On the Capacitively Coupled Transmission Channel for Body Network Application

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Abstract- Intrabody communication using the human body as the transmission channel enables low-power wireless communication within a body area network. Using intelligent nodes it is expected that condensed information packets are transmitted between nodes reducing the data rate to a few kbit/s. This paper investigates the practical low-frequency transmission quality using capacitive signal coupling via custom-made electrodes. The coupled signal is conducted by the body and a 3 V_{pp} carrier amplitude enables practical transmission with a median bit error rate of around 20% (reduced to 2.5% with 5V_{pp} amplitude) using Manchester coding.

I. Introduction

The current trend towards miniaturization of sensors and circuits for the recording of physiological data and for the control of prosthetic devices in medical rehabilitation and research applications enables multiple devices either being implanted or worn by a patient. The exchange of information between the units is a key factor for interconnecting individual devices into a larger structure such as a body-area-network (BAN) [1]. The local communication signals are transmitted wirelessly to yield maximum patient comfort and to allow unlimited placement of the sensors. Fig. 1 shows the principle network organization for the BAN. Any of the sensors may act as a relay station between a sensor and the central link if a direct connection is not available. A dedicated personal gateway node which is not as power or size restricted as the individual sensor nodes provides data exchange with the external infrastructure and may incorporate standard wireless technology, e.g., ZigBee or Bluetooth [2]. With advancing signal processing capabilities of the individual nodes it is anticipated that the data transmission rate between the nodes decreases: Individual nodes may extract relevant features of the data, e.g. the heart rate from the electrocardiogram (ECG), discard the raw data or store it for later inspection in local memory. The physiological data is thus condensed into an information package that can be sent to the gateway node together with optional timing and synchronization signals. Fig. 2 gives an estimate of the power required to store data in local memory or, alternatively, transmitting it. The color bands indicate the typical range of expected power consumption which clearly depends on the implementation details of the circuit. Whereas NAND-flash based storage is considered as on-chip memory, Multi-Media-Card (MMC) memory includes the power consumed by the memory host controller which results in a consumption which is less dependent on the data rate. The trend suggests that significant power can be saved by reducing the data rate (as expected) and that local storage of large amounts of data becomes increasingly economical compared to its transmission. This paper is concerned with the transmission of relatively low data rates of a few kbit/s using a simple setup which is sufficient for transmitting the reduced command and information data between nodes.

It has been shown that the human body can be used as a transmission channel to wirelessly interconnect a sender and receiver [3]. Either of two principle methods can be used to couple the signal into and out of the body:

1. Galvanic coupling [4]. Two electrodes are placed on the skin and a potential difference is applied across

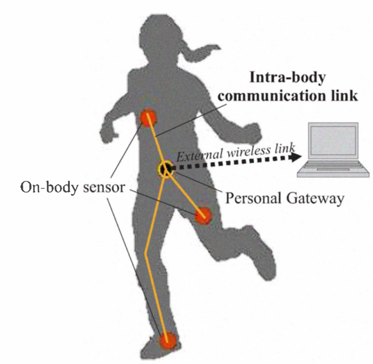

Fig. 1: Principle diagram of the communication paths of a BAN. Wireless intra-body communication connects individual nodes of the network.

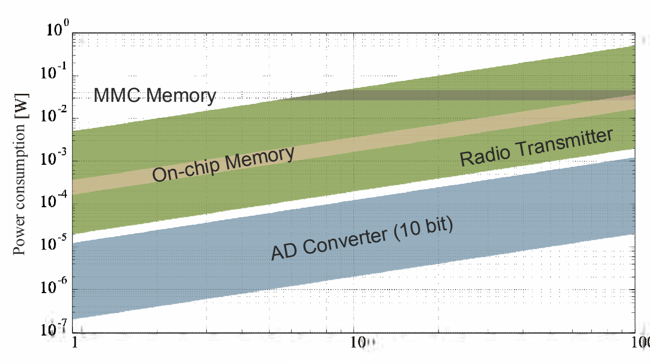

Fig. 2: Power estimate for transmitting and storing data (compared to the consumption of a 10-bit converter).

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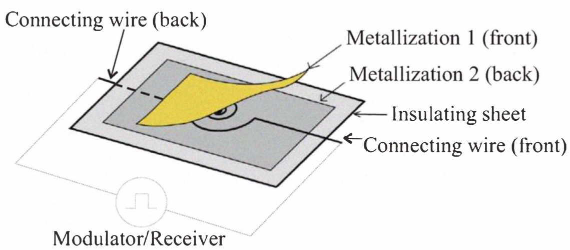

Fig. 3: Diagram of the custom made coupling electrode consisting of an insulation sheet sandwiched between a pair of metal foils.

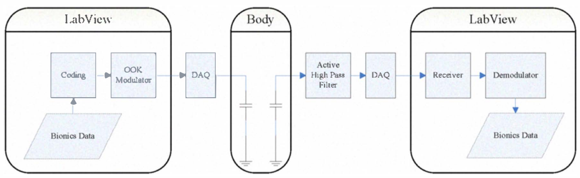

Fig. 4: Block-chart of the measurement setup. Signal coding and decoding is performed using Labview software.

