The body as a communication medium

João Henrique Donker
j.h.donker@student.utwente.nl Department of EMCS, University of Twente

ABSTRACT
Body sensor networks are currently not very intuitive and not very reliable. In the last couple of years body coupled communications has been rediscovered after a period of disinterest. In this paper an overview of recent research into body coupled communications is given. This research into body coupled communications shows that body sensor networks are not the only ubiquitous computing application where it could be useful. From recent research a number of guidelines for using body coupled communications are developed to help future research in ubiquitous computing.

Keywords
Body coupled communications, body sensor networks, sensor networks, ubiquitous computing, human area networks

1. INTRODUCTION
Ubiquitous computing (UC) has come a long way since its inception by Marc Weiser. Making computers intuitively blend into the environment has been a major area of research during the past twenty years. Many advances have been made in ubiquitous computing. One of them is the recent development of body sensor networks, but currently these networks are neither intuitive nor do they blend seamlessly into environment. Body coupled communications (BCC) is a new technology that might make body sensor networks more intuitive and more seamless.

1.1 Operating principles of Body coupled communications
Body coupled communications is a physical layer technology where the signals travels "on" and "in" the body instead of through and off the body as with radio. This can be seen in figure 1 citekaist:low. The electric field of the body is subtly modified so that a message can be sent and received. This gives a workable channel for communications that "sticks" to the body. The receiver and the transmitter are connected to this channel leading to an ethernet like network on the body [1] [2].

Body coupled communications in theory has a number of advantages compared to wired and radio communication. The first advantage is that wires are not needed to connect different devices. Secondly, because the signal sticks to the body the signal is inherently difficult to eavesdrop. Another advantage is that less power is needed to send data, because the data is not broadcast to everywhere, it is just send around the body. Another factor why this technology could be less power hungry in theory, is that changing an electric field consumes less power than generating electromagnetic waves [1] [2].

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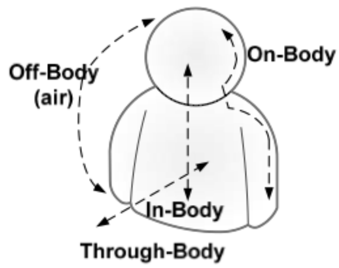

Figure 1: Communication in and around the body. Picture from SSL group KAIST

1.2 Current problems with communication in body sensor networks
While wireless sensor networks are gradually becoming mainstream, the smaller related body sensor networks are still in their infancy. Body sensor networks consists of number of intercommunicating sensors that can be worn and that monitor the body. These devices communicate to each other and possibly send data to an off body location for further processing. While related to wireless sensor networks the challenges are different. Body sensor networks have to deal with more dynamic environment than wireless sensor nodes because humans rarely sit still. This causes problems with the communication between the nodes with the radio techniques currently used. To overcome problems with transmission such as interference and disconnects the power of the transmission is increased [3]. This allows the signal to be received from a greater distance, leading to privacy concerns. Interference is a major problem with radio based technologies because most radio based techniques use frequencies that are near to each other and that are also used for other purposes like telephony [3] [4]. Because the signal strength is increased to minimize interference the power usage increases leading to batteries running out of power sooner.

In table 3 the bandwidth requirements of multiple sensors are given, combining this with table 1 shows that it is feasible to build body sensor networks with radio today. But the energy usage of such a network is too large to keep such a network running without constantly needing to recharge the nodes.

1.3 Other uses of body coupled communications
While body sensor networks are interesting for body coupled communications, it is not the sole area of interest for body coupled communications. Body coupled communications can also be used for more mundane tasks where the fact that a network is

made is completely oblivious to the user. Examples of this would be streaming music to headphones and unlocking doors by touching them when carrying a body coupled key. The only thing that the user would know is that the data travels through his or her body.

1.4 Previous work

Body coupled communications was discovered in the middle of the nineties. At MIT Zimmerman [5] discovered body coupled communications by accident while doing human interface research on position sensors. Simultaneously at the Sony Labs a similar technology was developed that resulted in the wearable key prototype [6]. These discoveries led to an initial media frenzy. But soon afterwards interest was lost in body coupled communications because of what was then thought were fundamental limitations of the technology (Zimmerman thesis mistakenly stated that the technology had fundamental limit of 852 Kb/s). During the initial stages there was also research done at powering devices via the body. But this did not lead to much [2].

