Transmission Frequency Optimization for Ultra-low Power Short Range Wireless Communications

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ABSTRACT

Analysis is introduced which determines the optimal transmission frequency for maximum power transfer across a short-range wireless link. This essentially consists of a comparison between two transmission methods known as near-field and far-field transmission. Constraints on antenna dimensions and the required transmission distance strongly influence the choice of frequency. Preliminary results for coil antennas of varying dimensions have been presented in the form of a surface plot. This illustrates the regions of superior power transfer for the two transmission methods depending on application parameters, thus enabling an optimal frequency to be chosen.

Keywords

Wireless, ultra-low power, near-field, far-field, antennas

INTRODUCTION

The ubiquitous computing paradigm envisages dense wireless networks connecting nodes of varying computational power. Central to this vision is the apparent invisibility of many of these devices to the user, who is aware of, but is not inconvenienced by their presence. This requirement places stringent limits on the acceptable size and weight of devices and encourages the embedding of network nodes into everyday objects. Even more challenging is that apparent invisibility demands minimal power consumption. A short battery lifetime for the nodes of a dense wireless network is completely impractical for the user, yet the battery capacity is limited by the size restrictions. Ultimately these devices should be self-powered, perhaps using either solar cells or vibration-to-electrical energy converters. This becomes conceivable when nodes begin to consume less than 100 microwatts [4].

For those nodes that act as sensors, have limited computational power, or whose main function is simply to relay the incoming data to the following node it is the RF communications that will likely dominate the power consumption. Equally the main limitation to size reduction will be the required antenna dimensions. Electrically small antennas (that is antennas, whose dimensions are much smaller than the wavelength) have exceptionally poor efficiency, inferring that small antenna dimensions require a high transmission frequency. It must be realized however that the power dissipated by the electronics increases with frequency [6]. The optimization of the above factors to minimize power consumption is thus necessary in the pursuit of an ultra-low power radio link for ubiquitous computing networks.

ANTENNA FIELD REGIONS

Three field regions surround a transmitting antenna [3], two of which need to be considered here. The reactive near-field contains stored energy in either an electric or magnetic field depending on antenna type. Conversely the propagation of energy as electromagnetic waves takes place in the far-field.

The field region in which the receiver lies is essentially determined by the transmission frequency for a particular transmission distance. The relationships governing the power transfer from transmitter to receiver differ substantially depending upon the field region. These must be fully analyzed to determine the application parameters for which low frequency near-field transmission outperforms high frequency far-field transmission in terms of transmitter to receiver power transfer.

MODELLING POWER TRANSFER

Far-field transmission can be modelled using the well-known Friis transmission formula [2] [3]:

$$\frac{P_{RX}}{P_{TX}} = p\,\eta_{TX}\eta_{RX}D_{TX}D_{RX}\,\frac{\lambda^2}{(4\pi x)^2} \qquad (1)$$

x is the transmission distance, λ the wavelength and p is the relative antenna polarization factor. η and D represent the standard antenna parameters of radiation efficiency and directivity respectively. Subscripts TX and RX distinguish between transmitter and receiver parameters.

A similar power transfer relationship (shown below) has been derived for the near-field case. The validity of this equation requires poor coupling between transmitter and receiver, which is generally the case since the transmission distance is significantly larger than the antenna dimensions for most applications.

$$\frac{P_{RX}}{P_{TX}} = p\,\frac{N_{TX}^2 N_{RX}^2 \pi^2 r_{TX}^4 r_{RX}^4 \omega^2 \mu_0^2}{16 R_{TX} R_{RX} x^6} \qquad (2)$$

for two antenna coils of N_{TX} and N_{RX} turns with radius r_{TX} and r_{RX} respectively. ω is the angular frequency and μ_0 is the permeability of free space.

Antenna Modelling

To evaluate these two expressions the antenna parameters for the two transmission methods have to be modelled. Preliminary analysis has concentrated mainly on loop (coil) antennas due to their benefit in the design of ultra-low power transmitter architectures [7]. Of great importance are the two dissipative elements in the coil - the loss resistance, R_{LOSS}, and the radiation resistance, R_{RAD}, which combine to from R_{TX} and R_{RX} in (2). Antenna efficiency, η, and directivity, D, depend on these parameters as follows:

$$\eta = \frac{R_{RAD}}{R_{RAD} + R_{LOSS}} \quad (3) \qquad D = \frac{E^2 L_e^2}{4 R_{RAD}} \quad (4)$$

where E is the incident Electric field strength and L_e is the effective antenna length.

The radiation resistance determines the amount of power transferred to the far field for a particular antenna input current. This has been modelled in MATLAB using an analytic equation derived in [1]. The loss resistance must be modelled by taking into account the proximity and skin effects, which explain how increasing frequency causes the cross section of the conductor, in which the current flows, to reduce. These effects have been modelled by utilizing equations and tables of parameters, derived and computed by S Butterworth and summarized in [5].

COMPARISON

Determining the regions in which a particular transmission method outperforms the other is a complicated process and depends upon the interaction of many parameters. Thus, only a brief overview can be given here.

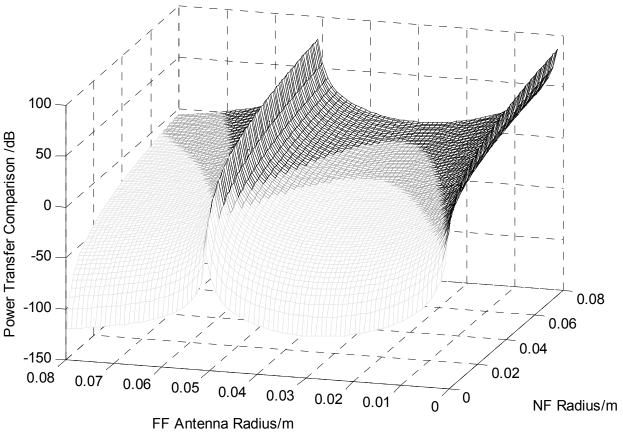

Fig 1: Power transfer comparison between near and far field transmission for varying antenna radius

Figure 1 is a comparison of near-field transmission (at 50MHz) with far- field transmission (470MHz) for a distance of 50cm, varying the near and far-field antenna dimensions (shortened to NF and FF respectively on the axis labels). The black region represents the area for which near-field transmission is superior. The darker gray area denotes the region where far-field transmission operates more efficiently than near-field transmission by a margin of 10dB or less. The use of near-field transmission should be strongly considered in this region since the lower operating frequency results in reduced power dissipation in the electronics [6]. To a first order approximation the power consumed by an analogue circuit can be considered to be directly proportional to frequency [6]. Depending upon the dominance of the electronics in the equations governing transmitter power consumption, the far field case could perform worse than illustrated in figure 1 by up to about 10dB for the frequencies used in this comparison. The lighter gray represents the area where far-field transmission is superior by a margin of 10dB or more.

CONCLUSION

The above surface plot (figure 1) suggests that near-field transmission should be employed once the allowable antenna radius exceeds 0.05m. Such graphs must be treated with caution, because the conclusions can alter sharply depending on other parameters. Distance is of particular importance, since near-field transmission decreases with $1/x^6$ compared to $1/x^2$ in the far-field case. It is also imperative that the optimal frequency within the two transmission methods for particular antenna dimensions is first evaluated in order that the correct comparison is made. This can also be achieved using the modelling introduced here.

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