Interference Cancellation for Coexisting Wireless Data and Power Transmission in the Same Frequency

Keita Yamazaki[1], Yusuke Sugiyama[1], Yoshihiro Kawahara[2], Shunsuke Saruwatari[1], Takashi Watanabe[3]

[1]Graduate School of Informatics, Shizuoka University, Japan
[2]The department of Information and Communication Engineering, The University of Tokyo, Japan
[3]Graduate School of Information Science and Technology, Osaka University, Japan

E-mail: [1]{yamazaki, sugiyama}@aurum.cs.inf.shizuoka.ac.jp, saru@inf.shizuoka.ac.jp, [2]kawahara@akg.t.u-tokyo.ac.jp, [3]watanabe@ist.osaka-u.ac.jp

Abstract. Combining wireless transmission of data and power signals enables wireless sensor networks to drive perpetually without changing batteries. To achieve the simultaneous data and power transmission, the present paper proposes power signal interference cancellation for wireless data and power transmission at the same time in the same frequency. We evaluate the performance of the proposed power signal interference cancellation using Universal Software Radio Peripheral N200 (USRP N200) software defined radio. Evaluations show that the proposed interference cancellation is feasible to receive data while transmitting power.

1. Introduction

Various devices are connected to wireless networks and exchange various information with other devices. Wireless power transmission [1] enables wireless devices to be powered permanently without the need for changing and charging batteries. The combination of wireless data and power transmission will lead to the invention of new types of wireless devices.

In this study, we use radio waves as the transmission medium as they offer two advantages: (i) long transmission distance and (ii) little calibration effort. The present paper focuses on the simultaneous data and power transmission in the same frequency to mitigate the depletion of radio resources. However, the simultaneous data and power transmission induces much interference between the data and power signals.

The present paper proposes power signal interference cancellation to achieve the simultaneous transmission even if the interference occurs. The interference cancellation subtracts a power signal from a received signal. To evaluate the performance of the proposed interference cancellation, we built an initial experiment using USRP N200 software defined radio [2] with a USRP hardware driver (UHD) [3] and C++. The evaluations show that the proposed interference cancellation reduces the power of power signal by 20 dBm at maximum.

2. Power signal interference cancellation

Figure 1 shows the final goal of our study. We assume that multiple access points are capable of transmission and reception at the same time in the same frequency. The access points cooperatively transmit data and power signals to wireless sensor nodes over a wireless network.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

The wireless sensor nodes send back a data signal using the received and charged power. At each access point, the transmitted data signal from each sensor node collides with its own transmitted power signal. To extract the data signal from the collided signal, each access point needs to use interference cancellation. However, the conventional interference cancellation only assumes a collision occurred by data transmissions [4]. To handle a collision occurred by data and power transmission, this paper proposes power signal interference cancellation. The proposed interference cancellation subtracts a known power signal from the collided signal to extract a data signal.

3. Implementation of sender and receiver

3.1. Overview

Figure 2 shows the experimental setup for the proposed interference cancellation. The experimental setup consists of two senders TX_1 and TX_2, one receiver RX, three control computers, and a Fury desktop used as an external clock. The senders and the receiver were implemented by USRP N200s and connected to each control PC (Panasonic Let's note CF-B11). To reduce frequency offsets among the USRPs, a 10-MHz signal was input from the Fury desktop to all USRPs.

Figure 3 shows transmitted and received signals as a function of time. TX_1 periodically sends an Orthogonal Frequency-Division Multiplexing (OFDM) signal as a data signal. TX_2 continuously sends a sine wave as a power signal. The details of the transmission signals are described in §3.2. The OFDM signal collides with the power signal at RX. RX extracts the OFDM signal by subtracting the power signal from the collided signal and decodes the extracted OFDM signal. The details of the receiver operation are described in §3.3.

