

THESIS OR DISSERTATION TITLE
TITLE LINE 2

by

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Abstract

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Chapter 1

Introduction

1.1 Motivation

Since the advent of modern digital communications in the 20th century there has been an explosion in the demand for wireless spectrum. As a result spectrum is becoming an increasingly scarce resource(Insert citation). This demand is a direct result of the availability and relatively inexpensive cost of such wireless device. Therefore in such environments as militaristic theatres the probability of interfering transmissions has steadily grown to a point where techniques need to be considered to combat such occurrences. More directly, in such situations when interfering signals are partially or completely understood measures can be taken to overcome such difficulties.

In military theatres it is extremely common to observe friendly operated high-power broadband jamming signals(citation). Such devices exist as part of group convoys in several branches of the military and in many other forms in contested territories or war-zones. Unfortunately such devices block both friendly and hostile communications, and current anti-jamming techniques haven't provided a viable solution to this problem. Therefore new avenues should be considered, utilizing more flexible radio technologies.

Understanding how to overcome such challenges is a complex task; with vastly different

transmission environments and differing operating devices and operating standards. A new system that could combat such downfalls should rely on all friendly information, or be able to construct solutions of its own from a set of tools given to the radio. Such tools should be flexible and easily modified, changed, or improved. This ability to easily change or adapt is a key feature as the technical requirements can change from day to day, or between branches of the military itself. As such a solution should have the following attributes:

- **Flexible:**
- **Resilient:**
- **Hardened:** in changing environments

1.2 State of the Art

Current implementations in anti-jamming technology lies on the straddling point of hardware and software in the communications world. This is true because hardware provides the speed and performance needed for digital data transmission, while software provides higher level intelligence and flexibility in such layers as the media access control layer and the network layer of the OSI model (insert citation of OSI model.) For anti-jamming applications, high intelligence allows for mobility against the jammer. Therefore a large implementation in software must be considered when investigating anti-jamming techniques.

Insert figure of OSI model

Current anti-jamming techniques include channel hopping, spatial retreat, jammed area mapping, node escape, retreat restoration, frame masking, and many more[6]. All of these techniques use mechanisms of evasion or deception. These can be quite effective when attacked by generally narrowband, non-dynamic/learning jammers. In the case of wide and ultra-wide band jammers, they fail miserably. This wide-band environment is the primary situation of interest, and it is generally considered a hopeless scenario. These anti-jam techniques are designed for specific situations and jammers.

Let us first examine these anti-jamming technics which are broken down into three primary categories: Proactive countermeasures, Reactive countermeasures, and Mobile agent-base countermeasures[6]. Reactive countermeasures relies on a varying array of detection mechanisms first to determine if that node is being jammed. These detection methods must be coupled with a countermeasure or the scheme is in operable. Examples of these detection methods include a transmitter-based approach and a receiver-based detection. In a transmitter-based approach, such as ad-hoc networks, a decision algorithm is used based on four metrics: PDR (Packet Delivery Ratio), RSSI (Received Signal Strength Indicator), Physical rate, and Noise levels[3]. In the receiver-based detection additional information must be injected into frames to help the receiver determine the number of frames lost. Since frames can be easily lost in wireless transmissions, the receiver is handicapped when determining the number of retransmissions that have occurred. In the transmitter the PDR is deterministically determined by the data-link layer, sequence numbers must be added to frames for the receiver to accurately calculate the PDR[3]. Several other detection methods exist including using a detected detector, cooperative detection among nodes in a wireless network, and more sophisticated methods of RF fingerprinting[3].

Once the jammer has been detected the reactive countermeasures come into play. Many evasion techniques exists to combat narrowband jammers such as: channel hopping, spatial retreat, retreat restoration, hybrid attacks, and many cognitive radio approaches[2]. Many of these technics utilize the network itself to adapt to the jammer, which is an appropriate assumpt because without a network communications are irrelevant. Channel hopping is quite simple and can be considered easiet to implement. If a channel is begining jammed simply hopto another channel. This is easily defeated in two cases, the first the jammer follows you or the jammer is simply wideband capable. The second, spatial retreat, is a mechanism to physically evade the areas being jammed. Based on the detection algorithm all nodes in a network try to estimate the jammed region and flee physically in the direction of safer place. Based on their estimation about the jammed region, nodes will utilize shortest path algorithms to determine location of retreat[1]. Retreat restoration is focused

around how to rebuild a network once the jammer has left. Retreat restoration can be done by coordinated or uncoordinated communication, and the transmissions are based on a pre planned hop patterns among nodes[8].

There also exists systems that are design to resist jamming proactively. These hybrid systems[7] utilize preventatives measure to resist jamming such as frequency hopping spread spectrum *FHSS*. Spread-spectrum signals are highly resistant to narrowband jamming, unless the jammer has knowledge of the spreading key. In military applications the spreading key is generally created using a cryptographic function(Need citation). More hybrid solutions include synchronous and asynchronous spectral multiplexing where intermediary nodes are used to communicate at multiple channels. When a node changes its channel because of jamming a neighbor will heal that connection by communicating with the node on its new channel and rest of the network on the old channel[4].

