement capabilities since implementation of advanced signal processing in the limited space of such a HA is costly.
- Access to each new emerging audio source will most likely require a whole new device, since the implementation in the small HA will be heavily optimized for a particular functionality.
- Upgrading to new signal processing algorithms will most likely require a whole new device for the same reason.
- The HA battery life will decrease significantly when advanced signal processing and audio access technology are running in the HA.
6.1.2 Proposed Architecture

The proposed architecture will make it possible for hearing disabled people to enjoy the audio sources that hearing people can enjoy today and in the future, e.g., FM/AM radio and mobile phone communication. In Figure 5 the proposed architecture is depicted.

6.1.2.1 Basic structure and motivation

Three physical units constitute the proposed system: The left and right hearing aids (HAs) and a personal communication system (PCS).

Two types of communication links are active in the system: 1) between the PCS and HAs (the so called body area network (BAN); should support bi-directional communications, 2) between PCS and the outside world (wide and local area communication networks).
networks (WANs and LANs) of different kinds, e.g., WIFI, Bluetooth, GSM and GPRS).

Based on the activation of the two communication links we define four modes of operation:

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| Mode 1            | No communication between HAs and PCS  
The HAs operate stand-alone and use internal signal processing to enhance the acoustic signal to fit the user's particular disability. |
| Mode 2            | Communication from HA to PCS and back to HA  
The acoustic signal is captured by the HA microphones and transmitted to the PCS for advanced signal processing. The processed signal is transmitted back to the HAs and played back with low latency to the user. |
| Mode 3            | Communication from PCS to Has  
Streaming of audio (received by or stored in the PCS) from the PCS to HAs with modification of the audio in the PCS to fit the user's particular disability. |
| Mode 4            | Mode 2 and 3 simultaneously. |

The benefits of separating the functionality between the HAs and the PCS can be summarized: each component of the system does what it does best. More specifically:

- Gives user maximum flexibility in that there is a choice of using the HAs in stand-alone mode or with the PCS. Thus, the proposed architecture provides new functionality without sacrificing any of the features of current techniques.
- With the added functionality that the PCS offers, the cost of the system is expected to be lower than for a corresponding all-in-the-ear system.
- The PCS provides a natural interface to the multitude of audio sources that exist today and new ones that will emerge in the future, and access can be provided with no modification of the HAs.
- Utilizing the processing power of the PCS enables advanced signal processing without increasing the battery consumption in the HAs.
- The system can be upgraded with new signal processing algorithms without expensive redesign of the HA hardware.
- To interface to all available audio sources, the HA need only have a BAN interface. Thus a simple technical solution is chosen in the HA where development and implementation costs are the greatest.

The potential disadvantages are:

- If the signal processing (for modification of the acoustic signal to the user's hearing loss) is done in the PCS, communication between the HAs
and the PCS and back to the HAs is required. This will lead to an increased latency. Further, if special care is not taken, the communication between the left and right HAs with the PCS may be slightly out of synch, leading to a distorted spatial image.

- Functionality to receive streaming audio (mode 3) in the HAs will increase battery consumption. The two-way radio communication in mode 2 will further increase battery consumption.
- The PCS is envisioned to be a mainstream device like a mobile phone or PDA with possibility to plug-in additional hardware. The availability of such devices in the future and compatibility issues are a source of uncertainty.

6.1.2.2 Components

The HAs and the PCS are the components of the system, see Figure 6. In order to maximize battery life, signal processing capacity, and the flexibility for the user, and to facilitate access to all audio sources that are - or will be - available, the following functionality/properties should be included in the HAs:

- The acoustic signal should be recorded by the HAs to preserve spatial information and to enable stand-alone operation.
Some basic signal processing should be kept in the HAs for stand-alone operation (mode 1).

Must support two-way, low latency communications over the BAN (mode 2).

Must be able to receive high quality, low latency streaming audio over the BAN (mode 3).

Should allow operation in mode 2 and mode 3 independently and simultaneously (mode 4).

Backward compatibility with the telecoil system must be implemented.

Ideally the PCS unit is a personal digital assistant (PDA) or a smart phone with the possibility to extend the functionality by plugging in a HA-card with capabilities as described above. A solution that requires no changes/adaptation of existing hardware is to let the PCS be a device using USB or similar and stream audio from the generic receiver in the PCS via USB to a separate unit that contains the BAN interface and the advanced signal processing unit, see Figure 4. It may be possible to have the advanced signal processing unit implemented in software on the PCS and transmit/receive audio to/from the HAs and transmit audio from the generic audio receiver via USB if latency and processing power requirements permit this. Regardless of the actual PCS platform, the following functionality/properties should be included:

- Must allow wireless transmission of high quality, low latency streaming audio over the BAN (mode 3).
- We do not specify the protocols and interfaces for communication between the PCS and the outside world. However, access to the “live” audio stream that is output from the PCS receiver must be possible.
- Must allow two-way, low latency communications over the BAN (mode 2).
- Should allow operation in mode 4.
- Should have sufficient processing power to execute advanced signal processing algorithms for audio enhancement for hearing disabled.

### 6.1.2.3 Protocols and interfaces

Two interfaces and associated protocols will be defined for the communication in mode 2 and mode 3 (mode 4 possibly requires a separate protocol). The protocols will ensure that the requirements specified in section 4.2 (User Interface Requirements) and 4.3 (Radio Link Requirements) are fulfilled. A complete specification of the protocols will be given in deliverable 8.2; here we outline the constraints on the communication links:

For mode 2 (communication from HA to PCS and back to HA),

- In order not to annoy a user (with completely occluding, binaural HAs), the latency of the complete processing chain from AD conversion in the HA, transmission to PCS, advanced signal processing in the PCS, transmission back to HA and DA conversion, must not exceed 15ms.
- The encoding and decoding associated with the data transmission from and back to the HAs must not incur any perceivable distortion.
- The radio link is expected to put a practical upper limit on the data rate at 300 kbits per second.
• The power consumption of the HA transmitter and HA receiver must be lower than 5 mW (in total) in order not to deter users that are used to state-of-the-art devices with a consumption on the order of 1 mW.
• Radio interference must be low to allow multiple simultaneous users close in space. This will be ensured by using short range radio communications and/or code (and/or time-frequency) division multiple access.

For mode 3 (communication from PCS to HAs),

• A low-latency link (less than 10 ms) is required to facilitate two-way voice communication (mobile phones are already operating close to what is a tolerable delay in a conversation).
• The BAN encoding and decoding must not introduce any perceivable additional distortion when done in cascade (so called transcoding) with contemporary audio codecs like mpeg, aac, and AMR-WB+.
• The audio streaming must be secured by some crypto.

6.2 Platforms

6.2.1 Cellular

6.2.1.1 GSM

6.2.1.1.a History

During the early 1980s, analog cellular telephone systems were experiencing rapid growth in Europe, particularly in Scandinavia and the United Kingdom, but also in France and Germany. Each country developed its own system, which was incompatible with everyone else's in equipment and operation. This was an undesirable situation, because not only was the mobile equipment limited to operation within national boundaries, which in a unified Europe were increasingly unimportant, but there was a very limited market for each type of equipment, so economies of scale, and the subsequent savings, could not be realized.

The Europeans realized this early on, and in 1982 the Conference of European Posts and Telegraphs (CEPT) formed a study group called the Groupe Spécial Mobile (GSM) to study and develop a pan-European public land mobile system. The proposed system had to meet certain criteria:

• good subjective speech quality,
• low terminal and service cost,
• support for international roaming,
• ability to support handheld terminals,
• support for range of new services and facilities,
• spectral efficiency, and
• ISDN compatibility.

In 1989, GSM responsibility was transferred to the European Telecommunication Standards Institute (ETSI), and phase I of the GSM specifications was published in 1990. Commercial service was started in mid1991, and by 1993 there were 36 GSM networks in 22 countries, with 25 additional countries having already
selected or considering GSM. This is not only a European standard - South Africa, Australia, and many Middle and Far East countries have chosen GSM. By the beginning of 1994, there were 1.3 million subscribers worldwide. The acronym GSM now (aptly) stands for Global System for Mobile telecommunications.

6.2.1.1.b Services

The developers of GSM chose an unproven (at the time) digital system, as opposed to the analog cellular systems like AMPS in the United States and TACS in the United Kingdom. They had faith that advancements in compression algorithms and digital signal processors would allow the fulfilment of the original criteria and the continual improvement of the system in terms of quality and cost. The 8000 pages of the GSM recommendations try to allow flexibility and competitive innovation among suppliers, but provide enough guidelines to guarantee the proper interworking between the components of the system. This is done in part by providing descriptions of the interfaces and functions of each of the functional entities defined in the system.