After a period of disinterest in the technology, between 2003-2006 the technology regained some research interest. During this time different techniques where tried and these managed to reach higher speeds. The first major breakthrough came from NTT (Nippon Telegraph and Telephone) in 2004. Using a electro optical implementation a speed of 10 Mb/s was reached. One of their applications was sending video through the body [7]. Around the same time the Skinplex technology became available which was very simple implementation with very low speeds and very low energy consumption [8]. This implementation was not advanced enough for body sensor networks and was mainly used for user identification. A few years later the SSL (Semiconductor System Lab) group from KAIST (Korea Advanced Institute of Science and Technology) was able to present a more power efficient implementation of body coupled communications using wide-band signaling [1]. This implementation has been steadily improved with higher data rates and features like interference robustness. The implementation of NTT is slowly moving towards commercialization. The first commercial implementation of their security technology is the NTT Firmo evaluation kit [9]. The implementation from KAIST is still in development in the lab and will probably be commercialized in the near future.

At the moment it appears that about five research groups are actively pursuing body coupled communications. Two of those groups have working advanced implementations and the others are still experimenting with the basic parameters. Most advanced research into body coupled communications seems to be happening in Japan and Korea with Europe and the United States lagging behind [3] [10] [4] [11] [12].

2. CHARACTERIZATION

To get a good overview of body coupled communications it first has to be characterized. Current research is examined with the following criteria.

- Reliability
- Power usage & data transmission speed
- Privacy & safety
- Software & Applications

2.1 Reliability

Reliability has two components, how reliable does the signal travel around the body and how is the signal affected by other signals . The first has been quite thoroughly researched up to now. The latter is a more recent avenue of research, since only now are body coupled networks becoming better understood and the implementations so refined that interference is becoming a problem.

2.1.1 Signaling

Currently a lot of research being done at characterizing how the signal travels around the body. In most cases this is done by measuring how the signal survives being sent around the body. An example would be measuring how much of the signal survives the distance between the two arms or the distance from the neck to the feet. Another example is measuring how the signal is affected by the sitting down and standing up [4] [11] [3]. This might seem silly but is very important since the grounding of the signal is different in these cases.

In the paper from the Waseda university in Tokyo a number of different techniques were compared. They mainly looked at how distance and modulation techniques influence the signal. With their setup they managed to reach 5 Mb/s over a very short distance (20 cm) and over longer distances they where able to reach 1 Mb/s (180 cm). MSK (minimum-shift keying) and BPSK (Phase-shift keying) where able to reach these speeds on short distances but at longer distances the BPSK method worked better than the MSK technique [11].

A recent paper of the Distributed Sensor Systems department from Philips mentions experimental research regarding different parameters like positions of the nodes around the body, interference from multiple sources, difference between sitting on chair compared to walking around and finally transceiver design. In their experiments they showed that only a certain part of the spectrum is useable because of interference from other devices and the property of the human body to act as an antenna at certain frequencies [3].

In the paper from NTT, a first look is given at their electro optical technique. Part of this paper looks at how reliable the link is maintained between two nodes. An interesting case was transmission between two persons. While they achieved excellent results with one person they had a lot of problems trying to maintain a connection between two people. (With one person they had a packet error rate of 0.04% compared to 3% between two persons in the best case) Another problem was that the connection was very unstable. What makes this technique remarkable for use with a single person is that it was the first that was able to reach the entire body and do this while maintaining reasonable speed [7].

2.1.2 Interference

While most papers currently do not deal specifically with the effects of interference a few of them do, and one actually tries to do something about it.

The paper from Philips takes a short look at how the signal is modified by having appliances placed in the same room. They concluded that the body coupled signals can receive interference from devices like computer monitors [3]. But they did not give any solutions for dealing with interference.

