

# Cone of Silence: Adaptively Nulling Interferers in Wireless Networks

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## ABSTRACT

Dense 802.11 wireless networks present a pressing capacity challenge: users in proximity contend for limited unlicensed spectrum. Directional antennas promise increased capacity by improving the signal-to-interference-plus-noise ratio (SINR) at the receiver, potentially allowing successful decoding of packets at higher bit-rates. Many uses of directional antennas to date have directed high gain between two peers, thus maximizing the strength of the sender's signal reaching the receiver. But in an interference-rich environment, as in dense 802.11 deployments, directional antennas only truly come into their own when they *explicitly null* interference from competing concurrent senders. In this paper, we present Cone of Silence (CoS), a technique that leverages software-steerable directional antennas to improve the capacity of indoor 802.11 wireless networks by adaptively nulling interference. Using *in situ* signal strength measurements that account for the complex propagation environment, CoS derives custom antenna radiation patterns that maximize the strength of the signal arriving at an access point from a sender while nulling interference from one or more concurrent interferers. CoS leverages multiple antennas, but requires only a single commodity 802.11 radio, thus avoiding the significant processing requirements of decoding multiple concurrent packets. Experiments in an indoor 802.11 deployment demonstrate that CoS improves throughput under interference.

**Categories and Subject Descriptors:** C.2.1 Network Architecture and Design: Wireless communication

**General Terms:** Design

**Keywords:** wireless, directional, beam steering, beam forming, phased array, nulling, interference.

## 1. INTRODUCTION

Spurred by the availability of low-cost commodity radio hardware and freely usable unlicensed spectrum, users have embraced 802.11 wireless networking in home and office environments. As these networks proliferate rapidly, particularly in populous urban areas, their deployment density increases significantly. Measurements of 802.11 base station deployments in major US cities taken in 2005 already showed thousands of cases in which four or more 802.11 access points mutually interfered [1]. As only three non-overlapping channels are available in 802.11b/g, these increasingly dense deployments pose a wireless capacity challenge—physically proximal networks must share finite bandwidth.

Directional antennas hold great promise for the improvement of throughput on wireless links in dense, interference-rich deploy-

ments. The throughput achievable on a link depends on how well the receiver can discern a sender of interest's signal while distinguishing it from competing background noise and interference from other concurrent senders—on the signal-to-interference-plus-noise ratio (SINR). The greater the bit-rate at which a packet is transmitted, the greater the SINR with which the receiver must receive the packet in order to decode it successfully. And at a given transmit bit-rate, as SINR increases, bit-error rate (BER) decreases, reducing costly link-layer retransmissions.

Extracting the greatest SINR from a receiver's directional antenna entails solving two distinct problems. First, how can one direct gain toward a sender of interest's signal, thus improving the strength with which it is received? And second, how can one avoid directing gain toward interfering signals from concurrent transmitters, and thus *null* interference? A system may independently address either or both of these problems. Solving either increases SINR, and can thus improve throughput. The relative benefits to SINR of directing gain toward a sender's signal vs. nulling interference depend heavily on the deployment scenario. In an interference-rich environment, nulling is vital to achieving the full SINR and throughput improvements a directional antenna can offer. Prior work has proposed maximizing gain toward a sender of interest indoors in an 802.11 network [2], but this technique does not explicitly null interferers.

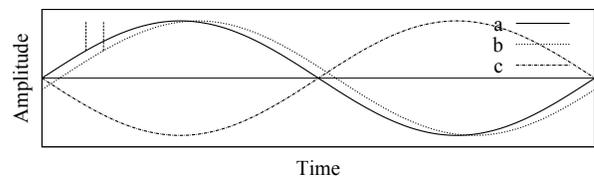


Figure 1: Three instances of one transmitted signal, *a*, *b*, and *c*, as received by three elements of a phased array. Notice the phase difference between *a* and *b*. Their sum is maximized when the waveforms align—achievable in this case by shifting the phase of signal instance *a* later by a few degrees. In contrast, signal instances *a* and *c* cancel each other.

## 2. DESIGN

*Cone of Silence* (CoS) is a technique for improving throughput under interference in 802.11 wireless receivers using phased array antennas. A phased array consists of several antenna elements. The wireless channel between sender and receiver causes attenuation and delay to a signal. In the case of a phased array, this attenuation and delay is different for each element because of their spatial separation. Figure 1 depicts the signal from a sender as it is received by three elements at a receiver. Notice the phase differences among the three received instances of the signal.

