Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp499-500

Energy-Efficient Body Area Network Transceiver Using Body-Coupled Communication

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Abstract

Body Coupled Communication (BCC) utilizes human body itself as a communication medium to provide connectivity between nodes on or around the body. Though the BCC is an attractive Body Area Network (BAN) methodology, it suffers with several challenges to overcome to be commercially viable. These challenges include 1) varying channel gain over space, time and subject, 2) varying environment, and 3) stringent power consumption requirements. This work reviews the issues related to BCC, and several efforts to overcome such issues. An example application that benefits from BCC is also discussed.

1. Introduction

Body Area Network (BAN) [1] forms a network among on/in body sensors to realizing healthcare, medical or multimedia applications. Conventional RF-based wireless standards such as Bluetooth, Medical Implant Communication Service (MICS) are not ideal for medical/healthcare BAN applications due to their limited data rate, high power consumption, and most importantly, body shadowing effects: the human body absorbs the majority of energy in GHz range [2]; the human body acts as a blockage or impeding medium. Textile-based [3] or conductive thread-based [4] wearable BAN are also possible methods, but these limit the deployment location since the network is based on wiring. Body Coupled Communication (BCC) utilizes the human body itself as a transmission medium, and it provides higher data rate (~10Mbps), has low power consumption and is free from Line-of-Sight (LoS) requirement [3]. Despite these superior properties, BCC still faces some practical issues: 1) varying channel gain over space, time and subject, 2) varying environment such as posture, swaying contacts and interference, and 3) stringent power consumption requirements. Recent BCC works are therefore focusing on these practical issues. This paper reviews the methods and efforts in recent works that lead to BCC to become a commercially viable option.

2. Body Coupled Communication Methods

There are largely three mechanisms in BCC: 1) galvanic, 2) magnetic resonance and 3) capacitive coupling (Fig. 1).

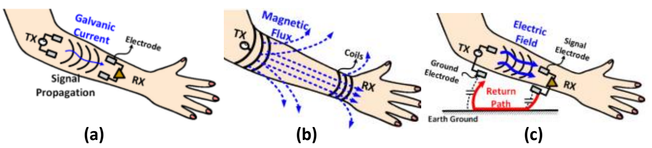

Fig. 1. BCC mechanism: (a) Galvanic [6], (b) Magnetic Resonance 0 and (c) Capacitive coupling [8].

A. *Galvanic Coupling*

Both TX and RX have two electrodes each (Fig. 1 (a)); the differential signal then induces a galvanic current that propagates through the skin [6]. This method is resilient to external environmental variation and reliable; however, due to its high path-loss, it is suitable for short range with limited data rate (~100 kbps). This method is a good choice if communication distance is less than a foot, and a stable communication is necessary.

B. *Magnetic Resonance Coupling*

Magnetic field travels through biological tissue better than electric field does 0. The magnetic resonant coupling exploits this property by adopting two resonant coils around the body as shown in Fig. 1. The coils at TX will generate the magnetic flux, which will be captured at the RX coil. As far as the magnetic resonance is kept constant, this is an energy efficient method. One limitation here is, however, to have the magnetic flux through the body, a coil should be surrounding the TX/RX points (as shown in Fig. 1 (b)); this limits the wearing/attaching points. For example, it is difficult to have a TX or RX around the chest or head. Also, maintaining resonance under motion artifact is another challenge. Regardless of these, if communication is on a limb, and if placing a coil around the TX and RX points is not a burden, the magnetic resonance coupling would be a good option.

C. *Capacitive Coupling [8]*

TX and RX each have a signal electrode each (no explicit ground electrode is present, Fig. 1 (c)). The forward path is through the body, and return path is formed by parasitic ground of TX / RX as well as body in between (Fig. 2). The channel gain measurement shows that the human body shows largely a band-pass characteristic, with channel gain is relatively flat at around 40-120MHz. Since there is only signal electrode with a floating ground, signal shorting is significantly reduced, and less pathloss is present; therefore, more energy is received from RX when compared to galvanic signaling. However, the return path is formed by parasitic ground, which varies over posture, subject, and electrode attachment. This results in a huge fluctuation in RX receiving signal strength, and is a challenge. The capacitive coupling is preferred choice if transmission distance should cover from an entire body, or the form factor requirement does not allow two electrodes (galvanic) or a coil around the point (magnetic resonance).