Using the ITU-T definitions, telecommunication services can be divided into bearer services, tele-services, and supplementary services. The digital nature of GSM allows data, both synchronous and asynchronourceous, to be transported as a bearer service to or from an ISDN terminal. Data can use either the transparent service, which has a fixed delay but no guarantee of data integrity, or a non-transparent service, which guarantees data integrity through an Automatic Repeat Request (ARQ) mechanism, but with a variable delay. The data rates supported by GSM are 300 bps, 600 bps, 1200 bps, 2400 bps, and 9600 bps.

The most basic tele-service supported by GSM is telephony. There is an emergency service, where the nearest emergency-service provider is notified by dialling three digits (similar to 911). Group 3 fax, an analog method described in ITU-T recommendation T.30, is also supported by use of an appropriate fax adaptor. A unique feature of GSM compared to older analog systems is the Short Message Service (SMS). SMS is a bidirectional service for sending short alphanumeric (up to 160 bytes) messages in a store-and-forward fashion. For point-to-point SMS, a message can be sent to another subscriber to the service, and an acknowledgement of receipt is provided to the sender. SMS can also be used in a cell-broadcast mode, for sending messages such as traffic updates or news updates. Messages can be stored in the SIM card for later retrieval.

Supplementary services are provided on top of tele-services or bearer services, and include features such as caller identification, call forwarding, call waiting, multiparty conversations, and barring of outgoing (international) calls, among others.

6.2.1.1.c Radio link

The International Telecommunication Union (ITU), which manages the international allocation of radio spectrum (among other functions) allocated the bands 890-915 MHz for the uplink (mobile station to base station) and 935-960 MHz for the downlink (base station to mobile station) for mobile networks in Europe. Since this range was already being used in the early 1980s by the analog systems of the day, the CEPT had the foresight to reserve the top 10 MHz of each band for the GSM network that was still being developed. Eventually, GSM will be allocated the entire 2x25 MHz bandwidth.
Since radio spectrum is a limited resource shared by all users, a method must be devised to divide up the bandwidth among as many users as possible. The method chosen by GSM is a combination of Time and Frequency-Division Multiple Access (TDMA/FDMA). The FDMA part involves the division by frequency of the total 25 MHz bandwidth into 124 carrier frequencies of 200 kHz bandwidth. One or more carrier frequencies are then assigned to each base station. Each of these carrier frequencies is then divided in time, using a TDMA scheme, into eight time slots. One time slot is used for transmission by the mobile and one for reception. They are separated in time so that the mobile unit does not receive and transmit at the same time, a fact that simplifies the electronics.

The procedure involved in digitally transmitting a voice signal in a GSM network includes some other features, such as discontinuous transmission and reception, used to improve voice quality, reduce the mobile unit's power consumption, and increase the overall capacity of the network.

The structure of the most common timeslot burst is shown in Figure 7. A total of 156.25 bits is transmitted in 0.577 milliseconds, giving a gross bit rate of 270.833 kbps. There are three other types of burst structure for frame and carrier synchronization and frequency correction. The 26-bit training sequence is used for equalization. The 8.25 bit guard time allows for some propagation time delay in the arrival of bursts.

![Figure 7 Structure of timeslot bursts](image)

6.2.1.1.d Data transmission

Data over GSM offers new opportunities for both GSM network operators and mobile workers alike. By using GSM to send and receive data or faxes, mobile workers have access to a level of geographic mobility previously unobtainable.

At present a user can send data over the GSM network at speeds of up to 9.6 Kbps per second (on GSM networks that operate at 900Mhz), or 14.4kbps (on GSM networks that operate at 1,800Mhz). Although this is notably slower than
today’s land line modems, ETSI7 is continuing to develop the GSM standard. A more detailed explanation is provided in the next section.

6.2.1.2 Higher bit rate data transmission: GPRS and HSCSD

**General Packet Radio Services (GPRS)** offers significantly enhanced data rates combining dynamically between 2 and 8 time slots to increase the available data rate (technique known as “multi slotting”). GPRS offers data rates up to a maximum of 170 Kbps. Essentially GPRS is a packet based technology, and thus is ideally suited for TCP/IP environments and allows the user to establish a “permanent” connection to the Internet or corporate LAN. GPRS was expected to be widely used to provide services such as World Wide Web browsing, where data is received in sporadic bursts. Interconnection to other packet based networks such as X.25 was also expected to be a key application for GPRS.

GPRS is not connection oriented. This means that a user wanting to send data does not need to first establish a call. Additionally, the user receiving data does not need to have their phone turned on, as the network stores the data for them. When the user connects to the network, they are notified that they have data waiting.

It was anticipated that GPRS would become popular in the corporate environment, as virtual connections can be established. Unlike traditional voice and data services, GPRS is charged on a “per bit basis”. Hence users are charged for sending or receiving data, as opposed to connection orientated services where the user is charged for the amount of time that they are connected to the service.

**High Speed Circuit Switched Data (HSCSD)** takes also advantage of Multi Slotting, offering a maximum data rate of up to 64 Kbps for a single user.

HSCSD has an advantage over GPRS in that HSCSD supports guaranteed quality of service because of the dedicated circuit-switched communications channel. This makes HSCSD a better protocol for timing-sensitive applications such as image or video transfer.

However, GPRS has the advantage over HSCSD for most data transfer because HSCSD, which is circuit-switched, is less bandwidth efficient with expensive wireless links than GPRS, which is packet-switched. Furthermore, to implement HSCSD operators need to make changes to the network infrastructure.

Due to this, HSCSD is not as widespread as GPRS. HSCSD is, however, currently available in over 27 countries.

6.2.1.3 Towards 3rd generation: EDGE and UMTS

The next generation of data heading towards third generation and personal multimedia environments builds on GPRS and is known as Enhanced Data rate for GSM Evolution (EDGE).

In addition to GMSK (Gaussian minimum-shift keying), EDGE uses 8PSK (8 Phase Shift Keying) for its upper five of the nine modulation and coding schemes. EDGE is producing a 3bit word for every change in carrier phase. This effectively triples
the gross data rate offered by GSM. EDGE, like GPRS, uses a rate adaptation algorithm that adapts the modulation and coding scheme (MCS) used to the quality of the radio channel, and thus the bit rate and robustness of data transmission. It introduces a new technology not found in GPRS, Incremental Redundancy, which, instead of retransmitting disturbed packets, sends more redundancy information to be combined in the receiver. This increases the probability of correct decoding.

It can carry data speeds up to 384 kbit/s in packet mode and will therefore meet the International Telecommunications Union's requirement for a 3G network. It also enhances HSCSD, increasing the data rate of this service.

In 2004, EDGE has been more actively supported by GSM operators in North America than anywhere else in the world because GSM/GPRS has a strong competitor: CDMA2000. Most other GSM operators view UMTS as the ultimate upgrade path and either plan to skip EDGE altogether or use it outside the UMTS coverage area. However, the high cost and slow uptake of UMTS have made some western European GSM operators re-evaluate EDGE as an interim upgrade.

Although EDGE requires no hardware changes to be made in GSM core networks, base stations must be modified. An EDGE compatible transceiver unit must be installed and base station system needs to be upgraded to support EDGE. New mobile terminal hardware and software is also required to decode/encode using the new shift keying scheme.

In the 3rd generation of mobile radio systems (UMTS), the numerous voice and non-voice services with variable bit rates are to be combined in one common system, offering users better service, more convenience, and greater mobility.

The tremendous success of GSM has created a need for evolution of the services towards higher bit rates. Universal Mobile Telecommunication System (UMTS), a third generation wireless system, targeting towards maximum peak bit rate of 2Mbps, is a natural continuation for the development of HSCSD and GPRS.

ETSI started the standardization of UMTS in 1991. The UMTS Terrestrial Radio Access Concept definition process was initiated in a workshop held in December 1996 by introduction of number of candidate radio access schemes.

ITU is developing common vision for third generation wireless system, which is called IMT-2000, International Mobile Telecommunications.

The deployment of UMTS services started in 2004 in Europe.

6.2.2 WLAN (IEEE 802.11 family)

In 1997 the IEEE adopted IEEE Std. 802.11-1997, the first wireless LAN (WLAN) standard. This standard defines the media access control (MAC) and physical (PHY) layers for a LAN with wireless connectivity. It addresses local area networking where the connected devices communicate over the air to other devices that are within close proximity to each other.

The standard is similar in most respects to the IEEE 802.3 Ethernet standard. Specifically, the 802.11 standard addresses:
Functions required for a 802.11 compliant device to operate either in a peer-to-peer fashion or integrated with an existing wired LAN
- Operation of a 802.11 device within possibly overlapping 802.11 wireless LANs and the mobility of this device between multiple wireless LANs
- MAC level access control and data delivery services to allow upper layers of the 802.11 network
- Several physical layer signalling techniques and interfaces
- Privacy and security of user data being transferred over the wireless media

<table>
<thead>
<tr>
<th>IEEE 802.11 Standards</th>
<th>OSI Reference Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logical Link Control (LLC)</td>
<td>Data Link Layer (LL)</td>
</tr>
<tr>
<td>Media Access Control (MAC)</td>
<td>Network Layer (NL)</td>
</tr>
<tr>
<td>Frequency Hopping</td>
<td>Direct Sequence Spread</td>
</tr>
<tr>
<td>Spectrum PHY</td>
<td>Infrared PHY</td>
</tr>
</tbody>
</table>

Figure 8 IEEE 802.11 standards mapped to the OSI reference model.