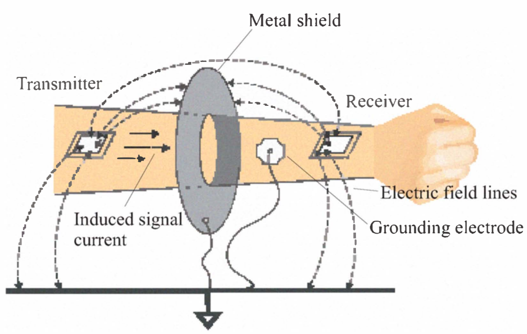

Fig. 5: Measurement setup to determine the transmission path. The shield and electrode are grounded to provide an obstacle for external field lines and conducted current respectively.

them. This causes small currents to flow in the body tissue surrounding the electrodes. The voltage drop caused by these small currents is detected by a second receiving pair of electrodes.

2. Capacitive coupling [5]. In this approach, the transmitter capacitively couples a displacement current through the human body to the receiver. The return path is provided by the "earth ground," which includes all conductors in the environment that are in close proximity to the device. This method of coupling does not require ohmic contact between the electrodes and the skin. Therefore, it can provide functionality even through thin layers of clothing. Also, sheets of protecting material can be brought onto the electrode surface to improve bio-compatibility.

The intra-body communication link using the latter method of coupling is investigated in this paper. Clearly, the body channel characteristics highly depend on parameters such as the distance between transmitter and receiver, grounding, or carrier frequency [10]. Here, we limit the discussion to a practical simple AC-coupled On-Off Keying (OOK) transceiver [6, 7]. Using OOK to modulate the digital data to be transmitted yields a compact and low-power transmission circuit. The feasibility of using capacitive coupling depends on the reliability of the transmission path and the expected transmission error rate. In Section III this paper reports practical measured results on the transmission quality for a carrier frequency of 200 kHz and using Manchester coding as well as direct binary transmission via custom made capacitive electrodes described in Section II. Conclusions are drawn in Section IV.

II. System Setup

Identical electrode types are used for coupling the signal in and out of the body. The custom made electrode consists of a 25 µm thin insulating sheet which is sandwiched between two conductive layers (conducting tape) as shown in Fig. 3. Connecting wires are placed below each conductive layer with their ends coiled to prevent being pulled out accidentally. The metallization measures 15mm x 8mm and yields a capacitance of 520 nF. The transmission signal is applied across the electrode capacitance and the sensed voltage is detected across the receiving electrode. The electrodes are attached to the body using medical tape. The transmitting voltage is generated using a data acquisition card (DAQ) connected to a PC running Labview software. A random digital signal is generated by the software and coded. A 200 kHz square wave carrier is modulated with this signal and applied to the transmitting electrode. A discrete first-order high-pass filter with a cut-off frequency of approximately 10 kHz connects to the receiving electrode. This active filter provides an additional pass-band gain of 17 V/V and serves to remove any electrode offset and power line interference. The filtered received voltage is acquired using another port on the DAQ card. This setup is shown in Fig. 4. Software digitizes the received and amplified analogue signal by comparing it with a threshold level (set to ¼ of the transmitter voltage) and yields the received digital data stream which is then decoded and compared with the originally transmitted data stream.

III. Measured Results

A. Transmission Path

The transmission principle is based on induced currents flowing on the surface of the body from transmitter to receiver [3]. The signal is thus confined to the body. A direct transmission between the electrodes through the air is not intended. To verify this assumption, the coupling mode and quality is examined first. The communication electrode pairs are affixed to the skin of a subject's arm at distance of about 15 cm. The

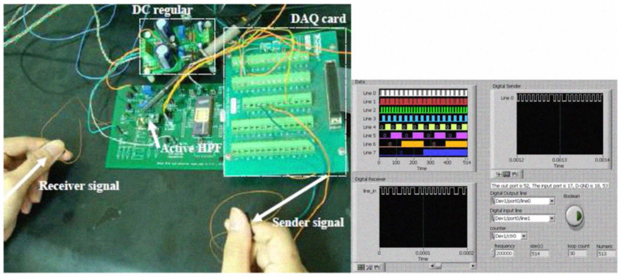

Fig. 6: Measurement setup to determine the BER with signal transmitted between two hands (left). The user interface for test signal generation and decoding after reception (right).

TABLE I: RECEIVED AMPLITUDE FOR A TRANSMITTED 5 V SIGNAL USING DIFFERENT OBSTACLES SHOWN IN FIG. 4. TRANSMISSION DISTANCE IS 15 CM.