A recent paper from the KAIST implements a frequency hopping technique. Their implementation continuously checks which channels are the most free of interference and tries to use those channels. This makes their implementation quite robust against environmental interference at a slight power consumption cost. This technique seems to work well in conjunction with body coupled communication since they are able to reach a SIR (signal-to-interference ratio) of -28 dB [12]. This allows the technology to be used in real life where interference sources are everywhere.

2.2 Power usage & data transmission speed

As seen in table 3, practical body sensor networks need to have a fair amount bandwidth available. But having a fast network that consumes a lot of power is undesirable for a human area network since the network is worn, and it is inconvenient if the nodes need constant recharging. The transmission speed of body coupled networks was for a long time a significant problem, because it was thought that there was a theoretical maximum of 852 Kbit/s [5].

To make an accurate comparison between radio and body coupled communication the energy usage of radio based techniques has to be documented. In a paper of the Human++ research group a comparison is made between various radio based technologies currently available. The most interesting two are Zigbee and Bluetooth since they have been widely used to build body sensor networks [13].

Table 1: Radio based communications

Type	Zigbee	Zigbee	Bluetooth
part	Chicpon CC2420	Motorola MC13192	Skyworks CX72303
Power usage	65.1 mW	181 mW	77 mW
Data rate	250 Kb/s	250 Kb/s	1000 Kb/s

The NTT group devoted to body coupled communication had the first major performance breakthrough with their electro optical technique. With this technique they where able to reach speeds of 10 Mb/s. Their technique uses a very sensitive crystal that changes the polarization of light depending on the electric field [10]. Light is sent through the polarizing crystal and depending of the underlying electric field the crystal lets the light travel to the detector. This technique is very fast but has certain disadvantages. The transmission is not duplex and its energy usage is quite large at 650 mW for the entire transceiver [7]. Their security implementation is able to achieve speeds of 230 Kb/s but its power consumption is currently not known. But they state that the current transceiver in the NTT firmo is able to function for a year without changing the batteries [9].

The KAIST group implementation has two goals: low energy usage and speed. According to their first papers they reached 2 Mb/s by using higher frequencies than previously tried. The human body appears to conduct the signals well between 10 KHz and 200 MHz [1]. They were able to reach the speeds with low energy usage by building integrated circuits that integrated all the transceiver logic. During the next few years they reached higher speeds while slightly lowering the energy usage of their implementation and adding features like interference rejection. Their current implementation gives scaleable performance between 60 Kb/s to 10 Mb/s by having a signal of 10 Mb/s and using the spare bandwidth for error correction. Depending on the application the level of error correction can be set. Even more remarkable is that this can be achieved with a power consumption of less than 5 mW [12] [14]. Thus opening the way to very low energy body sensor networks.

There is third implementation from a company called IDENT technology AG. It is called Skinplex and operates on the same basic principles but has a very low data rate and very low power consumption. The developers claim a data rate of about 9 Kb/s with an extremely low energy usage of 8 μW. But the applications are more limited in scope compared to other implementations [8]. Most applications are related to safety and evolve the human closing or breaking the electrical connection.

Table 2: Body coupled communications

	NTT	KAIST	Skinplex
Power usage	650 mW	5 mW	8 μW
Data rate	230Kb/s-10Mb/s	60 Kb/s-10Mb/s	9 Kb/s

Outside of the KAIST and the NTT group the implementations have not focused on speed and power usage. Most other research is currently more focused on how well the signal travels around the body.

Comparing the currently available radio techniques with body coupled implementations it becomes clear that body coupled communication implementations have clear advantages regarding transmission speed and in some cases energy usage. Being able to close an electrical circuit via a human allows body coupled communications to be used for more than just body sensor networks.

2.3 Privacy & safety

A major problem with radio based techniques is that the signal can be listened to without too much trouble.

The paper from Philips also researches how far away the signals can be received. In their measurements it appears that the signals loses strength a lot faster out of the body than inside the body. Within a few cm of the body the signal degraded so much that it was very hard to receive. Making sure that the transmissions around the body cannot be eavesdropped from a distance. This allows frequencies to be reused by separate BCC networks without these networks interfering with each other. But they also state that frequencies higher than 60 MHz cause the human body to act like an antenna making eavesdropping easier. This makes using higher frequencies undesirable from a security point of view [3].

