Model for UAV Jamming

Sean Caver @ Data Machines Corporation

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This model is cobbled together based on things I found on the web, things conveyed to me by colleagues at Data Machines, and my own logic and understanding. Uncertainty is so noted.

1 Scenario

The field of interest is a square in the Euclidean plane. In this field, there is a "source," or "sender," labeled S, a receiver, labeled R, and n different "jammers," labeled $J_1, \ldots, J_n$. We do not assume that the ability to communicate is symmetric—a separate calculation is needed when the roles of sender and receiver are reversed.

2 TL;DR

Let $P_j(d_j)$ be the power of jammer j at the receiver, at distance d_j. Let $P_S(d_S)$ be power of the source at the receiver, at distance d_S. Let P_N be the power of the ambient noise.

These functions are given by $P_j = \frac{M_j}{d_j^2}$, for $j = 1, \ldots, n$ and $P_S = \frac{M_S}{d_S^2}$; P_N is a constant.

The probability of a successful transmission is given by

$$\text{sigmoid}\left(10\log_{10}\left(\frac{P_S(d_S)}{P_1(d_1) + P_2(d_2) + \ldots + P_n(d_n) + P_N}\right)\right)$$

The quantity in the sigmoid is the strength expressed in decibels, of the signal against the background that includes all jammers and the ambient noise, see Equation (1) in reference [2]

3 Some thoughts about the man-in-the-middle

Billy had alerted us to the fact that it was more than just distance to jammer–jammers in the line of sight were more potent than those off of it.

I spent a long time trying to justify putting this feature explicitly in the model. But the model above seemed most consistent with what I was reading in the literature and it made sense. It is distance to receiver that matters. A man in the middle generally will jam the receiver, unless distances are great enough, the ambient noise is small enough, and the proportionality constant of the jammer is small enough compared to the proportionality constant of the sender. This makes sense to me.

There is such a thing as electomagnetic interferece. According to Wikipedia: "The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy." My reading of this is this: interference happens upon the reception of the signal, in the circuits of a radiocommunication system, not with signal itself. Electomagnetic waves don't interact, as far as I am aware, but it can be impossible to pick out the signal in the noise.

Having said all that, a directional receiving antenna would sharpen the effect of a man-in-the-middle jammer, versus one off to the side, but for the moment I'm keeping it simple and assuming the antennae have no preferred direction. Could change that next, though, by assuming they are optimally directed to receive the signal in a particular orientation, and to reject signals in substantially different directions.

4 Power

The power of the radio signal from a point source at a distance r is given by (assuming the free-space propagation loss model):

$$P_{\text{signal}}(d) = \frac{M}{d^2},$$

where M is a proportionality constant that depends on units, and even with the same units, can be different for different senders. Note that M is the power of the signal at distance 1. The value of M may be know for friendlies but need to be extimated for jammers. Equation (1) in reference [4], showed a similar equation for "path loss" relaxing the free-space propagation loss model with a proportionality exponent possibly different from 2. It seems that the units of distance are important in this model—see reference [4]. I note this observation for the future as I intend to use the free-space propagation loss model for now.

Equation (5) in reference [1] gives

$$M = \frac{P_T G_T G_R}{4\pi},$$

where P_T is the power of the transmitter, G_T is the gain of the transmitter in the direction of the receiver, and G_R is the gain of the receiver in the direction of the transmitter. Presumably the transmitter could be either the jammer or the source. Reference [4], gives a similar equation that may not be entirely consistent that has a dependence on wavelength, Equation (1). The basic thing

I get from this is kind of obvious for anyone raised in the era before cable television—it depends on the orientation of the anntena how strong the signal. Again, I am just putting this observation in this document for the future. For the first cut the power received by the anntena is just a function of the distance to the transmitter, not the orientation of the antenna.

5 Jamming

One reference I have [1] talks about channel capacity as the maximum bit rate $S \to R$, under the assumption of error correcting codes, etc. So it seems in this paradigm that it is not whether you are jammed or not, but how many bits get through per second. In several references, including this one there is a noise term which adds power to the jammer in a symmetric way. When the decibels in the equation above drops below the 0, the channel capacity falls below the bandwidth of the channel.

I am going to ignore the details of channel capacity and error correcting codes and just say probability of transmission is a function of the ratio of the powers of signal to background, expressed as a sigmoid of decibels.

References

[1] W. Xu, "On adjusting power to defend wireless networks from jamming," in *2007 Fourth Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services (MobiQuitous)*, pp. 1–6, IEEE, 2007.

[2] K. Pärlin, M. M. Alam, and Y. Le Moullec, "Jamming of uav remote control systems using software defined radio," in *2018 International Conference on Military Communications and Information Systems (ICMCIS)*, pp. 1–6, IEEE, 2018.

[3] W. Cadeau, X. Li, and C. Xiong, "Markov model based jamming and anti-jamming performance analysis for cognitive radio networks," *Communications and Network*, vol. 2014, 2014.

[4] E. Benner and A. B. Sesay, "Effects of antenna height, antenna gain, and pattern downtilting for cellular mobile radio," *IEEE transactions on vehicular technology*, vol. 45, no. 2, pp. 217–224, 1996.