6.2.2.1 IEEE 802.11 MAC

An IEEE 802.11 wireless LAN contains major components: stations, access points, distribution systems, and wireless medium. The IEEE 802.11 network MAC specification allows for two operating modes namely, the ad hoc and the infrastructure mode. In the ad hoc mode, two or more wireless stations (STAs) recognize each other and establish a peer-to-peer communication without any existing infrastructure, whereas in infrastructure mode there is a fixed entity called an access point (AP) that bridges all data between the mobile stations associated to it. The first one system receives the name of Independent Basic Service Set (IBSS), and an AP with its associated mobile stations form a Basic Service Set (BSS).

A collection of APs (connected through a distribution system DS) can extend a BSS into an Extended Service Set (ESS, see Figure 9). A Handoff occurs when a mobile station moves beyond the radio range of one AP, and enters another BSS (at the MAC layer). During the handoff, management frames are exchanged between the station (STA) and the AP. Also the APs involved may exchange certain context information (credentials) specific to the station. Consequently, there is latency involved in the handoff process during which the STA is unable to send or receive traffic. For further information about the handoff process, see Annex A.
### IEEE 802.11a, b, g

The IEEE 802.11 standard defines both the MAC and PHY layer requirements for wireless LANs. IEEE 802.11 family consists of different flavours; the products of 802.11 a, b, and g are available in the market. The main features of these three standards are compared in Table 22.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>5 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td></td>
<td>Underused 5 GHz band can coexist with 2.4 GHz networks without interference</td>
<td>Heavily used 2.4 GHz band. Interference from other 2.4 GHz devices such as cordless phones, microwave ovens, etc. may occur</td>
<td>Heavily used 2.4 GHz band. Interference from other 2.4 GHz devices such as cordless phones, microwave ovens, etc. may occur</td>
</tr>
<tr>
<td><strong>Modulation schemes</strong></td>
<td>DBPSK, DQPSK, CCK</td>
<td>CCK, OFDM</td>
<td>OFDM</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>54 Mbps 5X greater than 802.11b</td>
<td>11 Mbps Cable modem service typically averages no more than 4 to 5 Mbps</td>
<td>54 Mbps 5X greater than 802.11b</td>
</tr>
<tr>
<td><strong>Average Actual Throughput</strong></td>
<td>27 Mbps</td>
<td>4-5 Mbps</td>
<td>20-25 Mbps</td>
</tr>
<tr>
<td><strong># Channels / Non-overlapping</strong></td>
<td>12 / 8</td>
<td>11 / 3</td>
<td>11 / 3</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>Shorter range than 802.11b and 802.11g. Due to higher operating frequency, typically offers less range and is less capable of working through wall and floors.</td>
<td>Better range than 802.11a. 2.4 GHz signal travel farther, and can work through walls and floors more effectively than 5 GHz signals</td>
<td>Better range than 802.11a. 2.4 GHz signal travel farther, and can work through walls and floors more effectively than 5 GHz signals</td>
</tr>
<tr>
<td><strong>Compatibility</strong></td>
<td>Incompatible with 802.11b or 802.11g</td>
<td>Widely adopted. Will work in 802.11g networks</td>
<td>Backwards compatible with 802.11b networks (at 11 Mbps); Incompatible with 802.11a</td>
</tr>
<tr>
<td><strong>Popularity</strong></td>
<td>User base still relatively small. Limited selection on 802.11a equipment.</td>
<td>Currently has the largest user base. 802.11b is currently used in most hot spots including airports, hotels, campuses, and public areas. Wide selection of 802.11b equipment.</td>
<td>Latest ratified standard. With speeds up to 5 times faster than 802.11b. Expect this standard to overtake 802.11b as the standard of choice.</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Most expensive</td>
<td>Cheapest</td>
<td>Since this standard’s ratification, prices have dropped significantly. Pricing is competitive with 802.11b. Cheaper than 802.11a</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td>Excellent speed, unaffected by 2.4 GHz devices, can co-exist with 802.11b and 802.11g networks without interference</td>
<td>Largest user base, cheapest, used in most public hot spots, largest user base, wide selection of equipment</td>
<td>The speed of 802.11a with the range of 802.11b, compatible with 802.11b networks and hotspots, affordable</td>
</tr>
</tbody>
</table>

**Table 22 Comparison of 802.11 b, g and a**

Although these three standards have different features, they share the same MAC (Medium Access Control) layer defined in IEEE 802.11 standard [1].

More detailed information about some technical aspects, like the handoff delays and the characteristics of the different standards of the family, is provided in Annex A.

### 6.2.3 Bluetooth

#### 6.2.3.1 Introduction

The development of the Bluetooth industry standard started in 1998 when Ericsson, IBM, Intel, Nokia, and Toshiba formed the Bluetooth Special Industry Group (SIG) to develop and promote a global solution for short range wireless communication, operating in the unlicensed 2.4 GHz ISM band, between mobile computers, cameras, and other portable in-home devices.

The Bluetooth wireless technology serves as a replacement of the interconnection cables between a variety of personal devices, including notebook computers, cellular phones, personal digital assistants (PDAs), digital cameras, etc. The Bluetooth wireless technology would function as the universal low cost, user friendly, air interface that will replace the plethora of proprietary cables that people need to carry and use to connect their personal devices. While personal devices typically communicate based on the RS-232 serial port protocol, proprietary connectors and pin arrangements make it impossible to use the same set of cables to interconnect devices from different manufactures, and sometimes even from the same manufacturer. The primary focus of the Bluetooth wireless technology is to provide a flexible cable connector with reconfigurable pin arrangements permitting several personal devices to interconnect with each other.
6.2.3.2 Properties

The main properties of the Bluetooth wireless communication technology are:

- Low-cost, low power radio transceiver chip.
- A low nominal range of Bluetooth radio (10 meters) for saving battery power, extended range with external power amplifier (100 meters).
- Global operation available and unlicensed.

6.2.3.3 Technicalities

A Bluetooth radio operates on the license-free 2.4 GHz ISM band and is compliant with FCC part 15 regulations for intentional radiators in this band. The Bluetooth radio transmission uses a packet switching protocol with FHSS (Frequency Hopping Spread Spectrum). The hop frequency is 1600 hops per second. The frequency spectrum is divided into 79 hops of 1 MHz bandwidth each. Thus, eventually, Bluetooth devices occupy 79 MHz, but at any specific moment, only 1 MHz is occupied. Each of these hops goes to a slot that is 625 us long, (packets can last 1, 3 or 5 slots, but the hop frequency remains the same for each packet).

Frequency hopping is used to reduce interference and enhance security. The frequency-hopping scheme is combined with fast ARQ (Automatic Repeat Request), CRC (Cyclic Redundancy Check) and FEC (Forward Error Correction). A binary radio frequency modulation and simple link layer protocols reduce the complexity and the costs of the radio chip. Bluetooth provides a nominal data rate of 1 Mbit/s.

6.2.3.4 Bluetooth Networking

The Bluetooth system supports both point-to-point and point-to-multi-point connections.

6.2.3.4.a Piconets

When several Bluetooth devices are in close vicinity of each other, they form a piconet. One piconet consists of 1 master and up to 7 slaves where the master-slave principle is used to initiate and control the traffic between devices in a piconet. The master is responsible for defining and synchronizing the frequency hop pattern in his piconet. All packets are exchanged between a master and its slaves within a piconet. There is no direct master-master or slave-slave communication. A device can be a slave in several piconets but be a master in only one piconet. Bluetooth piconets can coexist in time and space independently of each other. Furthermore, a single device may be a member of several piconets, a case referred to as scatternet in Bluetooth parlance.

A piconet is formed in an ad hoc manner without any infrastructure assistance, and it lasts for as long as the creator of it needs and is available to communicate with other devices. The terms master and slave are relative to a particular existing piconet. To identify each slave, the master of a piconet assigns a locally unique active member address to the slaves participating in active communications in the piconet. The master regulates and controls who transmits and when. While up to seven slaves may be actively communicating in a piconet...
at one time, additional devices may be registered with the master and be invited to become active whenever necessary. These additional devices are called parked. A master can have up to 200 Bluetooth devices (in its vicinity) in parked mode. Bluetooth devices not associated with any piconet are in stand-by mode. Any Bluetooth device can perform the role of a master and/or a slave. The terms are not assigned to the radio units at manufacture time.

6.2.3.4.b Scatternets
Several piconets can be established and linked together ad hoc, where each piconet is identified by a different frequency hopping sequence. The resulting structure is called a scatternet.