3.2. Transmission signal

TX_1 sends an OFDM signal as a data signal. The number of subcarrier is 52 and the length of Fast Fourier Transform (FFT) is 64 to consider a guard band. We used three known OFDM symbols as preambles for frame detection and channel estimation. First OFDM symbol assigns known preamble values to the odd-numbered subcarrier to detect the start position of the frame by the self-correlation function. After Inverse FFT (IFFT), the first half of the first OFDM symbol is the same as the second half of the first OFDM symbol. Second and third OFDM symbol assign known preamble values to the 52 subcarriers for channel estimation. After the preambles, we assign modulated constellations to 48 subcarriers as data symbols and Binary

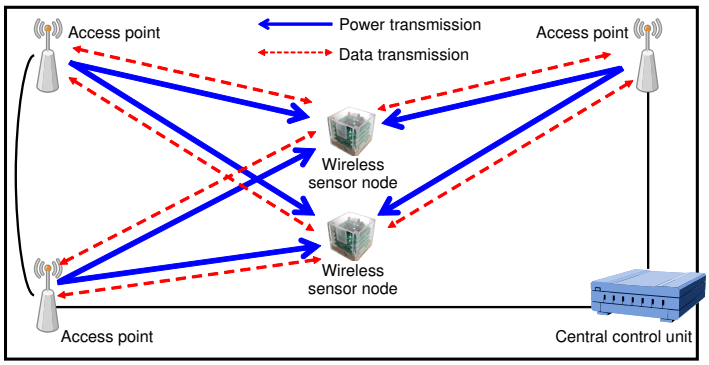


Figure 1. Final goal

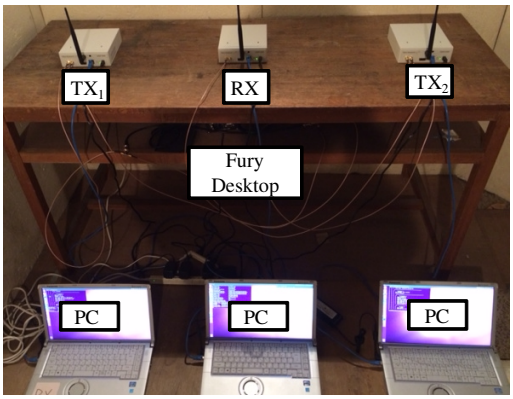


Figure 2. Experimental setup for power signal interference cancellation

Phase-Shift Keying (BPSK) signals to 4 subcarriers as pilot symbols. After IFFT, we copy 16 samples as cyclic prefix from the last to the first to mitigate Inter-Symbol Interference (ISI).

TX_2 sends a sine wave as a power signal. The sine wave $y[n]$ is described as follows:

$$y[n] = A\left(\cos\left(\frac{2\pi n}{N}\right) + i\sin\left(\frac{2\pi n}{N}\right)\right) \quad (1)$$

where n is the number of sample points, A is amplitude, and N is the number of samples in a symbol.

3.3. Receiver operation

Figure 4 shows the receiver operation to extract a data from a collided signal. The operation consists of 1) reproduction of a power signal, 2) extraction of a data signal, 3) symbol synchronization of an OFDM signal, 4) OFDM demodulation, 5) BPSK demodulation.

1) The receiver extracts samples from the received power signal and reproduces a power signal when a sender sends only a power signal. To reproduce the power signal, the receiver estimates the amplitude of the power signal by two level estimation: coarse estimation and fine estimation.

The coarse estimation extracts N samples in Eq. (1) from the received signal. The receiver regards the biggest amplitude in the samples as the estimated amplitude of the power signal. Note that we assume that N is the known value.

The fine estimation reproduces the power signal based on the estimated amplitude. The reproduced power signal approximates to the received power signal. The reproduction consists of three steps. First, the receiver adds the value from -0.01 to 0.01 in steps of 0.0001 to the estimated amplitude and lines up candidates for the amplitude of the power signal. Second, the receiver substitutes each candidate for amplitude A in Eq. (1) and generates a sine wave of one wavelength as a candidate of the power signal. Third, the receiver determines the amplitude, which achieves Minimum Mean-Squared Error (MMSE) between the generated sine wave and the received signal. To calculate MMSE, the receiver needs to detect the start position of the calculation. The receiver generates a sine wave based on Eq. (1) using the estimated amplitude in the coarse estimation. The receiver calculates MMSE between the generated sine wave and the received signal, which is shifted 0–N samples. After the calculation, the receiver detects the start position, which achieves the minimum MMSE.

2) The receiver subtracts the reproduced power signal in 1) from the received signal to obtain a subtracted signal. Figure 5 (a), (b), and (c) show the received signal, the generated power signal, and the subtracted signal, respectively.

