Power-Efficient Body-Centric Communications

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Abstract

Power-efficient communication based on body-centric textile multi-antenna systems increases the range and autonomy of battery-operated or energy-harvesting systems by allowing reliable communication at very low transmit powers.

Introduction

Wearable textile-antenna communication systems form important support tools for rescue workers during interventions. Such a system provides a reliable communication of data between rescue workers and allows monitoring of activities and life signs at the mobile command centre, allowing improved safety and efficiency of the interventions. Garments provide excellent platforms for energy-efficient communication systems.

A practical wearable communication system consists of sensors and actuators connected to a wireless transceiver equipped with textile antennas. Textile antennas are robust, easily integrated into clothing and also provide excellent radiation characteristics when operating on the human body. Active textile antennas, having a low-noise amplifier integrated on the antenna's feed substrate, can even further improve their performance.

Low-power wireless communication is important for battery-operated or autonomous systems. When setting up a communication link in an indoor environment, the propagated signals experience fading and shadowing. As fading and shadowing are only partially correlated for different on-body antennas, diversity techniques are capable of drastically improving the reliability of the communication.

In case of body-centric communication, multiple textile antennas can be deployed conveniently inside a garment. The communication link can then be enhanced by relying on MIMO- or beam forming techniques, allowing much lower transmit powers to obtain a prescribed bit error rate at the receiver. Low-energy signal processing algorithms also open possibilities for low-power receiver implementations.

Energy-efficient wearable textile antennas

Wearable textile antennas are robust system components offering high radiation performance. These antennas are comfortable for the user as the antenna patch is completely composed of flexible materials and is flat, breathable and washable. Seamless integration into clothing comes naturally.

The electrical characteristics of textile antennas are excellent, provided suitable materials are used:

- Low-loss and low moisture regain materials for the substrate allow high radiation efficiency.
- Highly-conductive electro-textiles for the conducting elements.

At the microwave frequency bands, the garments offer ample space for implementation of multiple half-wavelength antennas with reproducible and stable antenna characteristics.

Additionally these antennas can be fire-resistant, water-repellent and shock-absorbing. As an extra protection from the environmental conditions, the antenna is commonly integrated inside the garment, underneath the outer moisture and thermal barriers. Figure 1 displays such a textile antenna.

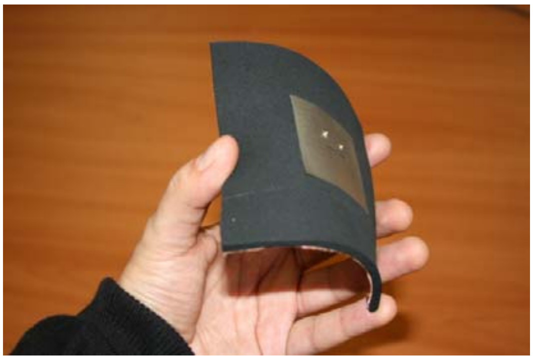

Figure 1: A dual-polarized textile antenna.

For energy-harvesting equipment, it is important that the wireless transceiver does not cause excessive energy consumption for the system. Even for battery-operated wearable systems, power requirements should be kept to a minimum, as flexible lightweight batteries are typically used. Hence, the wireless system should be designed for maximum energy efficiency.

The ground-plane of the textile microstrip patch antennas ensures stable characteristics when the antenna is deployed on the human body, concentrating the energy in the directions away from the body and limiting the body's radiation exposure.

Wearable patch antenna arrays offer the additional possibility of off-body beam forming, concentrating the radiated power towards the receiver. Confining the radiated beam to low elevation angles provides significant array gain to users on the same altitude and also reduces the number of multipath components as well as the resulting fading fluctuations.

A further optimization of the antenna-transceiver RF-link is realized by using an active-antenna topology, integrating a low-noise amplifier on the antenna feed substrate. Noise matching or impedance matching can be applied to achieve optimal receiver performance. An example of an active textile antenna is shown in Figure 2.

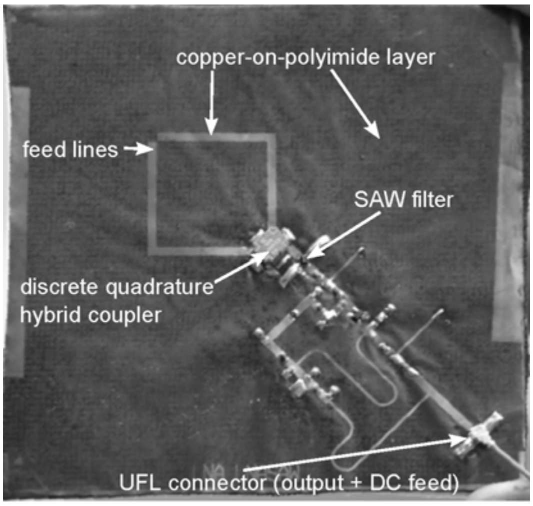

Figure 2: An active textile antenna.

