Numerical Calculations of the Information Capacity of a Transmitting Antenna

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Abstract

We discuss the information capacity of the transmitting antenna through numerical examples. Antennas with different radiation proportions are considered. It is shown that given an antenna geometry and characteristics, the antenna information capacity can be measured and is limited by an upper bound. We also show that the capacity of a directional antenna is greater than that of an omni-directional antenna for a given size.

Introduction

Rapid adoption of mobile wireless technology has produced a number of constraints on the deployment of efficient mobile terminal antennas. Lack of complete global alignment on wireless spectrum allocation demands that mobile antennas be capable of many more frequency bands. Users have come to expect smaller devices with no visible antenna structure, which directly opposes the need for greater antenna efficiency. The expectation of greater information capacity for next generation wireless systems raises further questions of the antenna's impact on available information capacity.

The capacity of a communication system as a whole depends on a number of elements including the antenna. It can be increased by increasing the number of antennas [1] and/or by optimizing the performance of the antenna(s) in the desired bands. It is therefore important to examine the information capacity of an antenna as a step in understanding system capacity.

In this paper, we compute the capacity of a transmitting antenna numerically and show that the capacity of the transmitting antenna is limited by an upper bound once the antenna size is defined. Our validation is through numerical examples where the capacity for an omni-directional and a directional antenna is computed.

Information Capacity of a Transmitting Antenna

System capacity C can be defined by the following adaptation of Shannon's theorem as the mutual information transfer between the input(s) and the output(s) [1, 2].

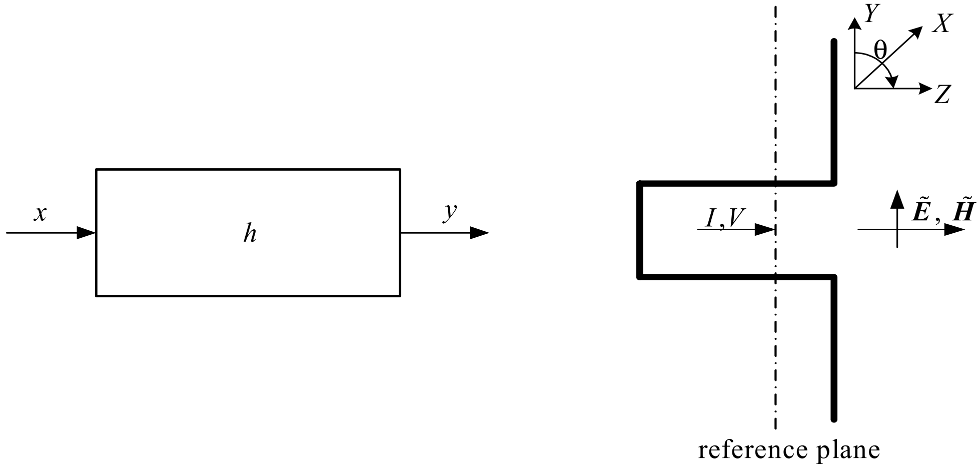

Fig. 1. System definition: (a) block diagram, (b) the transmitting antenna as a system.

$$C = \log_2 \left[1 + \frac{P}{\sigma^2} \boldsymbol{H}\boldsymbol{H}^{\dagger} \right]. \tag{1}$$

In (1), P and σ are the signal and noise power in a given bandwidth, respectively. $\boldsymbol{H}$ is the transfer matrix relating the inputs of the system to its outputs. For a single-input single-output system such as the antenna, $\boldsymbol{H}$ reduces to the transfer function h.

We assume that the antenna is excited by a narrowband band pass stochastic process producing a narrowband band pass stochastic electric and magnetic far fields. The transmitting antenna can be considered as a system that transforms the normalized terminal current i at the input x [see Fig. 1] to the normalized radiated field $\tilde{\boldsymbol{E}}$ ($\tilde{\boldsymbol{H}}$) at the output y. Therefore, the transfer function h is the ratio y/x, i.e.,

$$h = \frac{\boldsymbol{E}(r,\theta,\phi)\big/\sqrt{2\eta}}{I\sqrt{R^{rad}/2}} \tag{2}$$

where $\boldsymbol{E}(r,\theta,\phi)$ is the radiating far field as a function of position (r,θ,ϕ), R^{rad} is the radiation resistance and $i = I\sqrt{R^{rad}/2}$. Using (2) in the system capacity definition (1) we arrive at the capacity of the transmitting antenna as [3]

$$C(r,\theta,\phi) = \log_2 \left[1 + \frac{P}{\sigma^2} \frac{|\boldsymbol{E}(r,\theta,\phi)|^2}{|I|^2 \eta R^{rad}} \right] = \log_2 \left[1 + \frac{P^t}{\sigma^2} G(\theta,\phi) \right]. \tag{3}$$

Note that the information capacity of the antenna (3) is a function of the position, the signal-to-noise ratio (SNR) P^t/σ^2, and the antenna gain. The right-hand side

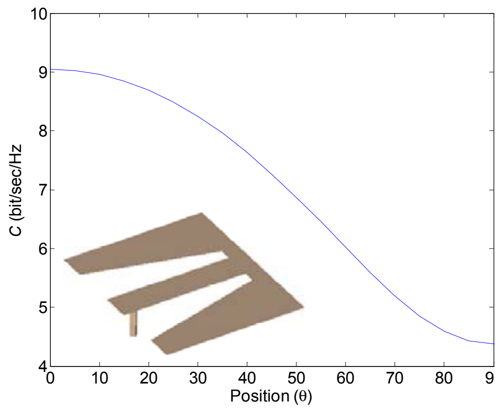

Fig. 2. The capacity of a directional antenna as a function of position at $ka = 1.57$.

