Modulation Schemes in Ambient Backscatter Communication

[Extended Abstract]

Oliver Harms
Chalmers University of Technology
Gothenburg, Sweden
mail@oliverharms.eu

ABSTRACT

This paper presents a low-cost backscatter system using off-the-shelf components. It uses simple modulation schemes and is usable with a constant carrier as well as with ambient television signals as carrier.

The evaluation of the system shows that ranges of up to 225 m are coverable in line-of-sight environments using a constant carrier. Furthermore, it is usable with ambient TV signals with bit error rates as low as 10^{-3}. These results show that this backscatter system outperforms state-of-art backscatter systems.

KEYWORDS

Backscatter communication, Internet of Things, Wireless

1 INTRODUCTION

In the world of Internet of Things (IoT) low power communication is more and more important. One way to reduce power needs to a bare minimum is backscatter communication. However, many backscatter systems use expensive hardware.

This project presents a backscatter system with sensor tags using different modulation schemes to transmit data receivable by off-the-shelf radio chips. Figure 1 gives an overview over such a system. For studying the best possible performance of this setup, a constant carrier is needed generated by an Software Defined Radio (SDR). But the ultimate goal is to even remove this carrier and use ambient TV signals for communication. Those signals are available almost everywhere and would therefore be the optimal carrier for a cheap backscatter solution.

2 BACKGROUND

Backscatter communication. Backscatter communication is a passive communication method not requiring to actively generate RF signals. Instead the radar cross-section (RCS) of the antenna of the backscatter tag is modulated to either absorb or reflect a carrier signal. This modulation of the RCS is performed by changing the impedance of the antenna circuit between two states.

To communicate on a frequency different to the frequency of the carrier signal, a shifting operation in addition to the RCS modulation is performed. This is achieved by multiplying the carrier signal with a square wave generated by the circuit of the backscatter tag. The frequency of this square wave is the required offset Δf, between the carrier frequency f_c and

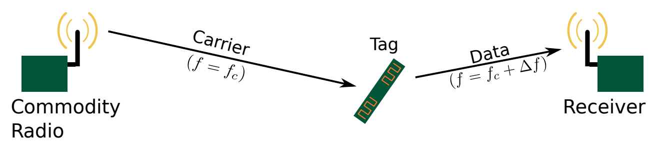

Figure 1: Backscatter System. Shift of carrier signal to avoid self interference. Data encoding on shifted signal.

the desired frequency. The backscattered signal has the form

$$2 \sin ft \sin \Delta f_c t = \cos(f_c - \Delta f)t - \cos(f_c + \Delta f)t.$$

This means that the backscattered signal is shifted to the frequencies $f_c + \Delta f$ and $f_c - \Delta f$ [3, 6].

TV signals. Terrestrial television signals are available in the most places and transmitted continuously. Therefore they are theoretically usable as a carrier signal. The terrestrial TV signals available in Europe and many other places worldwide are DVB-T signals using the signal format OFDM with a maximum bandwidth of 8 MHz [2, 4].

3 DESIGN

The design presented in Figure 1 consists of three parts. The carrier generator, a SDR in this project, a backscatter tag and a receiver.

The receiver used is a CC2500 transceiver of Texas Instruments. Its task is to receive and decode the backscattered data. It supports different modulation schemes like Frequency-Shift-Keying (FSK) and On-Off-Keying (OOK) with bitrates between 1.2 and 500 kbps [5].

The backscatter tag consists of the Analog Devices RF switch HMC190BMS8 as its front-end and a BeagleBone Black as its back-end. The BeagleBone has a programmable real-time unit (PRU) and is therefore able to execute time-critical software. This makes it possible to backscatter data using FSK and OOK with a frequency offset of over 2 MHz and a deviation for FSK of ∼95 kHz without using an FPGA [1].

4 EVALUATION

The evaluation begins with experiments in a line-of-sight outdoor environment using a constant carrier. From the first experiments on FSK showed much better performance than

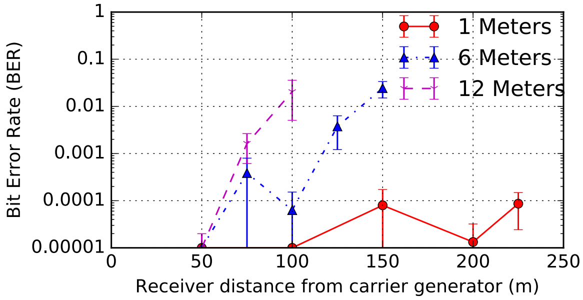

Figure 2: Low bitrate (2.9 kbps) with tag close to the carrier generator (outdoors). High range achievable by placing the backscatter tag close to the carrier generator.