![A Bluetooth Scatternet](image)

**Figure 10** A Bluetooth Scatternet

A Bluetooth radio may serve either as a master or as slave at different times. A single Bluetooth unit may send/receive at a maximum data rate of 721 kbit/s or a maximum of 3 voice channels (of 64 Kbit/s each with CVSD – Continuous Variable Slope Delta Modulation). Both a Synchronous Connection Oriented (SCO) link and an Asynchronous Connectionless (ACL) link for each master-slave pair are supported. Within the same Bluetooth radio range, separate and independent piconets may be formed. These may build up so-called scatternets to allow for a higher number of Bluetooth devices being active and/or for a
higher aggregate bandwidth. The Bluetooth radios come in three power classes, depending on the transmit power:

- Class 1 radios transmit power of 20 dBm (100 mW).
- Class 2 radios transmit power of 4 dBm (2.5 mW).
- Class 3 radios transmit power of only 0 dBm (1 mW).

Due to the power and cost constraints of the various personal devices that use Bluetooth radios, class 3 and class 2 radios are expected to be the ones mostly used.

6.2.3.5 Bluetooth v2.0 + EDR

At the end of 2004, The Bluetooth SIG announced the adoption of Bluetooth Version 2.0 + EDR (Enhanced Data Rate). Increased data rates (up to three times current levels) and lower power consumption will improve the Bluetooth user experience when running multiple Bluetooth devices simultaneously and transferring large data files, as well as enabling longer battery life in mobile devices (up to two times current levels).

The main features of Bluetooth Core Specification Version 2.0 + EDR are:

- 3 times faster transmission speed (up to 10 times in certain cases)
- Lower power consumption through reduced duty cycle
- Simplification of multi-link scenarios due to more available bandwidth
- Backwards compatible to earlier versions
- Further improved BER (Bit Error Rate) performance

The Bluetooth SIG expects products based upon the specification to be available in 2005. Products from the PC industry are expected to be the first on the market with the new specification, followed by devices for audio and imaging use cases.

6.2.4 Ultra Wide Band (UWB)

The origins of UWB technology come from works begun in 1962, which were generally referred to as impulse radio, baseband or carrier-free communications. The term “ultrawideband” was first coined by the U.S. Department of Defense in 1989, and early applications leveraged the technology’s properties as ground-penetrating radar. Today, the definition for ultrawideband, according to the FCC, is any radio technology with a spectrum that occupies greater than 20 percent of the centre frequency or a minimum of 500 MHz. Recognizing the advantages of new products that could incorporate this technology to benefit public safety, enterprise and consumer applications, in 2002 the FCC allocated unlicensed radio spectrum from 3.1 GHz to 10.6 GHz expressly for these purposes. Additional spectrum is also available for use by medical, scientific, law enforcement, fire and rescue organizations.

Rather than requiring a UWB radio to use the entire 7.5 GHz band to transmit information, or even a substantive portion of it, the FCC defined a specific minimum bandwidth of 500 MHz at a -10dB level. This minimum bandwidth (in conjunction with other requirements of the FCC ruling) would substantially protect incumbent users of the spectrum. The flexibility provided by the FCC
ruling greatly expands the design options for UWB communication systems. Designers are free to use a combination of sub-bands within the spectrum to optimize system performance, power consumption and design complexity. UWB systems can still maintain the same low transmit power as if they were using the entire bandwidth by interleaving the symbols across these sub-bands.

Given this option for a multi-band system, information can either be transmitted by the traditional pulse-based single carrier method or by more advanced multi-carrier techniques. Pulse-based single-carrier systems transmit signals by modulating the phase of a very narrow pulse. While this is a proven technology that only requires a very simple transmitter design, several inherent disadvantages exist. It is difficult to collect enough signal energy in a typical usage environment (with many reflecting surfaces) using a single RF chain; switching time requirements can be very stringent at both the transmitter and receiver; the receiver signal processing is very sensitive to group delay variations introduced by analog front-end components; and, spectral resources are potentially wasted in order to avoid narrowband interference.

UWB is a wireless radio technology for transmitting data point-to-point between consumer electronics, PC peripherals and mobile devices within short range at very high speeds, while consuming little power. Therefore, it is ideally suited for transfer of high-quality multimedia content, such as the wireless streaming of family videos from the digital video recorder to a high-definition television in the living room, or wirelessly connecting a mobile PC to a projector in a conference room to deliver a presentation. Seamless connectivity is a compelling proposition to the typical consumer. Devices that automatically discover and communicate with each other, print or play on command without user intervention provides value in its simplicity. However, a confusing array of cables for various interfaces that will not and cannot talk to each other is the current reality. Widespread adoption of UWB-based products will depend on ease of use at an affordable cost, hence the importance of low complexity CMOS solutions. Consumers also expect a reliable, consistent user experience. Interoperability is a key issue to allow transparent operation for the end user regardless of what brand they choose. Therefore, it is crucial to develop standards-based protocols and incorporate into a unified platform to deliver on these objectives.

The ability to display, edit, listen, share, and download content between devices in the home without becoming a networking technologist is an attractive proposition to many potential consumers. Three basic categories have evolved within the “typical” home environment: computing, multimedia and mobile communications devices. PC’s, printers and other peripherals, as well as residential gateways, modems, and routers represent primary elements of a data centric network; the broadcast entertainment cluster generally consists of home theatres, video display monitors, audio equipment and camcorders; while mobile devices such as PDA’s, multifunction cell phones and laptops roam the premises. The convergence of data, entertainment and mobile communications within the home has created the need for bridging these devices into a single network architecture more capable than legacy technologies of supporting and integrating each sector’s unique requirements.
6.2.5 BAN

Development proposal of BAN contemplates the following elements:

- A ULP (Ultra Low power) device incorporated in the PDA using the SD-card interfaces and obtaining power from the PDA itself.
- A ULP device incorporated in the hearing aid, powered by the hearing aid battery.
- A RF digital communication channel based on low frequency, low power and low range technologies.

Figure 11 BAN Block diagram

6.2.5.1 Introduction

A more detailed description of the proposed BAN is made for internal use. This description reflects confidential suppliers’ technologies and is reserved to signers of the corresponding NDA with Philips Electronics.

6.2.5.2 Human body surface technology

More recently new emerging technologies begin to have more importance to be used as Body Area Network. The Human Area Networking technology, developed by NTT (http://www.redtacton.com) uses the surface of the human body as a high speed network transmission path. It uses the minute electric field emitted on the surface of the human body. Technically, it is completely distinct from
wireless and infrared. A transmission path is formed at the moment a part of the human body comes in contact with a transceiver.

Communication is possible using any body surfaces, such as the hands, fingers, arms, feet, face, legs or torso. The developed system works through shoes and clothing as well.

Using a new super-sensitive photonic electric field sensor, this system can achieve duplex communication over the human body at a maximum speed of 10 Mbps. By making Human Area Networks feasible, it will enable ubiquitous services based on human-centred interactions and therefore more intimate and easier for people to use. Many applications can be imagined with this new technology. It can carry speech, music or video between headsets and mobile devices, or mobile phones. All kind of digital device can be personalized with just a touch. Every body area network applications can be used this safe, high speed, low power technology.
Some prototypes have been already developed and this technology aims to be enhanced within the next years. For example, a prototype with a PCMCIA interface, in half-duplex mode at 10Mbps using a TCP/IP protocol, is already available.

6.2.6 Comparative and Compatibility

6.2.6.1 Comparative performance

![Figure 14 Comparative of throughput capacity of PAN technologies [23]](image)

6.2.6.2 Compatibility and interference

This chapter describes how one wireless technology affects another. The interference is examined by its effect on the throughput. Interference is generally due to either collision, which might be occurred when two wireless systems are closed, or by the corruption by a specific device which operates in the vicinity of the wireless system.

6.2.6.2.a Bluetooth

No relevant interference could be measured when a Bluetooth pair is in the vicinity of another one. It can be shown for example that there wasn’t much difference between the average time it took to complete the file transfer in each case. Because Bluetooth hops at 1600 hops per sec, the chances of collision are low. Besides a Bluetooth packet is small and hence, retransmissions are smaller. Thus the effective bandwidth is not affected to a great extent.
6.2.6.2.b 802.11

802.11 is definitely the most sensitive wireless technology. Moreover it might be disturbed not only by a near microwave device but also by another 802.11 network or another wireless network.

When another pair of 802.11b wireless devices is introduced in the same network of a first pair, there is interference between the two causing the signal to fluctuate due to the collision between the two pairs. The interference is much higher with another additional pair. The 802.11b standard defines 11 possible channels that may be used. Each channel is defined by its “centre frequency". The centre frequencies are at distances of 5 MHz from each other. Since the high bandwidth could give a signal as wide as 16 MHz, multiple co-located networks channels have to be spaced out from another. Thus, one 802.11b network could operate at any channel, but 2 co-located networks would have to have enough spacing, say channel 2 and 10, giving a minimum of 24 MHz in between them.