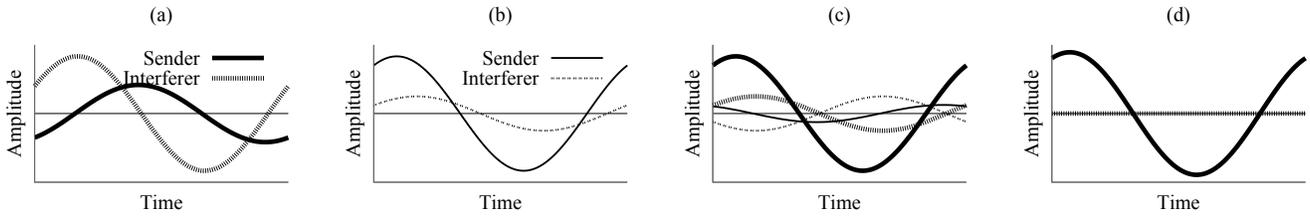


Figure 2: (a) Concurrent transmissions from a sender and interferer as received by a receiver’s antenna element 0. (b) The same sender’s and interferer’s transmissions as received by a receiver’s antenna element 1. (c) The four signals from the two elements, after applying a phase shift and attenuation at element 0 so that the interferer’s signals arriving at elements 0 and 1 cancel one another. (d) The same signals from the two elements, showing the resulting sum for the sender and interferer.

Instances of the same signal received by distinct elements combine either constructively or destructively. In the former case, a transmission is received with greater total power, leading to greater SINR and reduced BER (as is the case between instances *a* and *b* in Figure 1). In the latter, the combined signals cancel each other out, reducing aggregate received power, leading in turn to a decrease in SINR and hence increased BER (as is the case between instances *a* and *c* in Figure 1). Phased array antenna hardware allows software to programmatically apply a different phase shift to the signal received on each element. If the phase differences among elements are known, one may shift the phases of all elements in order to align the signals received at different elements, maximizing total received power.

The first component of CoS is *SamplePhase*, a method for channel estimation based on simple RSSI measurements. A received signal consists of a received power level and a phase, which together comprise a vector. When two elements are active at the same time, the vector for a received signal is the sum of the vectors received on each element. Using the RSSI values for packets received by a pair of elements configured with a known phase difference and those received by each element on its own, it is possible to calculate the *true* phase difference of the signals arriving at each element. The relative attenuation the two signals experience can be computed by similar means. In order to mitigate variability in RSSI values caused by measurement error and fading, unlike prior work [2], *SamplePhase* uses multiple measurements at different phase differences between elements and employs a Least Square Error estimator to compute the true phase difference. When channel conditions are known, one can apply correct phase shifts and power attenuations to all elements to maximize received power at a receiver from one sender using Maximum Ratio Combining [3].

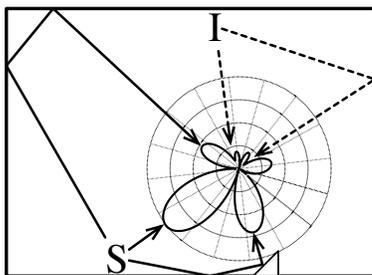


Figure 3: Example of multipath propagation between a sender *S*, interferer *I*, and a receiving directional antenna. Solid arrows represent components from *S*; dashed from *I*. Boundaries are reflective walls; the triangle represents a reflective object.

The second component of CoS is *Silencer*, which builds upon *SamplePhase* to null interference. The phased array receives each transmission multiple times—in the case of the antenna used in our implementation, eight times—such that each signal can be repre-

sented as an 8-dimensional vector. *Silencer decorrelates* the interferers’ signals, aligning them in such a way that they cancel each other out, while attempting to preserve as much power from the intended sender as possible [3]. The end result is shown in Figure 3: because of multipath propagation, many reflections reach the receiver from the sender and interferer; the receiver nulls signals from the interferer; and directs gain toward signals from the sender.

### 3. EVALUATION

We have implemented CoS and begun a preliminary evaluation. Figure 4 shows measurements for 8 different topologies. For each of them we compare throughput achieved by CoS with that achieved by a scaled omnidirectional pattern. The scaling was done in order to compare the patterns when they all use the same amount of power. We perform experiments in an indoor 802.11 testbed where a sender and an interferer send concurrently using bit-rate adaptation to an AP that is CoS-enabled. Each measurement is the mean of 10 one-minute runs with error bars representing 95% confidence intervals. From the logs of the experiments we can see that whenever the pattern derived from CoS is used, the sender chooses higher bit-rates more often. Our measurements indicate that CoS offers substantial gains in throughput, in some cases up to 17.5 $\times$ . In further experiments we have verified that CoS can also null two interferers successfully.

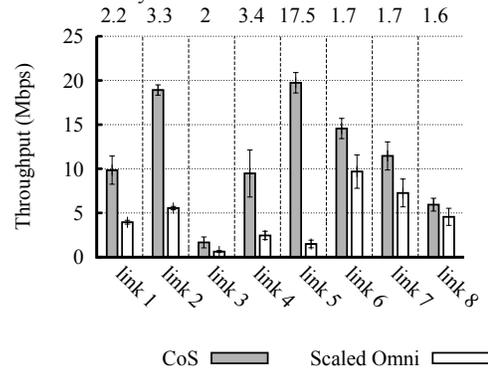


Figure 4: Empirically measured throughput in the presence of one interferer, for CoS and a scaled omnidirectional pattern (“omni”) for 8 different testbed links. The value above the bars for each link indicates the throughput improvement achieved by CoS over omni.

### References

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