But in some cases eavesdropping might be useful. For example users could share contact information with a handshake. The only literature available at the moment regarding this aspect is from NTT, in which they claim that interbody networking is very unreliable [7]. This could be regarded positive in some cases, (eavesdropping is not possible by simple touching someone) but it is a limitation regarding possible usage scenarios. The paper from Philips raises certain interesting question since in their research the network reacts differently to different people, in some people the signal loses strength faster [3].

The human safety aspect of body coupled communications is an important issue. In the PhD thesis of Partridge a number of people were invited to a lab and they were allowed to use a body coupled system. Some of these users were fearful of long term effects caused by the constant low level energy emitted [2]. Currently the long term health effects of using body coupled networks is completely unknown. Interestingly most papers state that the amount of energy exposure to the body is minute and well below the current safety standards [1]. NTT even states that the transmitter never touches the body directly because it is wrapped in an insulator [7].

Body coupled communications is able to give nearly the privacy that a wired network gives with the advantages that the nodes do not need to be directly connected to each other by wires. Due to its low power the health risks are probably limited. But there is no knowledge how the body behaves with long term exposure to such electric fields.

2.4 Software & Applications

Before looking at various applications of BCC described in literature the basic bandwidth and error rate requirements of various applications needs to be understood.

Table 3: Data rates and error rates for common body area network data

Type	bandwidth (Mb/s)	BER	Application
EEG	< 0.1 Mb/s	10^{-9}	Medical
ECG	0.2 Mb/s	10^{-9}	Medical
EMG	0.5 Mb/s	10^{-9}	Medical
Audio	1 Mb /s	10^{-5}	Multimedia
Voice	0.2 Mb/s	10^{-3}	Telephony
Unlocking objects	< 0.1 MB/s	10^{-7}	Safety
User detection	< 0.01 MB/s	10^{-4}	Security

As can seen in table 3 [12], the possible uses are quite diverse and each application has its own specific requirements.

While body coupled communications is mainly a physical layer technology it does not hurt to look at the higher layers of the software stack.

2.4.1 Medium access & low level software

Now that the physical properties of body coupled communications have been characterized it is time to take a look how the these techniques can be used to create a viable network. The first step is the medium access protocol.

The implementation from KAIST does not use an ethernet-like protocol but has its own more optimized protocol. The protocol is based on the assumption that most sensor data is 16 bit. The protocol is designed to send multiples of 16 bits from 0 to 4080 bits. The protocol only allows 255 addresses to be reached. The protocol also contains a preamble to allow interoperability with other MAC protocols like CDMA (Code Division Multiple Acces) In simulations with GloMoSim it was determined that a star network was the ideal for such a body coupled network when looking at the energy consumption [14].

The fastest version of Red Tacton (NTT) can be used with TCP/IP in half duplex mode. Slower versions use a proprietary protocol. On their devices they basically implement an IEEE 802.3 half-duplex communications network which allows applications to use TCP/IP or any other protocol that can use ethernet. This allows it to be used as a WLAN substitute in certain scenarios [15] [7].

2.4.2 High level software & applications

NTT has two implementations of Red Tacton. One is meant for non data intensive applications and one for data intensive applications. The non data intensive implementation is mainly meant for security applications like user identification. An example of this would be that the user prints a document, and the document starts printing when the user touches the printer. The data intensive version is suited for TCP/IP connections. An example given by NTT is using the body as an ethernet cable for a laptop in a crowded room to prevent performance loss due too a crowded WLAN [15] [7].

In the PhD thesis of Kurt Partridge a simple Body coupled communication implementation was used to create a number of simple applications. His implementation tested a security application. The user carried a body coupled transmitter in their shoes which unlocked the door if the knob was touched. Another application was copying and pasting between different computers by first touching the first computer and then touching the other computer [2].

The implementation from KAIST SSL lab is more experimental at the moment. It is mainly used for sending and receiving motion sensor data and ECG data [1]. It can also be used to send music wirelessly to headphones. In figure 2 the music streaming prototype is shown [1].