When a Bluetooth network is present in the environment of a 802.11 network, it has been clearly shown that there is interference between the two technologies. In fact, when both Bluetooth and 802.11b devices occasionally hop to the same frequency, packets get lost and then throughput is significantly reduced. However, as the interferer is positioned further away, the interference is reduced. If the distance between the two is more than 10m, then the throughput is only minimally reduced compared to normal.

As a conclusion, we see that the user may experience some degradation in the performance, especially in the WiFi WLAN connections, when operating in concurrence with Bluetooth for the BAN. But the reduction of throughput is not expected to be critical.
<table>
<thead>
<tr>
<th>Name</th>
<th>Bluetooth 2.0</th>
<th>UWB</th>
<th>Zigbee</th>
<th>WIFI a</th>
<th>WIFI b</th>
<th>WIFI e</th>
<th>WIFI g</th>
<th>H2</th>
<th>WiMax</th>
<th>Irda</th>
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<tbody>
<tr>
<td>Specifications</td>
<td>WPAN</td>
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<td>802.11g</td>
<td>ETSI BRAN</td>
<td>802.16</td>
<td>IrDA Data 1.1</td>
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<td>Emitted Freq Band</td>
<td>2,4 Ghz ISM</td>
<td>1,5 Ghz ISM</td>
<td>3.1/10.6GHz</td>
<td>2,4 Ghz</td>
<td>5 Ghz</td>
<td>2,4 Ghz</td>
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<td>Max Throughput</td>
<td>723 kbps</td>
<td>2Mbps</td>
<td>110-480Mbps</td>
<td>240 kbps @2,4Ghz</td>
<td>54Mbps</td>
<td>11Mbps</td>
<td>54 Mbps</td>
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<td>Modulation</td>
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<td>Address space</td>
<td>10/20/100m</td>
<td>10m</td>
<td>5-500m (30m)</td>
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<td>Transmitted power</td>
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<td>1/2,5/100</td>
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<td>Interferences</td>
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<td>Voice capability</td>
<td>CVSD, 64kbps</td>
<td>A2DP HiFi, unidirectional</td>
<td>VoIP</td>
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<tr>
<td>Status of deployment</td>
<td>Fully deployed</td>
<td>Not deployed</td>
<td>Not deployed</td>
<td>Fully deployed</td>
<td>Fully deployed</td>
<td>Fully deployed</td>
<td>Fully deployed</td>
<td>Fully deployed</td>
<td>Discontinue d</td>
<td>Not deployed</td>
</tr>
</tbody>
</table>

Table 23 - General Performance
7 Roadmaps

Road maps contain historical notes and sightseeing tips. A software or hardware roadmap in particular must keep integrating the present as it passes by, or it soon becomes useless. It records design decisions and their rationales. It reflects unforeseen terrain and unexpected inventions as they emerge, rather than starting from some (unrealistic) fixed architecture and proceeding through implementation.

The following items are contemplated:

- brief history.
- where we're going
- milestone schedule

7.1 Hearing devices

7.1.1 Availability of Telecoil

At present, in about 50% of the hearing aids, a so-called hearing aid telecoil is available for magnetic information transmission. The ability to have a telecoil in a hearing aid depends strongly on the available space to build in. For this, four form-factors are distinguished for hearing aids:

- **Behind The Ear (BTE)** hearing instrument as worn behind the ear. The sound is fed into the ear canal by means of a transparent tube and custom-made earpiece. BTE aids will vary in size depending on the required amplification. Most BTE’s nowadays are relatively small and can be worn almost without being noticed. All, or almost all, BTE hearing instrument types have a built-in telecoil.

- **In The Canal (ITC)** hearing instruments as worn in the ear canal. This type of custom-made instrument is made as small as possible in order to fit as much as possible in the ear canal, such that it will have minimal visibility. ITC instrument have limited amplification and therefore are suitable for light to moderate hearing losses only. Due to the minimal size no telecoil can be built in.

- **In The Ear (ITE)** hearing instruments as worn in the canal and concha of the ear (the concha is the inner part of the ear’s visible part or auricle). Being custom-made and placed partly in the concha it will be visible for other persons when looking from aside. ITE’s have more amplification than ITC (but not as much as BTE’s). The building-in of a telecoil is a general option for ITE’s, but will increase size and as such visibility. About only 5-20 % of ITE’s will have a telecoil (depending of country).

- **Body-Worn (BW)** hearing instruments as worn on the body of the person, with wiring to 1 or 2 earpieces. This type of off-the-shelf instrument allows
large amplification and therefore is used mainly by the very hard of hearing or nearly deaf persons. A telecoil is a standard option.

The preference for BTE compared to ITE/ITC is very dependent on the idea of what is the cosmetic best solution, the amount of hearing loss and the methods of audiological care and retail. In Western Europe, BTE’s are the dominant form-factor. Therefore telecoils are included in some 60% of hearing aids, but this still varies considerably by country. In North America the ITC and ITE are the dominant form-factor and therefore telecoils are included in less than 20% of all hearing aids.

The usage of magnetic inductance by telecoil is also very depending on the availability of telecoil loops. Examples of places with telecoil loops are:

- Theatres and concert halls;
- Places of worship;
- Points of sale;
- Private home loop for audio, TV and warning signals;
- Personal loop as a necklace for connection to a mobile phone.

Again Western Europe shows the highest availability of telecoil loops. In USA, south and east Europe the availability of loops is relatively low. In general the best chances for a loop are in churches and theatres.

### 7.1.2 Migration from Telecoil to new technology

The usage of telecoil in hearing aids has a number of disadvantages. The main disadvantages of the telecoil/loop system can be summarized as:

- Being 1-way only: information can only be received;
- Being location dependant: only where a magnetic inductance loop has been installed and also by being exactly within that loop;
- Being broadcast information only: there is no possibility for personalized information;
- Being subject to magnetic interferences (TL-light, electronic equipment having transformers etc).

Replacement of telecoil/loop systems by a new technology will be possible when:

- providing a solution for the above disadvantages,
- new technology will be available with more functionality at the same or smaller size and having low power requirements that allows integration onto hearing aids,
- integrated into mainstream developments to increase its usability, to reduce costs and to reduce stigma of hearing aid use,
- having a viable transfer path from existing telecoil technology to the new technology,
• adopted by all major players in the field.

For the replacement of telecoil technology by a new technology a number migration strategies can be researched. The main characteristics of such strategies as seen from the hearing aid are:

• **Backwards compatibility by double system.**
  Both the telecoil and new technology systems are used independently. The hearing aid must support both systems in parallel and in general will have separate components for each. This means that both the telecoil and a new technology transceiver must be built in separately. In case the size of the new technology is relatively large, the total size of the hearing aid will increase. In general this will not be a viable option. In case the size is relatively small (e.g. integrated on the hearing aid processor chip and with a small antenna) this option can be viable still.

• **Backward compatibility by integration.**
  The new system has implicit backward compatibility for the older system. The hearing aid supports the new system but can also pick up the magnetic field signal of the traditional loop. This implies that the new system applies a component with similar (magnetic) properties as a telecoil.

• **Full replacement without backward compatibility.**
  The new system is introduced as a completely new communication system, including a complete infrastructure. The function of the new technology is that much better that no need for compatibility with the old telecoil system will be required. Implicitly all functionality of the old telecoil system will be succeeded by the new (superior) system. This scenario may apply better when the new technology is part of or easily added onto mainstream developments.

• **Backward compatibility by add-on devices.**
  In this situation backward compatibility is offered by providing an add-on device that supports the telecoil system.

• **Forward compatibility by add-on devices.**
  In this situation the new technology is introduced by add-on devices that fit onto the hearing aid. In general the functionality is reduced as the coupling will not be perfect (e.g. 1-way audio only). Examples of this are:
  - **Phonak FM link.**
    This is a dedicated 1-way FM link that connects to other (dedicated) devices like a remote microphone, or a school class communication system.
  - **ELI Bluetooth device (Microtech / Starkey).**
    This recently announced add-on device offers 1-way Bluetooth connectivity between hearing aid and a Mobile phone. A microphone is built in also for use with the mobile phone. Applications also refer to the use with audio and PC equipment.
Both examples apply the hearing aid standard “audio-shoe” (1-way) that is applicable to BTE’s only.

- **Add-on with telecoil as intermediate path.**

Another class of add on devices is the use of the telecoil as intermediate transmission. Examples of this are Bluetooth headsets as used for mobile phones or audio. Many of these headsets produce a sufficient magnetic field that allows coupling with a telecoil. In that method the headset should be placed on the ear with the hearing aid (BTE or ITE with telecoil) direct adjacent. By switching to telecoil a 1-way Bluetooth audiodpath is transmitted to the hearing aid.