3. Coping with BCC Challenges

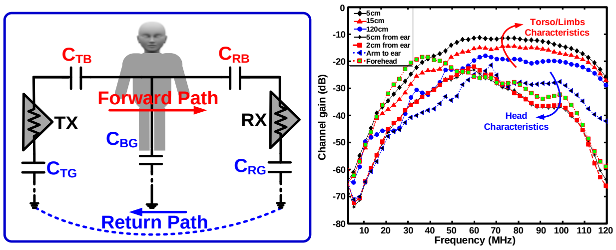

Fig. 2 (left) Simplified model of capacitive BCC, and (right) the channel gain measurement [3].

All three BCC mechanisms are affected by varying channel gain and environmental change, although there is a trade-off between coverage over channel reliability. In specific, channel gain may vary over the subject, posture, and communication distance; this is especially the case for the capacitive coupling, where return path relies on the parasitic ground, and hence the ground amount changes significantly (ground effect [2]). Therefore, without proper compensation, the BCC will be corrupted significantly. To overcome such issues, the TX power and the RX sensitivity can be adapted with a feedback. We can also adopt OFDM at a slight power consumption penalty, or utilize Hybrid (or Pseudo) OFDM method [2],[9] (Fig. 3). It transmits baseband OFDM symbol over an adaptive frequency hopping FSK to mitigate the varying parasitic ground and varying channel gain over time.

It is also important to note that in galvanic and capacitive coupling, electrodes are attached to the human body, and the attaching strength affects the channel gain. To make matters worse, the electrode attachment strength may well change over time, since many BCC applications are mobile and wearable. The RC-Relaxed Contact Impedance Monitor (RRCIM) can mitigate this by detecting the contact impedance change with minimal power consumption [9]. In the band of interest, the capacitive component dominates the skin-electrode impedance; the weaker the contact, the lower the capacitance value. The RRCIM combined with an RX gain adaptation effectively mitigates the skin-electrode impedance change issue.

4. BCC BAN Applications

BCC BAN covers a variety of domains, ranging from healthcare to multimedia applications. Especially, when an application requires communication around the head area, the conventional RF suffers due to body shadowing effect [2]; it is shown that on conventional RF, the binaural hearing aid system needs to use 80% of its power consumption on transceiver only. BCC can mitigate this issue effectively. Another application that can benefit from BCC is healthcare. All three BCC methods are free from LoS requirement, which is a must for a healthcare application; as an example, a patient should not have his/her data lost due to body shadowing effect.

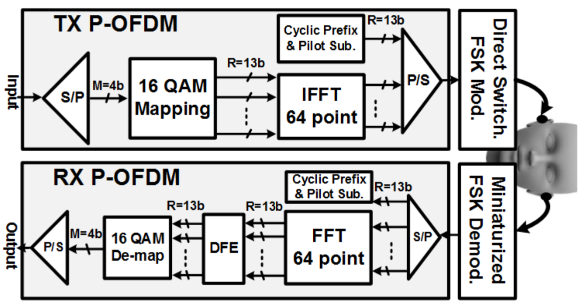

Fig. 3. Pseudo OFDM Transceiver [2].

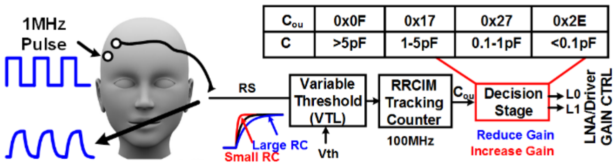

Fig. 4. Skin-electrode impedance monitoring circuit [9].

5. Conclusions

In this paper, we reviewed and compared three different BCC mechanisms for BAN. Galvanic coupling has the least coverage but has the strength in stable and reliable communication strength. Magnetic coupling can cover more area with a stable connection, but requires coils surrounding the TX/RX are, which may not always be possible. Lastly, capacitive coupling has the largest coverage (the whole body area), but with varying channel pathloss. Therefore, proper circuit level compensation is required.

Acknowledgments

This work was funded by the National University of Singapore with WBS No. R263000C62133/R263000C62731. It was also funded by the Semiconductor Research Corporation (SRC) under the ATIC/SRC Center of Excellence for Energy Efficient Electronics Systems (ACE4S), Task Number 2440.008. The authors acknowledge Prof. Wala Saadeh and Mr. Yonatan Kifle for their technical contribution.

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