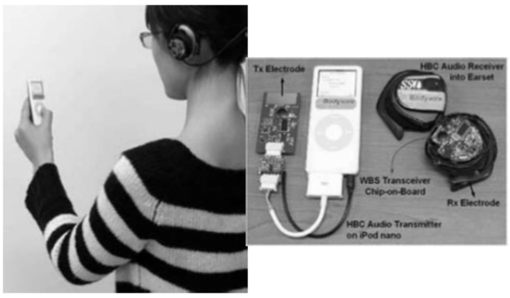

Figure 2: Music streaming prototype from the SLL group KAIST

The applications of Skinplex are more related to security and safety. (Security deals with the user authenticating themselves while safety deals with avoiding possible dangerous situations) They give examples like not allowing the driver to change settings on the radio while driving but only allowing the companion to change the settings as not to distract the driver. Another example given was that user could authenticate himself or herself to a computer via a Skinplex key worn on the body. These are fairly simple applications that do not need a lot of bandwidth but could improve safety and ease of use [8].

The group from Waseda university seems to have gone in a different direction. They have tried to build a finger identification scheme using intrabody communication. This could for example be used to detect if someone is typing correctly on keyboard, since before it was not possible to correlate a keystroke to a finger without visual analysis [16].

3. HOW CAN BODY COUPLED COMMUNICATIONS BE USED

In the previous section it became clear that body coupled communication can be used for widely different applications with really different requirements.

On the low end simple networks have been made that are basically closing the circuit which is mainly useful for safety applications. In between there are security applications and medical body sensor networks. On the high end multimedia and internet packets flow through the body. And last but not least there are scenarios where information is shared between people via physical contact. These are very diverse applications and each of these have very diverse requirements.

3.1 Communications hierarchy

Technically there are two types of body coupled communications.

- interbody communication
- intrabody communication

The division between interbody and intrabody is the most fundamental differentiator for technical reasons since connecting devices by traversing two people is technically harder to achieve with reasonable performance. This is because some people might not be compatible with each other and people move which causes the connection to become unstable. Interbody networking also means that two networks could temporary merge which could cause troubles with the software configuration of such networks.

Interbody networking deals with the special case that two bodies make physical contact and information is send over the physical connection. A good example of such a network would be a network that is created every time somebody gives a handshake and via this handshake contact information is exchanged.

In intrabody communication there are many different usage scenarios. Three types of communication can be classified within intrabody communication.

- person bound communication
- person to object communication
- object to object communication

Together this forms a hierarchy that can be seen in figure 3.

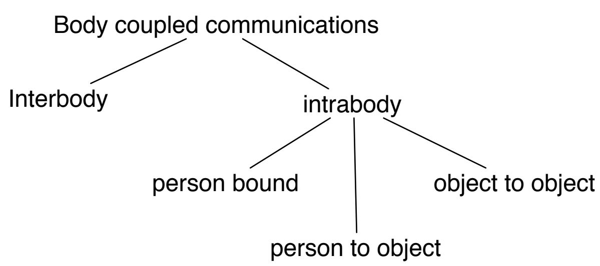

Figure 3: Communications hierarchy

While the NTT group mention these types of communication in their paper [15], they do not see interbody communication as a different type of communication distinct from intrabody networking. This is strange since they showed that interbody networking was problematic and had different physical properties than intrabody networking.

It is important to know that these classifications are not set in stone. All of these are examples of ubiquitous computing and it should not be too hard to imagine scenarios where all of these types of communication are desired.

3.1.1 Person bound communication

Person bound communication consists mostly of traditional body sensor networks where the radio has been replaced with a body coupled communication physical layer. But it could also mean multimedia that is streamed around the body between two devices that are worn by the user.

Most of these applications have a high demand for bandwidth either to send data themselves or the data needs to be error free thus requiring significant error correction. For example sending music to headphones might require a lot of bandwidth but the signal does not need to be error free. While an ECG does not require a lot of bandwidth but the signal needs to be nearly error free which means that more bandwidth has to be devoted to error correction.