Setting / Received Signal	No Obstacle	Grounded Electrode	Shielded	Shielded and Grounded Electrode
Amplitude(Vpp)	110mV	18mV	90mV	14mV

transmission amplitude is 5 V_{pp}. Fig. 5 shows the diagram of the measurement setup. The received amplitude (referred to the input of the filter amplifier) is measured as 110 mV_{pp}. The measured signal loss is thus low compared to the loss of a giga-hertz radio transmitter signal of around 35 dB [8]. In a further step, a grounded metal shield with a diameter of around 25 cm is placed around the arm halfway between the electrodes. The shield is isolated so as not to make ohmic contact with the skin. The metal plate is expected to intercept the majority of the electric field lines between the electrodes which establish a potential parallel signal path through the air. The measured received signal amplitude reduces only slightly to 90 mV_{pp} with the shield in place. This confirms that the signal is predominantly conveyed through the body. Interrupting the signal path through the body should thus reduce the received signal significantly. In a next step, the skin is connected to the ground reference potential using a silver/silver-chloride electrode also shown in Fig. 5. Making this ground connection reduces the measured received signal to 18 mV_{pp} as anticipated. Additional shielding yields a received amplitude of 14 mV_{pp}. Table I summarizes these results.

B. Transmission Error Rate

The bit error rate (BER) is measured using the bench test setup shown in Fig. 6. A volunteer holds onto one of the electrodes with each hand respectively. The signal is sent from the DAQ card through the arm and body. The signal is received via the DAQ card input. The serial output of a binary 8-bit counter is used as the test pattern to test the OOK transmission. The data transmitter user

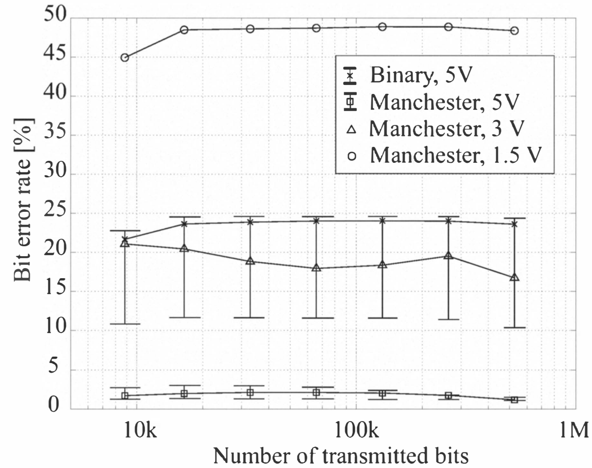

Fig. 7: Measured BER for different coding and carrier amplitudes vs. packet length. Error bars for 5V data indicate min/max values around the median for 4 independent measurements.

interface programmed in Labview is also shown in Fig 6. The interface shows the decimal test data (0-512) coded as binary numbers and, in a separate window, the bit stream placed onto the serial output line. After the signal passed through the body the program obtains the digital readout and decodes it. Clearly, the received binary signal becomes attenuated by the high-pass filter if a long string of successive logic *ones* is transmitted, since this leads to a reduction in the nominal transmission frequency. Manchester coding ensures at least one signal edge for each carrier cycle and is thus a practical solution overcoming this limitation. The BER of the transceiver is measured for different transmission packet lengths between 8,823 and 526,335 transmitted bits. The results are shown in Fig. 7. Initially, the BER is determined using direct binary transmission and using Manchester coding respectively, both with a carrier amplitude of 5 V_{pp}. Four sets of measurements are performed independently at different points in time. The error bars in Fig. 6 show the minimum/maximum error rate and the markers indicate the median values. It is observed that direct binary transmission yields a transmission error rate of around 20%, whereas the error rate for the Manchester coded signal is only around 2.5%. In all measurements the BER does not depend strongly on the packet length. In a next step, the Manchester coded signal is transmitted using different carrier amplitudes of 5V, 3V and 1.5V, respectively. The results, also shown in Fig. 7, suggest that the BER depends over-proportionally and inversely on the carrier amplitude. The error rate is approximately 48%, 20% and 2.5% for amplitudes of 1.5V, 3V and 5V.

Error correcting code can be used to encode the transmission channel and reduce the effective BER at the cost of additional complexity and power consumption due to the encoder and decoder. Since the error rate does not depend on the transmitted block length a convenient length for encoding can be chosen. The performance of the Reed Solomon channel code for physiological data was evaluated in [9] with data from which redundancy was removed prior to transmission by compression. A coding gain around 3 is deemed practical, so that an error rate of below 1% appears achievable with 5V carrier amplitude.

IV. CONCLUSIONS

It is anticipated that data rates in the range of a few kbit/s are sufficient to connect devices in a BAN using intelligent nodes. Simple custom made sheet electrodes are used to capacitively couple a digital signal into the human body and to receive the signal. A suitably simple interface is thus realized. Measurement confirms that successful coupling is achieved with practically all signal being conveyed through the body. Transmission through the air is negligible. Over a distance of 15 cm a signal with 2.2% of the transmitted carrier amplitude is received, sufficient for signal communication. The BER is determined, suggesting that a 3 V_{pp} carrier amplitude yields a median bit error rate of 20%, which improves to 2.5% with a 5 V_{pp} carrier. This error rate is achieved using Manchester coding. Direct binary transmission results in a 12-fold increase in the error rate since long sequences of logic *ones* are attenuated by the receiving filter, making this mode of transmission impractical in this kind of simple setup. Using error-correcting code can yield practical transmission quality using capacitive coupling for BAN communication as long as the body is not in direct contact with a grounding earth potential located between the communicating electrodes.

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