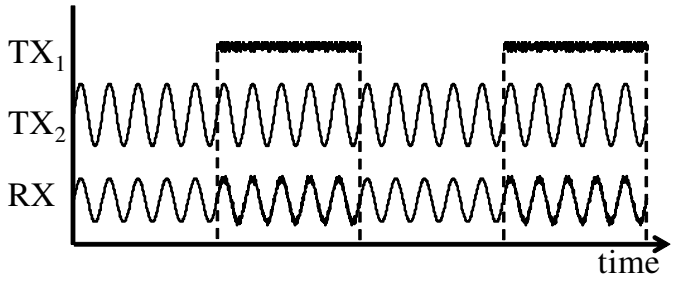


Figure 3. Transmitted and received signals as a function of time

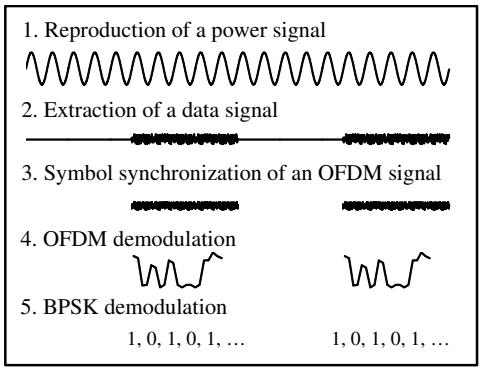


Figure 4. Receiver operation

3) After the subtraction, the receiver detects a frame. The receiver uses the first preamble of the subtracted signal to detect the frame. Since the first half of the first OFDM symbol is the same as the second half of the first OFDM symbol, 48 samples in the first OFDM signal is the same as 48 samples in the half-wave delayed OFDM signal. The receiver calculates the self-correlation of two signals for half-wave length by convolutional integral. After the calculation, the receiver detects peaks in the cyclic prefix. However, when the received power is large and the Auto-Gain Control (AGC) does not converge, the receiver detects a wrong peak. To prevent the detection of the wrong peak, the receiver normalizes the value of self-correlation by dividing by the received power. By calculating the moving average for the normalized self-correlation among 16-samples window, a peak appears in the start position of the frame. The receiver detects the peak based on a threshold obtained by experimental measurement and determines the start position of the frame.

4) The receiver removes the cyclic prefix and extracts a signal on subcarriers by FFT. The receiver removes the first 16 samples from each symbol, which are the cyclic prefix, based on the start position of the symbol synchronization of an OFDM signal.

5) The receiver obtains a bit stream from the extracted signal. When the real value of the extracted signal is greater than 0, the receiver decodes 1. On the other hand, when the real value is smaller than 0, the receiver decodes 0.

4. Evaluation

We evaluated power signal interference cancellation operating in 5.11-GHz band at the anechoic chamber in Shizuoka University, Japan. The sampling rate is 195.3125 ksps. The payload size of the OFDM signal is 1500 bytes. Power-signal samples were fixed at 500 samples.

Figure 6 shows the Bit-Error Rate (BER) as a function of Signal-to Noise Ratio (SNR). The evaluation compared theoretical values in additive white gaussian noise (AWGN) channel with experimental results. The power ratio between the OFDM signal and the power signal was -31.23–-5.57 dB. If BER is zero, we plotted 10^{-5} for convenience sake. Figure 6 shows that the digital cancellation is successful because the experimental results approach to the theoretical results.

Next, we evaluated the decoding rate as a function of the power ratio. To analyze the difference in performance between cancellation of a known power signal and an unknown data signal, the decoding rates of conventional and our implemented interference cancellation of the power signal were compared.