3.1.2 Person to object communication

Person to object or object to person, are the most diverse of the different profiles. A simple scenario would be opening a secure door by touching the knob when carrying a body coupled key. An advanced example would connecting to the internet with a mobile device via the body. These two are fairly different applications and as such have different requirements. The authentication example only has very short connections and does not need to send a lot of data around so its power requirements are modest. While using such a network to get a high speed internet connection the data rate might be very important and the power usage might become less important.

3.1.3 Object to object communication

Object to object communication is a very different type of network. The body serves as a connection between two body coupled devices that are not worn by the user. It could also be used to prevent a piece of machinery from operating if the user is in an unsafe position thus increasing safety. These applications do not need a lot of bandwidth and only need to use minimal power because of that.

While person bound, person to object and object to object communication are electrically nearly the same, on a protocol layer they are very different. For example object to object communication does not need to have to have a very complicated protocols, but something like body sensor network might need significant error correction and quality of service to be available for it to be able to function effectively.

3.2 How BCC fits within UC

At the moment there are three viable implementations of body coupled communications, the Red Tacton technology from NTT, the Biocle chips from KAIST and Skinplex.

Disappointingly high performance interbody networking is still not a reality yet. So this is mostly an open problem at the moment. The major problem here is that the connection cannot be maintained reliably. While interbody communication certainly is possible as it is featured in Zimmerman's original thesis [5]. Sending more than simple contact information is currently not very practical due to the connection beinig unstable [7].

But for intrabody networking the choices are clearer. Most body coupled communication implementations have a specialization. For example Skinplex is best suited to object to object communications. The data rates are simply too low for it to serve as a body sensor network. But the data rate is enough for safety and security applications.

While for example the implementation from KAIST is mostly optimized towards person bound communications, mainly because the underlying protocol is designed to maintain error correction between different speeds and the protocol running on top is designed for limited networks. While it is possible to use a different protocol, this has not been done yet. Since they have build networks with more than two devices making it is suitable for person bound communications.

Finally Red Tacton (NTT) seems to be specialized towards person to object connections. Since it has a high power consumption and has the capability to use protocols designed to communicate with the rest of the world. Most examples given in their papers are security applications. While there is no recent information available about the power usage of Red Tacton, the known power usage is too high to be used continuously on a body sensor network. But its high power usage might not pose a big problem if the connections are short like authenticating someone to print when touching the printer. Currently all examples given in their papers evolve communication with two devices, making it not very suitable for person bound communications. Which can have networks with more than two devices.

The research happening at Waseda university is a good example of using intrabody communication for something quite different than body sensor networks. (But their work could fit in person to object communication) By using the properties of body coupled communication they successfully build a finger identification scheme.

3.3 Comparison with radio

While in a few areas body coupled communications might compete with traditional radio based techniques it also has a number of niches where it is the only game in town. An advantage it will always have is that eavesdropping on a body coupled network will always be hard, since the signal can only be received very near the body. In certain cases body coupled communications might also have an advantage in speed and power usage.

4. DISCUSSION

4.1 Availability

The biggest problem with body coupled communications is that it is not really available to currently build systems with. The only two available implementations on the market right now is the security implementation of Red Tacton (NTT) and Skinplex. To get a NTT evaluation kit still costs 7000 euros (June 2009) which is far too expensive. But since research is happening around the world it will only be a matter of time until more implementations appear on the market. While the implementation from KAIST looks like it could be commercialized in the near future.

4.2 Relationship with other trends in body sensor networks

While body coupled communication might be able to make body sensor networks more practical it is just one of the components needed to build a viable body sensor network. Other areas of research are the integration of all pieces of the stack onto a single piece of silicon. (Like the group at KAIST did) Another interesting approach currently taken is to try and harvest energy from= the human body.[1] A recent example of this the Human++ research, which looks at combining a number of modern technologies and integrating them into a working body sensor network node. This includes integrated chip design and energy harvesting [13]. But sadly they do not use BCC.

While energy harvesting does not make sense with BSN using radio due to their energy usage, the energy usage of some body coupled communications techniques might make it feasible to actually use energy harvesting to partially power body sensor networks.