### 7.2 Services

#### 7.2.1 Telecoil services

The usage of magnetic inductance by telecoil is very depending on the availability of telecoil loops. Examples of telecoil services are:

- Podium sound and announcement in theatres and concert halls;
- Podium sound in places of worship;
- Sound from home loops for audio, TV and warning signals;
- Speech at points of sale.

#### 7.2.2 Existing wireless sound services

The most important existing wireless sound systems are:

- **School systems.**
  In particular, for schools with hearing impaired pupils. Most systems are based on FM; some experiments ongoing using new technologies like DECT or Bluetooth.
- **Personal sound systems for theatres.**
  Present systems based on InfraRed, FM and few Bluetooth.
- **Translation systems.**
  Present systems based on InfraRed, FM and few Bluetooth.
- **Museum and exhibition information systems.**
  A few demonstration systems exist in which a Bluetooth headset will provide specific information at each location. In some cases the user may interact for additional information.
- **Prototype Bluetooth systems** for hearing aids (see BlueEar project).
- **Closed group communication systems** for security services.

Most of the above services are available for closed group only. This means that each system is dedicated for a limited area and type of user.

Public wireless sound systems do exist in the form of:
• Mobile phone services;
• Broadcast Radio (and TV).

7.2.3 New services

For a new technology that replaces telecoil usage for hearing impaired people the following new services are possible:

• Public announcement services (airport, train/bus-stations, waiting rooms, theatres, exhibitions etc);
• Integration with phone functions;
• General entertainment (Theatre, Music-hall, etc);
• Personal entertainment (at home, in trains, planes, car etc);
• Warning and alarm systems;
• Guiding information at exhibitions;
• Private information at points of sales.

The above new services may also have a large potential for use by the general public without hearing problems. In that way integration into mainstream technology will be possible with a number of potential advantages and disadvantages.

Integration into mainstream technologies will have advantages like:

• Large functionality;
• Low costs for equipment and services;
• Reduced stigma for hearing impaired people using the services.

Potential problems or drawbacks can be:

• Commercial dominance that insufficiently addresses the specific needs for people with hearing and communication problems;
• Possible short lifetime of new technology that may limit the payback period for specific adaptations required for hearing and communication impaired people.

7.3 Configurations

The basic configurations will be developed within HearCom SP4; Chapter 4 of this report gives a first overview.

7.4 Milestone Schedule

The following table reflects the major work items and the planned specification development of prototype and service deployment dates.
<table>
<thead>
<tr>
<th>MS Nr.</th>
<th>Major Work item</th>
<th>Spec.</th>
<th>Prototype</th>
<th>Demo Availability</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Prototype of HearCom PDA link:</td>
<td>March 06</td>
<td>Dec 06</td>
<td>March 07</td>
</tr>
<tr>
<td></td>
<td>• WIFI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• GPRS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Bluetooth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BAN simulated (wired or Bluetooth)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Prototype of HearCom PDA services:</td>
<td>Sept 06</td>
<td>March 07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Rolling txt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Server ASR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BAN Technology Protocols IC’s</td>
<td>March 06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PDA interface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Hearing aid interface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>BAN Prototype</td>
<td>June 06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BTE implementation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PDA SD implementation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8 Prototype Key Elements

8.1 Introduction

The aim of this chapter is to provide an overview of the elements participating on the different services and scenarios which are identified. These elements include also the specification of some hardware elements (server, PCS, HA, set top boxes, net access points...) that may be present on the different scenarios (open air, closed areas, at user’s home...). Then some technical information is provided to define the different technologies usually involved for the communication (WiFi, cellular...) in the PAN and WAN areas (see Table 1), in the case of public and private communication services.

All the scenarios and services of communications or the related various technical elements are not naturally all completely settled or determined in the HearCom project, but this chapter allows to define a direction or an idea of what can be the targeted applications and how they can be defined.

8.2 Definition of public communication services

In this section we describe some of the communication services that are available today and some that we expect to be available in the near future. Many of the services are ubiquitous for normal hearing persons, and with HearCom technology they will also be available to hearing disabled persons.

8.2.1 Wide area systems

Wide area systems are typically associated with costly investments in infrastructure, and they carry information vital to the functioning of society. The systems can be divided into broadcast and two-way communication systems. Telephony services, especially mobile telephony services, form the dominating means of person-to-person interaction over large distances. Public radio and television are traditional broadcasting techniques. Broadcasting services based on streaming audio and video signals over the Internet are expanding rapidly. Similarly, Internet based telephony is growing quickly.

Compatibility with all these communication services will be managed through an assistive device carried by the user. This assistive device in turn is connected to the body-area network that includes the head set. Naturally, compatibility with telephony services is a requirement for the HearCom communication link. It is envisioned that the mobile telephone network will communicate directly with the assistive device carried by the user (see also other sections of this report). Compatibility with radio and television services, whether based on traditional technology or based on emerging Internet technology will be provided by LAN-based interfaces. Radios, televisions, and computers owned by the user will have to be equipped with LAN interfaces.
The wide area systems generally form a relatively undemanding usage of the HearCom communication link if they are sound only. Since the far-end is not directly visible or audible to the user, a delay of up to 200 ms can be tolerated, (unlike the more restrictive scenario of face-to-face conversation, where the limit was 150ms). Together with high quality coding algorithms (which do need to be selected for delay) the user experience should be excellent.

If video services are provided, then the delay of the LAN interfaces relative to the video signal must be minimized. This can be done by delaying the video signal appropriately.

A relevant Internet based service in this context is the HearCom server (or portal) with which the hearing aid user will communicate to access various features, see subproject 5 of the HearCom Annex I – “Description of work”. This portal will provide access to other wide area systems.

8.2.2 Closed installations

By closed installations we mean local public communication systems that can be fixed installations or temporary communication systems, set up in, e.g., churches, cinemas, train stations, conference venues, concerts, sport events, etc. Due to their limited size they are typically associated with a lower cost of deployment. Most of the local public communication systems are broadcast systems. With the multitude of local services that can be expected to emerge, access to these services is vital to the user and, thus, to the HearCom communication link. It is envisioned that the LAN interface of assistive device will be used for receiving broadcasts in closed installations. This allows the usage of standardized, inexpensive technology.

Closed installations form a major challenge for the HearCom communication link because the user can often directly see and/or hear the source of the audio signal. This means that any latency becomes critical. However, LAN interfaces generally have significant delay. In certain applications (cinema) this latency can be eliminated by early transmission of the audio stream, but in other applications (churches, sports events, concerts) delay will degrade the user experience. Thus, it is important to design and select algorithms and devices so as to minimize the latency.

8.3 Definition of private communication services

This section deals with the short range and medium range area systems related to the PAN, and to a part of the BAN. It corresponds to private environment applications. Some of the communication services are also described in this section for today and near future applications. Even if many of theses services are ubiquitous for normal hearing persons as well as for the wide area system, the services described in this section could be more dedicated to the hearing disabled persons.
8.3.1 Private area systems

Personal area systems can be associated a priori with low-costly investments in infrastructure, especially when existing technologies are used. It is more difficult to foreseen the cost of investments for emerging or future technologies. The systems can be divided into two different communication systems. The first one refers to the interconnection with the BAN. This connection requires two-way communication service with a very specific technical requirement which is the low delay capability. The exchanges between both networks will be managed through an assistive device carried by the use. The second one, which fits better with this section, refers to the connection to closed environment such as at user’s home in a private environment. This connection requires a priori only one-way communication service with the more specific technical requirement which is the high rate capability. It corresponds to the connection to private environment devices such as television, radio and audio systems, or computers.

Another important requirement is the strong need of interference protection against other wireless systems or microwave generator generally already existing in a private area. Compatibility with radio and television services, whether based on traditional technology or based on emerging Internet technology will be provided by LAN-based interfaces. Radios, televisions, and computers owned by the user will have to be equipped with LAN interfaces.

8.3.2 Set top boxes

The advantage of private area is the possibility to envisage enduring installations set up in, e.g., home, workplace, office. The interest is also the capability to personalize the hearing aid system in order to better fit with the deficiency of a single user. The final application corresponds more specially to a reception, and a processing, of broadcasted information.

Even if the LAN interface of assistive device could be used for receiving broadcasts in closed installations, which are standardized and often inexpensive, the use of emerging technologies such as human body surface technology could be envisaged for the final system. The main interest of these technologies is to offer high data rate applications without any interference with other wireless devices. Any way, for the prototype key element, the use of low-cost LAN interfaces fits well for our application, such as Bluetooth or Bluetooth v2.0.
9 Standards

Standardization can be defined as: The development and implementation of concepts, doctrines, procedures and designs to achieve and maintain the required levels of compatibility, interchangeability or commonality in the operational, procedural, materiel, technical and administrative fields to attain interoperability.

This section exposes the relationship of this development with different standards. First, there are listed the references to all the standards involved in the development of the project. After that, it is analysed how this project can contribute to the development and wider introduction of current or new standards, not only those merely technical but also those related to bioengineering and medical systems.