The largest problem with these techniques is they all have are designed to combat narrowband jammers, and even friendly jammers. If high powered wideband jammers enter the equation, all of these solutions fall apart. Note these techniques primarily exploit the dimensionality of their environment by simply avoiding the jammer, and all techniques require intelligent flexible hardware solutions. To implement such solutions requires sophisticated hardware implementations, that can be quite rigid for rapidly changing communication environments and adversaries. To compensate solutions that push more of the radio operations from their original rigid hardware implementations into the more flexible software domain, provide a more cost effective and elegant solution. These software focused radios, also known as Software defined radios, have provided a solid platform for very adaptive anti-jamming technologies under the name cognitive radios. These radios have the ability to easily learn and adapt to their environment, which is the primary requirement of anti-jamming devices.

As mentioned above, it is quite common for the military to self-jam its own channels. Unfortunately this can hinder their own use unintentionally. These disrupted users are known as "disadvantage users". They are commonly small mobile hand held devices and cannot simply overcome the jammer computationally or in raw power; therefore, more manageable and

eligent solutions must be considered for such disadvantaged users. Beside self-jamming, adversarial jammers must also be considered. Fortunately certain characteristics can be statistically exploited if these jammer abide by certain properties. Since adversarial jammers tend to inject random data or energy to block communication, if these transmissions can be shown to repeat they can be exploited. In the case of self-jamming, the signal characteristic can be known *a priori*; therefore they also can be exploited or removed, negating the effects of such devices. Such scheme must consider the energy or symbols of the jammer that are orthogonal and/or non-orthogonal to the symbols of the communication itself.

The goal of this project is to exploit a self-jammed and statistically deterministic adversarially jammed channel, through the utilization of cognitive radio, implemented on a software defined radio platform. Software defined radios, defined as the intersection between hardware radios and computer software[5], provide a platform flexible enough to support highly intelligence operations such that anti-jamming requires. A proposed adaptive signal processing software solution for mitigating the effects of both intentional and unintentional jamming (including wideband jamming) via the combination of antenna subset selection, spectral subtraction, and blind source separation (BSS) techniques in order to extract specific transmissions from a mixture of intercepted wireless signals. The goal of our proposed solution, called BLind Spectrum Separation (BLISS), is to enable reliable, high throughput, and robust end-to-end wireless communications.

1.3 Thesis Contributions

This thesis will contribute the following to the wireless communications and signal processing research communities:

- A basis for blind source separation of define subset of signals, and tools on estimating and removing those signals.
- A practical implementation using over the air communications of a anti-jamming system utilizing software defined radios. This implementation will tackle wideband

non-orthogonal and orthogonal jamming, and provide evidence of probability of operational.

1.4 Thesis Organization

This thesis will be organized into the following chapters. Chapter 2 provides the necessary background to understand basic communication system design, anti-jamming techniques, and signal processing. Chapter 3 puts forward a theoretical simulations and a design of a physical anti-jamming system. Chapter 4 presents the results of the physical implement and analysis of its findings. Chapter 5 concludes the thesis, summarizing the accomplishments and outlines possible future work.

Chapter 2

Background

Here is some background you'll need to know about my research.

2.1 Background subsection

Bibliography

- [1] Mithun Acharya and David Thunte, *Intelligent jamming attacks, counterattacks and (counter)2 attacks in 802.11b wireless networks*, Proceedings of the OPNETWORK Conference, 2005.
- [2] Faraz Ahsan, Ali Zahir, Sajjad Mohsin, and Khalid Hussain, *Survey on survival approaches in wireless network against jamming attack*, Journal of Theoretical and Applied Information Technology **30** (2011), no. 1, 55–67.
- [3] Kwang-Cheng Chen and Ramjee Prasad, *Cognitive radio networks*, John Wiley and Sons, 2009.
- [4] Karthikeyan Mahadevan, Sojeong Hong, and John Dullum, *Anti-jamming: A study*, December 2005.
- [5] J. Mitola, *The software radio architecture*, IEEE Communications Magazine (1995).
- [6] Aristides Mpitziopoulos, Damianos Gavalas, Charalampos Konstantopoulos, and Grammati Pantziou, *A survey on jamming attacks and countermeasures in wsns*, IEEE Communications Surveys and Tutorials **11** (2009), no. 4, 42–56.
- [7] Kristopher W. Reese and Ahmed Salem, *A survey on jamming avoidance in ad-hoc sensory networks*, J. Comput. Sci. Coll. **24** (2009), no. 3, 93–98.
- [8] Jingpu Shi, Theodoros Salonidis, and Edward W. Knightly, *Starvation mitigation through multi-channel coordination in csma multi-hop wireless networks*, in CSMA Multi-hop Wireless Networks,” in Proceedings of the International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), 2006, pp. 214–225.