5. CONCLUSION

In the paper it is shown that body coupled communications is used in more ways than just a drop in replacement for radio based techniques in body sensor networks. The applications range from very simple and low cost implementations to very advanced communications and just about everything in between. Body coupled techniques opens the door for innovative new ubiquitous computing applications like authentication by touch and low power body sensor networks. Sadly currently body coupled techniques are still stuck in development and are not widely available. But this may change in the near future, with more commercial implementations becoming available. But for simple experimentation it has been shown in the past that it can be done by graduate students with limited budgets [5] [2]. But more advanced implementations currently require integrated circuit manufacturing like used by the group from KAIST or integrated optics used by the NTT group. Making it difficult and expensive to build body coupled networks but this situation might change when more affordable implementations become available of the shelf.

[1] This is not entirely new, kinetic watches already do this.

6. ACKNOWLEDGMENTS

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REFERENCES

[1] H.J. Yoo, S.J. Song, N.Cho, and H.J. Kim. Low energy on-body communication for bsn. In *Body sensors networks 2007*, 2007.

[2] K.Partridge. *Associating Users and Devices using Attention-Correlated Communication*. PhD thesis, University of Washington, 2005.

[3] T.C.W. Schenk, N.S. Mazloum, L. Tan, and P. Rutten. Experimental characterization of the body-coupled communications channel. In *International Symposium on Wireless Communication Systems (ISWCS 2008)*, 2008.

[4] A.T. Barth, Mark A.Hanson, H. C. Powell, D.Unluer, S.G.Wilson, and J.Lach. Body-coupled communication for body sensor networks. In *Proceedings of the ICST 3rd international conference on Body area networks*, 2008.

[5] T.G. Zimmerman. Personal area networks (pan): Near-field intra-body communication. Master's thesis, MIT, 1995.

[6] N. Matsushita, S. Tajima, Y. Ayatsuka, and J. Rekimoto. Wearable key: Device for personalizing nearby environment. In *ISCWC00*, 2000.

[7] M.Shingawa, M.Fukumoto, K.Ochiai, and H.Kyuragi. A near-field-sensing transceiver for intrabody communication based on the electrooptic effect. *IEEE Transactions on instrumentation and measurement*, 53(6), Dec. 2004.

[8] Skinplex website. Available: `http://www.ident-technology.com/index.php?option=com_content&task=blogcategory&id=3&Itemid=4&lang=en` (visited: 2009, May 24).

[9] J.M. Lytle. Networking the human body opens countless doors. Available: `http://www.techradar.com/news/world-of-tech/future-tech/networking-the-human-body-opens-countless-doors-326496` (visited:2009, May 25).

[10] A. Sasaki, M. Shinagawa, and K. Ochiai. Principles and demonstration of intrabody communication with a sensitive electrooptic sensor. *IEEE Transactions on instrumentation and measurement*, 58(2), february 2009.

[11] J.A. Ruiz and S. Shimamoto. Experimental evaluation of body channel response and digital modulation schemes for intra-body communications. volume 1, pages 349–354, June 2006.

[12] L.Cho, L.Chan, J.Bae, and H.Yoo. A 60 kb/s - 10 mb/s adaptive frequency hopping transciever for interferance-resilient body channel communication. *IEEE Journal of Solid state circuits*, 44(3), March 2009.

[13] J.Penders, B.Gyselinckx, R.Vullers, M. De Nil, J. van de Molengraft, F. Yazicioglu, T.Torfs, V.Leonov, P.Merken, and C.Van Hoof. Human++:from technology to emerging health monitoring concepts. Available: http://www2.imec.be/imec_sites/objects/7be71c7cb514f2be8c963ae242994a9a/human___white_paper_jp042008.pdf (visited: 2009, May 24).

[14] J.Yoo, N.Cho, and H.Yoo. Analysis of body sensor network using human body as the channel. In *Bodynets 2008*, 2008.

[15] M. Shinagawa, K.Ochiai, H.Sakamoto, and T.Asahi. Human area networking technology: Redtacton. *NTT Review*, 3(5), May 2005.

[16] N. Kobayashi, A.M. Alshehab, J.A. Ruiz, and S.Shimamoto. Experimental evaluation of detection methods for finger identification schemes based upon intra-body communication. In *ICC '08. IEEE International Conference on Communications*, 2008.