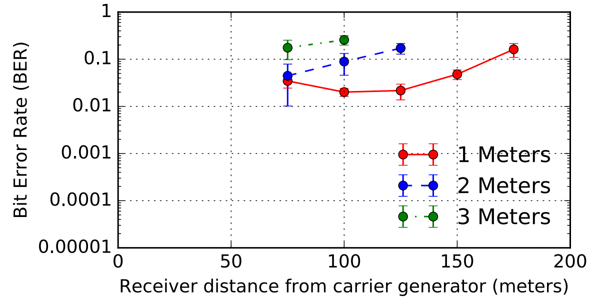

Figure 3: High bitrate (197 kbps) with tag close to the carrier generator (outdoors). The achievable range is smaller than for low bitrates and more errors are introduced.

SNR	0	8	16
FSK (constant)	0.01	0.0001	0.00001
OOK (constant)	0.1	0.01	0.001
FSK (TV)	0.1	0.08	0.003
OOK (TV)	0.2	0.1	0.001

Table 1: Bit error rate of OOK and FSK for different carrier signals and signal-to-noise ratios.

OOK which was expected. Therefore experiments evaluating the maximum possible performance of the system were performed for FSK only.

Figure 2 shows the results for short distances between the carrier generator and the backscatter tag using a bitrate of 2.9 kbps. It shows that distances of 225 m, 150 m or 100 m between the carrier generator and the receiver are reachable depending on the tag placement. In the most cases the BER is below 10^{-2}. Figure 3 shows results for a high bitrate of 197 kbps. Even for this bitrate distances of up to 175 m are coverable with small distances between the carrier generator and backscatter tag. The better performance for a placement of the tag close to the carrier generator is common for backscatter systems and an explanation of it can be found e.g. in [3].

To study the performance of TV signals as carrier, a DVB-T signal was recorded and replayed in the 2.4 GHz ISM band. This was necessary to compare both carrier systems using the same receiver. For this comparison both modulation schemes OOK and FSK were used. Due to the low signal strength of maximally -40dBm of the replayed signal, only short distances were coverable and therefore the comparison was done based on the signal-to-noise ratio. Table 1 shows the bit error rate for different signal to noise ratios using FSK or OOK with a constant carrier or a TV signal as carrier. The results are that OOK with a constant carrier and both modulation schemes with a TV signal as carrier show overall comparable performance whereas FSK with a constant carrier shows much better performance. Generally speaking, a TV signal as carrier is usable especially for SNR values of 16 or more.

5 CONCLUSION & FUTURE WORK

This paper presents a backscatter system which is capable of achieving ranges beyond 200 m with off-the-shelf components using a constant carrier. Moreover, it shows that using TV signals as carrier is possible with bit error rates below 10^{-2}.

In future work, a sub-GHz receiver should be used to build a backscatter system working directly with TV signals and evaluating possible ranges coverable with such a system.

REFERENCES

[1] beagleboard.org. 2015. PRU-ICSS Resources. (2015). Accessed 18-07-2017. http://beagleboard.org/pru.

[2] electronicsnotes. [n. d.]. What is DVB-T: Digital Video Broadcasting. ([n. d.]). Accessed 18-07-2017. https://www.electronics-notes.com/articles/audio-video/broadcast-tv-television/what-is-dvb-t-basics-tutorial.php.

[3] Bryce Kellogg, Vamsi Talla, Shyamnath Gollakota, and Joshua R. Smith. 2016. Passive Wi-Fi: Bringing Low Power to Wi-Fi Transmissions. In *NSDI 16*. 151–164. https://www.usenix.org/conference/nsdi16/technical-sessions/presentation/kellogg

[4] Vincent Liu, Aaron Parks, Vamsi Talla, Shyamnath Gollakota, David Wetherall, and Joshua R. Smith. 2013. Ambient Backscatter: Wireless Communication out of Thin Air. In *Proceedings of the ACM SIGCOMM 2013 Conference on SIGCOMM (SIGCOMM '13)*. 39–50. https://doi.org/10.1145/2486001.2486015

[5] Texas Instruments. [n. d.]. CC2500. ([n. d.]). Accessed 18-07-2017. http://www.ti.com/lit/ds/symlink/cc2500.pdf.

[6] Pengyu Zhang, Dinesh Bharadia, Kiran Joshi, and Sachin Katti. 2016. HitchHike: Practical Backscatter Using Commodity WiFi. In *Proceedings of the 14th ACM Conference on Embedded Network Sensor Systems CD-ROM (SenSys '16)*. 259–271. https://doi.org/10.1145/2994551.2994565