9.1 Incorporation of Standards to HearCom

<table>
<thead>
<tr>
<th>Standard</th>
<th>Organization</th>
<th>Available at:</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>ETSI</td>
<td><a href="http://www.etsi.org">http://www.etsi.org</a></td>
<td>Cellular standard</td>
</tr>
<tr>
<td>GPRS</td>
<td>Initially ETSI. Currently 3GPP (3rd Generation Partnership Project)</td>
<td><a href="http://www.3gpp.org">http://www.3gpp.org</a></td>
<td>GSM extension for 2.5 generation</td>
</tr>
<tr>
<td>UMTS</td>
<td>3GPP</td>
<td><a href="http://www.3gpp.org">http://www.3gpp.org</a></td>
<td>represents the European/Japanese answer to the ITU IMT-2000 requirements for 3G Cellular radio systems</td>
</tr>
<tr>
<td>EDGE</td>
<td>3GPP (it is accepted by the ITU as part of the IMT-2000 family of 3G standards)</td>
<td><a href="http://www.3gpp.org">http://www.3gpp.org</a></td>
<td>enhancement to 2G and 2.5G (a.k.a. GPRS) networks. This technology is working in TDMA and GSM networks</td>
</tr>
<tr>
<td>IEEE 802.11 (a, b, g, r)</td>
<td>IEEE</td>
<td><a href="http://grouper.ieee.org/groups/802/11">http://grouper.ieee.org/groups/802/11</a></td>
<td>a.k.a. WiFi</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>Bluetooth SIG</td>
<td><a href="http://www.bluetooth.org">http://www.bluetooth.org</a></td>
<td>Bluetooth is an industry specification IEEE 802.15.1 standard was developed from Bluetooth v1.1</td>
</tr>
</tbody>
</table>

Table 24- Incorporation of Standards to HearCom
9.2 HearCom contribution to Standards

It is expected that the main opportunity of HearCom contributing to a standard will be in the area of the Body Area Network (BAN). Specifically in the definition of the RF link, with the employment of mainstream technologies and ultra low power (ULP) elements.
10 Dissemination and Exploitation

This report is focusing on the early technical and user requirements. At this stage of specification of the personal link, it is of limited use to disseminate these findings to the end-users or professionals. However, the results from the user and professional requirement questionnaires will be very important to focus to the needs of the hearing impaired and to construct the plans for the personal link.

When prototype systems and demonstration samples will become available later in the project, there are likely to be opportunities to disseminate these developments to deaf and hard of hearing people, and interested professionals, via various media (websites, newsletters, trade press etc.). It will be at this stage, once there are more tangible and 'visible' materials appropriate to disseminate these proposals, when responses from both professionals and the public will be very interesting to receive.

With regard to exploitation of the personal link and its services, the potential for exploitation will strongly depend on mainstream developments (hardware, carrier services) and the role the results of the Project will play in that. The best route will become clear at a later stage when the services have been defined and when demonstration models have been constructed. The possibility of carrying out a survey to the potential manufactures and service providers will be evaluated, since it could provide very valuable information in order to specify the exploitation plans.
11 Conclusions

Current HA systems aim at giving hearing disabled persons the same abilities to function in an acoustic environment as normal hearing persons. However, these systems do not take into account the new plethora of information and multimedia sources that are emerging, e.g. mobile phones, music players (home stereo, mobile players) and home cinema systems, and they do not provide an interface to these sources.

Many of the problems highlighted in this report are related to the fact that the inductive loops (telecoils) currently employed are niche technology that is developed only to assist people with a hearing problem. What is needed in future systems is a better integration with the mainstream world and the new and existing systems and technologies. An important solution is to resolve this problem with mainstream products, rather than with specific assistive devices alone. This would also reduce the stigma that is experienced by many people when using assistive technology rather than mainstream products.

For the replacement or evolution of telecoil technology to a new technology, a migration strategy should be selected from those proposed. During the definition and developments of the new system, it is recommended that users are involved at regular intervals during the development process to test and refine new design ideas.

The proposed architecture is based on one or two hearing aids (HA) and a new Personal Communication System (PCS). This solution provides two active communication links: between the PCS and the HAs – i.e., by a novel Body Area Network or BAN –, and between the PCS and the outside world – i.e. by wide and local area networks of different kinds. By studying different scenarios and subsequent activation needs of the two communication links, several modes of operation are specified. The personal communication device (PCS) is central to the operation and is the clearing house of all user communications. It will provide access to several communication platforms, initially GSM/GPRS, WiFi and Bluetooth, but paying attention also to the availability of future alternatives such as UMTS or UWB. The element proposed for the implementation of the PCS is a PDA such as the HP iPAC PocketPC h6340, or similar.

One of the most restrictive requirements of a novel system is the necessity of combining low power consumption requirements (approximately the same as current technology) with the size of the HAs (not bigger than current HAs) and size of the PCS (not bigger than a typical PDA), while getting an adequate performance and quality of service. It will also be necessary to comply with the requirements of security and confidentiality.

Quality achieved after the processing of audio signals will be measured using both objective tests, i.e. done by a model, and by subjective tests requiring human listeners. However, it is necessary to take permanently into account that there is a trade-off between the facilitation of advanced signal processing and the delay introduced by that, which will give some loss of quality that should be unnoticeable or acceptable for the end-user.
Annex A - IEEE 802.11 Standard

A.1 IEEE 802.11 Handoff procedure

The handoff is a physical layer function carried out by at least three participating entities, namely the station, a prior-AP and a posterior-AP. The AP to which the station had physical layer connectivity prior to the handoff is the prior-AP, while the AP to which the station gets connectivity after the handoff is the posterior-AP. The state information that is transferred typically consists of the client credentials (which allow it to gain network access) and some accounting information. This transfer can be achieved by an (currently draft) Inter Access Point Protocol (IAPP), or via a proprietary protocol. For an IEEE 802.11 network that has no access control mechanism, there would be a nominal difference between a complete association and a handoff / reassociation. Looking at it another way, the handoff-latency would be strictly greater than association latency as there is an additional inter-access point communication delay involved.

The complete handoff process can be divided into two distinct logical steps:

Discovery: Attributing to mobility, the signal strength and the signal-to-noise ratio of the signal from a station’s current AP might degrade and cause it to loose connectivity and to initiate a handoff. At this point, the client might not be able to communicate with its current AP. Thus, the client needs to find the potential APs (in range) to associate to. This is accomplished by a MAC layer function: scan. During a scan, the card listens for beacon messages (sent out periodically by APs at a rate of 10 ms), on assigned channels. Thus the station can create a list of APs prioritized by the received signal strength. There are two kinds of scanning methods defined in the standard: active and passive. As the names suggest, in the active mode, apart from listening to beacon messages (which is passive), the station sends additional probe broadcast packets on each channel and receives responses from APs. Thus the station actively probes for the APs.

Reauthentication: The station attempts to reauthenticate to an AP according to the priority list. The reauthentication process typically involves an authentication and a reassociation to the posterior AP. The reauthentication phase involves the transfer of credentials and other state information from the old-AP. As mentioned earlier, this can be achieved through a protocol such as IAPP[2]. In the experiments detailed in this paper, we do not have the draft standard IAPP communication setup but the proprietary inter-access point communications were allowed (between APs of the same vendor). Thus the authentication phase is just a null authentication in our experiments.

Figure 15 shows the sequence of messages typically observed during a handoff process. The handoff process starts with the first probe request message and ends with a reassociation response message from an AP. We divide the entire handoff latency into three delays:
Probe Delay: Messages A to E are the probe messages from an active scan. Consequently, we call the latency for this process, probe delay. The actual number of messages during the probe process may vary from 3 to 11.

Authentication Delay: This is the latency incurred during the exchange of the authentication frames (messages E and F). Authentication consists of two or four consecutive frames depending on the authentication method used by the AP. Some wireless NICs try to initiate reassociation prior to authentication, which introduces an additional delay in the handoff process and is also a violation of the IEEE 802.11 [3] state machine.

Reassociation Delay: This is the latency incurred during the exchange of the reassociation frames (messages G and H). Upon successful authentication process, the station sends a reassociation request frame to the AP and receives a reassociation response frame and completes the handoff. Future implementations will include additional IAPP messages during this phase which will further increase the reassociation delay.
A.2 IEEE 802.11 Family Description

A.2.1 IEEE 802.11a

802.11a [1] defines one of several different 802.11 Physical Layers (PHYs). The actual name of 802.11a is the "High Speed Physical Layer in the 5GHz band," commonly referred to as the "OFDM PHY." The 802.11a PHY is quite different than 802.11b, which uses direct sequence spread spectrum (DSSS). 802.11a specifies the use of OFDM to support higher data rates.