Energy-efficient body-centric communication links

In conventional wireless links, employing only one antenna at each side of the connection, the indoor environment is very challenging for the system's performance. Adverse propagation conditions, including fading as well as shadowing, lead to very low-quality links requiring high signal-to-noise ratios – and hence a large transmit power – to ensure low bit error rates at the receiver.

In case of body-centric communication, additional shadowing occurs when the human body is situated between the antenna and the base-station, causing a severe extra attenuation of the signal.

Employing front and back antenna patches at the body can drastically reduce these phenomena by means of spatial as well as pattern diversity, such that only one antenna patch is expected to be shadowed by the body at any given time.

Additionally, the use of dual-polarized antenna patches allows the excitation of two orthogonally polarized waves by means of a single patch, doubling the diversity order in a convenient fashion.

Space-time coding for transmit diversity: body-centric MIMO communication

A body-centric system with two dual-polarized textile antennas located at the front and back allows full coverage of two orthogonal hemispheres around the body, creating fourth-order diversity in an indoor multipath propagation environment. This dual-pattern / dual-polarization diversity system operates in receive- as well as transmit-mode, using maximal ratio combining or space-time coding, respectively, and resulting in a 4x4 MIMO communication link.

The effect of the diversity order on the performance of the communication link was studied for persons of significantly different body sizes, showing that significant system gains are achieved for all test persons, with higher gains corresponding to the larger diversity orders, as illustrated in Table 1.

Note that nearly 20dB system gain is achieved for the median 4x4 link compared to the median 1x1 link in all cases, reducing the power requirements by almost a factor 100 for a 10% outage probability.

Size	Length [m]	Weight [kg]	1x1 SISO [dB]	2x2 MIMO [dB]	4x4 MIMO [dB]
S	1.67	52	26.3	37.7	45.2
M	1.75	73	24.8	36.7	44.1
L	1.85	104	28.0	38.8	46.2

Table 1 : Median received E_b/N_0 for 10% outage probability in the 1x1 SISO, 2x2 and 4x4 MIMO cases measured in non line-of-sight conditions, for persons of different body sizes.

For the implementation of a practical body-centric wireless communication system, further challenges remain as the performance of the signal combining using space-time coding strongly depends on the accuracy of the channel estimation, an accuracy that degrades for decreasing signal-to-noise ratios. The latter effect can be mitigated by employing a larger number of pilot symbols, however, causing more overhead and hence a lower effective data throughput. Data-oriented tracking of the time-variant channel provides an effective solution with less pilot-symbol overhead.

Body-centric zero-elevation beam forming

Alternatively, beam forming can be employed at the transmitter instead of space-time coding. Theoretically dynamic beam forming is optimal but unfortunately requires high-rate channel information feedback which is generally not available. Static zero-elevation beam forming was studied as a low-cost solution to concentrate more radiated power towards receivers on the same floor of a building.

The performance of beam forming and space-time coding were compared experimentally in equal propagation conditions, using a vertical four-element textile antenna array at the human body and a four-element dipole array at the receiver. Figure 3 displays the textile antenna array used in the experiments.

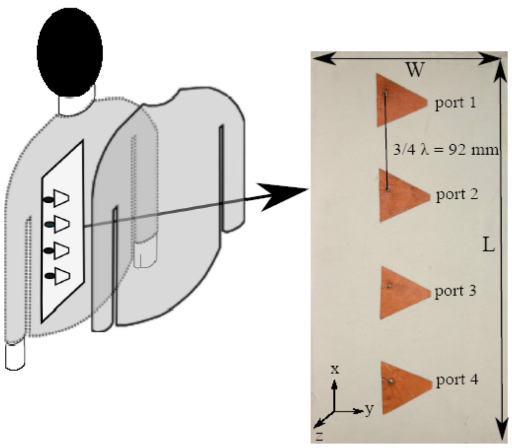

Figure 3: Four-element textile patch array.

The efficiency of the off-body beam forming is confirmed by measurements, in both anechoic and indoor environments. Measurements in line-of-sight as well as non line-of-sight in an indoor environment lead to the following interesting observations:

- Front and back antenna arrays are necessary to mitigate the shadowing by the human body.
- Larger average received signal levels result for beam forming, compared to space-time coding, in line-of-sight as well as non line-of-sight propagation conditions.
- In case of beam forming, receiver diversity is necessary to counter signal fading and to compensate for the absence of diversity at the transmitter.

In case of fourth order receiver diversity, the experiments demonstrate comparable performance for beam forming and space-time coding systems.

Beam forming systems, however, can be implemented using simple phase shifters, hence providing a low-cost solution compared to space-time coding.

Conclusions

For wireless off-body communication links, reliability and power-efficiently go hand in hand. MIMO and beam forming techniques provide system gain at the transmitter, whereas diversity techniques – at the transmitter, receiver or both – limit the signal fading which is detrimental to the reliability of the communication.

The large platform that garments have to offer can be exploited by integrating wearable antennas into clothing. Combined polarization and pattern diversity can be realized using space-time coding for diversity. Static low-elevation beam forming can achieve similar performance in case of receiver diversity at lower power consumption, thanks to the simpler hardware and absence of extra processing at the transmitter.

Acknowledgements

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