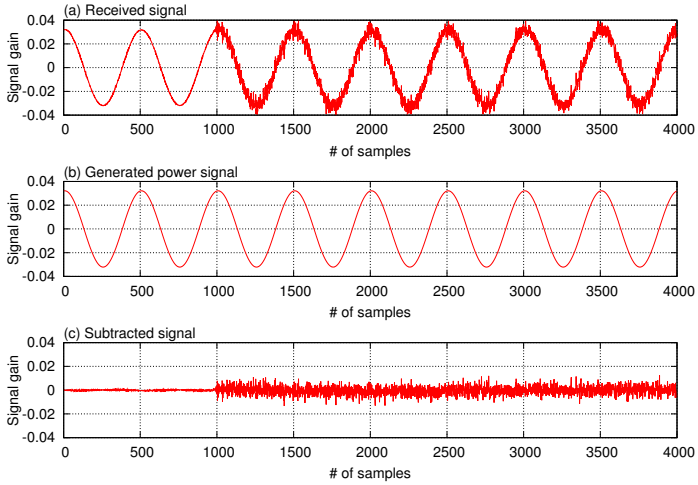


Figure 5. Signal before and after subtraction

Figure 7 shows the decoding rate as a function of the power ratio between the two signals. Data and power are proposed for power signal interference cancellation, whereas only data signals are used in conventional SIC. We calculated the power ratio with the received-signal strength indicator (RSSI) of the two signals, P_{a} and P_{b} as $10\log(P_{\mathrm{a}}/P_{\mathrm{b}})$. In the data and power signal scenario, P_{a} and P_{b} are the RSSI of OFDM and power signals, respectively. In the data only scenario, P_{a} and P_{b} are the RSSI of weak and strong OFDM signals, respectively. Figure 7 shows the following:

(i) The decoding rate is small when the power ratio is small. The dynamic range of the data signal becomes smaller because AGC controls the gain based on the power signal. When the power ratio is small, the RSSI of the power signal is larger than that of the data signal. For example, when the power ratio is −30 dB, the RSSI of the power signal is 1000 times larger than that of the data signal.

(ii) The decoding rate of data and power achieved is 100% when the power ratio is higher than approximately −20 dB. This means that digital interference cancellation is successful when the RSSI of the power signal is about 100 times larger than that of the data signal. When the power ratio is smaller than −20 dB, the receiver needs to combine analog interference cancellation [5] to receive the data signal.

(iii) The decoding rate of data and power achieved is larger than that achieved with data and data. Unlike the waveform of a power signal, the waveform of a data signal is unknown. When the decoding of a strong data signal fails, the decoding of a weak signal also fails automatically.

5. Conclusions

The present paper proposed power signal interference cancellation for wireless data and power transmission at the same time in the same frequency. Currently, we study a frequency sharing protocol to improve frequency utilization by intentional collision of data transmission and electric power transmission.

References

[1] Bieler T, Perrottet M, Nguyen V and Perriard Y, *IEEE Transactions on Industry Applications* pp 1266–1272, 2002.
[2] Ettus Research, USRP N200/N210 Networked Series, 2012.
[3] Blum J, *In GNU Radio Conference (GRC'11)*, 2011.
[4] Halperin D, Anderson T and Wetherall D, *Proceedings of the 14th ACM Annual International Conference on Mobile Computing and Networking (MobiCom'08)* (San Francisco, California) pp 339–350, 2008.
[5] Jain M, Choi J I, Kim T M, Bharadia D, Seth S, Srinivasan K, Levis P, Katti S and Sinha P, *Proceedings of the 17th ACM Annual International Conference on Mobile Computing and Networking (MobiCom'11)* (Las Vegas, NV) pp 301–312, 2011.

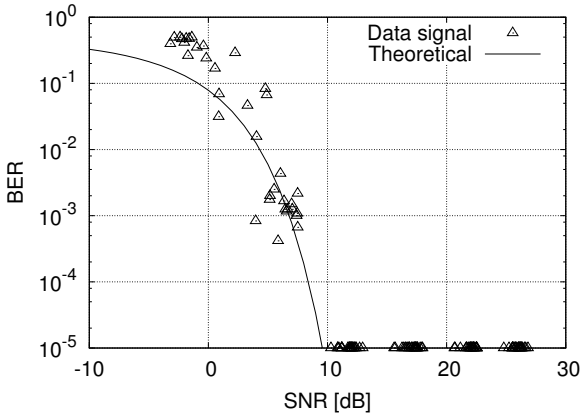


Figure 6. BER as a function of SNR

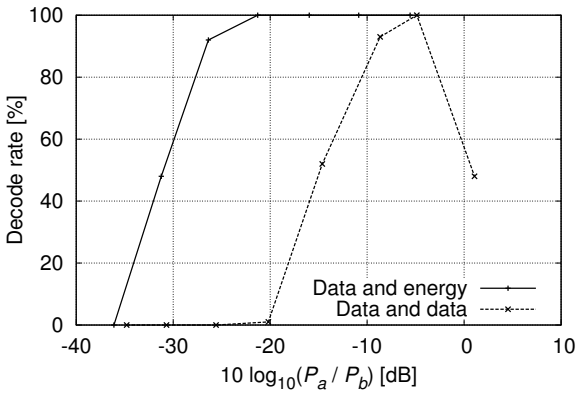


Figure 7. Decoding rate as a function of power ratio between OFDM signal and power signal