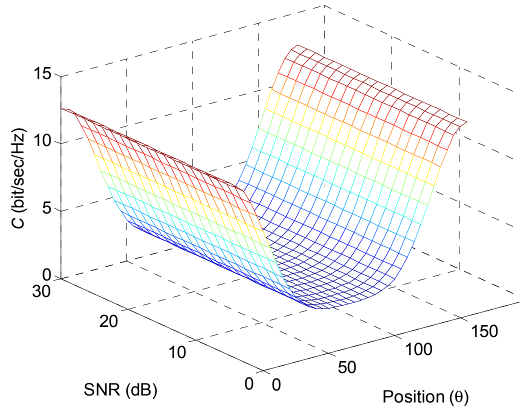

Fig. 3. The capacity as a function of SNR and position for the directional antenna at $ka = 1.57$.

of (3) is the maximum information capacity ($C_{\max}$) of an arbitrary transmitting antenna.

Numerical Examples

The information capacity of a directional, modified E-shaped antenna [5] (c.f. inset of Fig. 2) and an omni-directional (dipole) antenna are examined and compared. Calculations were performed using the commercial electromagnetic solver FEKO [6].

Fig. 2 shows the capacity in bits/sec/Hz computed using (3) for the hybrid patch antenna at SNR 20 dB. The capacity is computed as a function of the slant offset angle θ for a fractional bandwidth of 10%. As shown, the capacity changes with the position. This means that changing the position and/or antenna geometry to achieve higher gain increases (decreases) the gain (bandwidth) of an antenna increasing (decreasing) its information capacity. The effect of the SNR on the capacity is also examined as shown in Fig. 3. Increasing SNR improves the capacity, but in a real system this link margin is subject to practical limits.

The information capacity of the dipole antenna is also computed at SNR 20 dB and a fractional bandwidth 10%. The same general behaviour is observed with the omni-directional dipole antenna shown in Figs. 4 and 5. Again, capacity improves with the increase in the SNR.

Note that for the different positions and gain, the capacity for the directional antenna is larger than that for the omni-directional antenna. In general, higher gain is achieved with the directional antenna compared to the omni-directional antenna, which has a positive impact on the information capacity of the respective antenna.

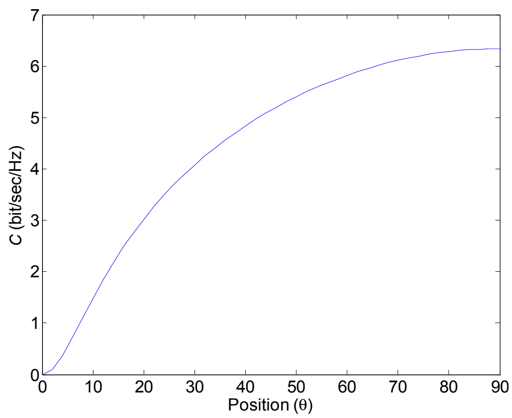

Fig. 4. The capacity of an omni directional antenna as a function of position at $ka = 1.57$.

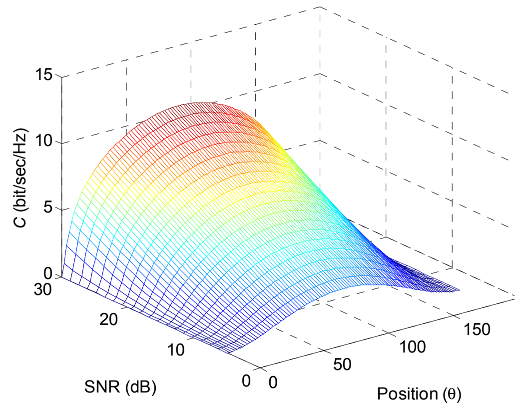

Fig. 5. The capacity as a function of SNR and position for the omni directional antenna at $ka = 1.57$.

The capacity can be increased by optimizing the antenna performance. However, once the optimum performance is achieved for a given size ka, the capacity is limited to the maximum of $C_{\max}$. In these examples, the maximum computed capacities are below the capacity bounds given in [3].

Conclusion

We numerically examine the information capacity of an omni-directional and a directional antennas. We show that the capacity is related to the antenna parameters – size, radiation characteristics, etc. Once the antenna is optimized for a given frequency band, its best performance is defined, which bounds its information capacity. Our calculations show that the information capacity of the directional antenna is higher than that of the omni-directional antenna.

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