OFDM divides the data signal across 48 separate sub-carriers to provide transmissions of 6, 9, 12, 18, 24, 36, 48, or 54Mbps of which 6, 12, and 24Mbps are mandatory for all products. For each of the sub-carriers, OFDM uses PSK (phase shift keying) or QAM (quadrature amplitude modulation) to modulate the digital signal depending on the selected data rate of transmission. In addition, four pilot sub-carriers provide a reference to minimize frequency and phase shifts of the signal during transmission. This form of transmission enables OFDM to operate extremely efficiently, which leads to the higher data rates, and minimize the affects of multi-path propagation.

The operating frequencies of 802.11a in the U.S. fall into the national information structure (U-NII) bands: 5.15-5.25GHz, 5.25-5.35GHz, and 5.725-5.825GHz. Within this spectrum, there are twelve, 20MHz channels, and each band has different output power limits.

OFDM is becoming very popular for high speed transmission. In addition to being selected as the basis for the 802.11g PHY, OFDM is the basis for the European-based HiperLAN/2 wireless LAN standards.

A.2.2 IEEE 802.11b

IEEE 802.11b [1] data is encoded using DSSS (direct-sequence spread-spectrum) technology. DSSS works by taking a data stream of zeros and ones and modulating it with a second pattern, the chipping sequence. In 802.11, that sequence is known as the Barker code, which is an 11-bit sequence (10110111000) that has certain mathematical properties making it ideal for modulating radio waves. The basic data stream is exclusive OR'd with the Barker code to generate a series of data objects called chips. Each bit is "encoded" by the 11-bit Barker code, and each group of 11 chips encodes one bit of data.

The wireless radio generates a 2.4-GHz carrier wave (2.4 to 2.483 GHz) and modulates that wave using a variety of techniques. For 1-Mbps transmission, BPSK (Binary Phase Shift Keying) is used (one phase shift for each bit). To accomplish 2-Mbps transmission, QPSK (Quadrature Phase Shift Keying) is used. QPSK uses four rotations (0, 90, 180 and 270 degrees) to encode 2 bits of information in the same space as BPSK encodes 1. The trade-off is that you must increase power or decrease range to maintain signal quality. Because the FCC regulates output power of portable radios to 1 watt EIRP (equivalent isotropically
radiated power), range is the only remaining factor that can change. Thus, on 802.11 devices, as you move away from the radio, the radio adapts and uses a less complex (and slower) encoding mechanism to send data.

In order to provide the higher rates, 8-chip Complementary Code Keying (CCK) modulation scheme is employed as the modulation scheme. The CCK code word is then modulated with the QPSK technology used in 2-Mbps wireless DSSS radios. This allows for an additional 2 bits of information to be encoded in each symbol. Eight chips are sent for each 6 bits, but each symbol encodes 8 bits because of the QPSK modulation. The spectrum math for 1-Mbps transmission works out as 11 megachips per second times 2 MHz (the null-to-null bandwidth of a BPSK signal) equals 22 MHz of spectrum. Likewise, at 2 Mbps, you are modulating 2 bits per symbol with QPSK, 11 megachips per second, and thus have 22 MHz of spectrum. To send 11 Mbps, you’d send 11 million bits per second times 8 chips/8 bits, which equals 11 megachips per second times 2 MHz for QPSK-encoding, yielding 22 MHz of frequency spectrum.

**Physical Signals**

The wireless physical layer is split into two parts, called the PLCP (Physical Layer Convergence Protocol) and the PMD (Physical Medium Dependent) sublayer. The PMD takes care of the wireless encoding explained above. The PLCP presents a common interface for higher-level drivers to write to and provides carrier sense and CCA (Clear Channel Assessment), which is the signal that the MAC (Media Access Control) layer needs so it can determine whether the medium is currently in use (Fig XX1).

The PLCP consists of a 144-bit preamble that is used for synchronization to determine radio gain and to establish CCA. The preamble comprises 128 bits of synchronization (scrambled 1 bits), followed by a 16-bit field consisting of the pattern 11110011000000. This sequence is used to mark the start of every frame and is called the SFD (Start Frame Delimiter). The next 48 bits are collectively known as the PLCP header. The header contains four fields: signal, service, length and HEC (header error check). The signal field indicates how fast the payload will be transmitted (1, 2, 5.5 or 11 Mbps). The service field is
reserved for future use. The length field indicates the length of the ensuing payload, and the HEC is a 16-bit CRC of the 48-bit header.

To further complicate the issue (and degrade performance) in a wireless environment, the PLCP is always transmitted at 1 Mbps. Thus, 24 bytes of each packet are sent at 1 Mbps. The PLCP introduces 24 bytes of overhead into each wireless Ethernet packet before we even start talking about where the packet is going. Ethernet introduces only 8 bytes of data. Because the 192-bit header payload is transmitted at 1 Mbps, 802.11b is at best only 85 percent efficient at the physical layer.

A.2.3 IEEE 802.11g

802.11g merged two incompatible wireless networking standards, 802.11b (goes far but not fast) and 802.11a (goes fast but not far), to create a standard that has same range as WiFi, but whose top speed is 54 Mbps (as opposed to WiFi's comparatively puny 11 Mbps).

The 802.11g standard utilizes existing elements from the original CCK-ODFM and PBCC-22 proposals. Each of these proposals called for true 802.11a OFDM operation in the 2.4 GHz band as an optional mode to the primary proposed modulation, either CCK-OFDM or PBCC-22. The 802.11g standard makes OFDM the mandatory technology, offering 802.11a data rates in the 2.4 GHz band, requires mandatory implementation of 802.11b modes and offers optional modes of CCK-OFDM and PBCC-22. This balanced compromise offers a much clearer bridge between 802.11a and 802.11b, plus is a straightforward means to develop true multi-mode WLAN products. 802.11g achieves the high 54 Mbps data rates of 802.11a in the 2.4 GHz band, thereby maintaining compatibility with installed 802.11b equipment.

The PHY defined in 802.11g is known as the Extended Rate PHY (ERP). The ERP builds on the payload data rates of 1 and 2 Mbit/s that use DSSS modulation and builds on the payload data rates of 1, 2, 5.5, and 11 Mbit/s that use DSSS, CCK, and optional PBCC modulations. The ERP uses the 802.11a standard to provide additional payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s. Of these rates, transmission and reception capability for 1, 2, 5.5, 11, 6, 12, and 24 Mbit/s data rates is mandatory. Two additional optional ERP-PBCC modulation modes with payload data rates of 22 and 33 Mbit/s are defined. An ERP-PBCC station may implement 22 Mbit/s alone or 22 and 33 Mbit/s. An optional modulation mode known as DSSS-OFDM is also incorporated with payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s.

The changes to the base standard required to implement the ERP are summarized as follows:

ERP-DSSS/CCK: The PHY uses the capabilities of 802.11b with the following exceptions:

Support of the short PLCP PPDU header format capability is mandatory.

CCA has a mechanism that will detect all mandatory 802.11g sync symbols.
The maximum input signal level is –20 dBm.

Locking the transmit centre frequency and the symbol clock frequency to the same reference oscillator is mandatory.

ERP-OFDM: The PHY uses the capabilities of 802.11a with the following exceptions:

- The frequency plan is in accordance with 802.11b.
- CCA has a mechanism that will detect all mandatory 802.11g sync symbols.
- The frequency accuracy is ±25 PPM as for 802.11a.
- The maximum input signal level is –20dBm.
- The slot time is 20 µs in accordance with 802.11b, except that an optional 9 µs slot time may be used when the BSS consists of only ERP terminals.
- SIFS time is 10 µs in accordance with 802.11b.

ERP-PBCC (Optional):

This is a single-carrier modulation scheme that encodes the payload using a 256-state packet binary convolutional code. These are extensions to the PBCC modulation in 802.11b.

DSSS-OFDM (Optional):

This is a hybrid modulation combining a DSSS preamble and header with an OFDM payload transmission. DSSS-OFDM defined modes with payload data rates are 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s.

If the optional DSSS-OFDM mode is used, the supported rates in that mode are the same as the ERP-OFDM supported rates.

A.2.4 IEEE 802.11r Fast Roaming/Fast BSS Transition

This is an IEEE effort to standardize handoff for fast roaming among APs, including authentication keys, to allow fast roaming that will support voice over wireless in addition to data over wireless. It would also address roaming across segments.

The 802.11r Task Group is working on MAC mechanisms to minimize or eliminate the amount of time which the Station is absent during a Basic Service Set (BSS) transition (the station transfers from one AP to another) supporting seamless mobility within the same ESS. The need for these mechanisms sprung from the fact that 802.11e (QoS) and 802.11i (security) will increase this transfer time while next generation WLAN applications demand decrease it. Faster handoffs will be critical to meeting the real-time requirements of delay-sensitive applications such as voice, especially in mobile settings where client devices can be expected to roam frequently. This standard will facilitate the deployment of SIP-based Voice over WiFi (VoWiFi) portable phones.

TGr was approved in March 2004 and therefore no work on a technical specification has begun yet. Standard is stated to be complete by 2006.