Your Noise, My Signal: Exploiting Switching Noise for Stealthy Data Exfiltration from Desktop Computers[*]

Zhihui Shao[†]
University of California, Riverside

Mohammad A. Islam[†]
University of Texas at Arlington

Shaolei Ren
University of California, Riverside

ABSTRACT

Attacks based on power analysis have been long existing and studied, with some recent works focused on data exfiltration from victim systems without using conventional communications (e.g., WiFi). Nonetheless, prior works typically rely on intrusive direct power measurement, either by implanting meters in the power outlet or tapping into the power cable, thus jeopardizing the stealthiness of attacks. In this paper, we propose NoDE (Noise for Data Exfiltration), a new system for stealthy data exfiltration from enterprise desktop computers. Specifically, NoDE achieves data exfiltration over a building's power network by exploiting high-frequency voltage ripples (i.e., switching noises) generated by power factor correction circuits built into today's computers. Located at a distance and even from a different room, the receiver can non-intrusively measure the voltage of a power outlet to capture the high-frequency switching noises for online information decoding without supervised training/learning. To evaluate NoDE, we run experiments on seven different computers from top vendors and using top-brand power supply units. Our results show that for a single transmitter, NoDE achieves a rate of up to 28.48 bits/second with a distance of 90 feet (27.4 meters) without the line of sight, demonstrating a practically stealthy threat. Based on the orthogonality of switching noise frequencies of different computers, we also demonstrate simultaneous data exfiltration from four computers using only one receiver. Finally, we present a few possible defenses, such as installing noise filters, and discuss their limitations.

CCS CONCEPTS

• **Security and privacy** → **Side-channel analysis and countermeasures**.

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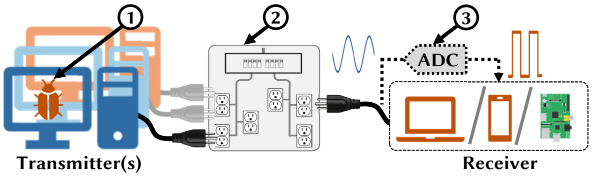

Figure 1: Threat model. ① Modulation program in the transmitter. ② Building's power network. ③ An analog-to-digital converter (ADC) inside an innocuous-looking device.

1 INTRODUCTION

In the wake of growing risks of data theft, a proactive defense is to keep sensitive data within an enterprise network at all times and impose strictly restrictive access to outside networks — all data transfer from and to the outside is tightly scrutinized. Nevertheless, such systems may still suffer from data exfiltration attacks that bypass the conventional communications protocols (e.g., WiFi) by transforming the affected computer into a transmitter and establishing a covert channel.

In this paper, we design a new data exfiltration system, called NoDE (Noise for Data Exfiltration), where a malware modulates the victim computer's power consumption to send data over a building's power network to the attacker's receiver. The key novelty is that NoDE uniquely exploits high-frequency voltage ripples (i.e., electronic switching noises) generated by power factor correction (PFC) circuits built into today's power supply units for power-consuming devices like computers. Like the existing data exfiltration attacks, NoDE exhibits several desirable properties: a reasonable achievable bit rate (28.48 bits/s), good effective distance (27.4 meters), and no line-of-sight requirement. Additionally, NoDE adds the two distinguishing features to the literature. First, NoDE uses *indirect power measurement* that does not require any tampering of the building's power network and hence is more stealthy. Second, by exploiting the (approximate) orthogonality of PFC-induced switching noises, NoDE can *simultaneously exfiltrate data from multiple computers* using only a single receiver.

2 THREAT MODEL

We consider a broadly-interpreted enterprise environment and focus on desktop computers which are the predominant type of end-user computer. Our threat model is illustrated in Fig. 1 where, without using any network or removable storage, sensitive information is sent from the infected computer(s) or *transmitter(s)* to the *receiver* connected to the same power network.

Like in the existing literature on covert channels, our threat model builds upon the malware's capability of obtaining sensitive information, and is not intended for sending large files due to rate limits. The malware can use the transmitter's CPU like any

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[†] Both authors contribute equally to this work.

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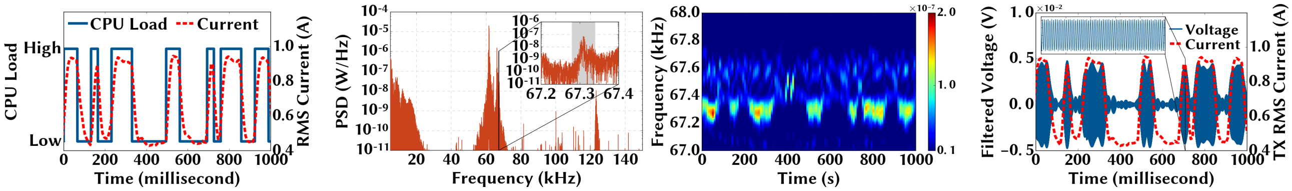

(a) Transmitter's CPU load and current amplitude

(b) Frequency analysis of the received voltage signal

(c) Frequency spectrum of the received voltage signal

(d) Filtered voltage signal and transmitter's current

Figure 2: Experiment in Lab #1 with transmitter and receiver separated by 55ft. By applying a filter with passband of <67.28kHz, 67.34kHz>, the amplitude of filtered voltage signals acquired by the receiver matches the transmitter's current amplitude.

normal programs, but no special privileges are assumed by NoDE. The receiver, on the other hand, can be any innocuous-looking device that is plugged into an outlet in the same building's power network as the transmitter. The receiver needs an ADC (analog to digital converter) for digitizing its received voltage and can be easily hidden inside a laptop/cellphone charger. Moreover, the receiver can be located in a distant room different than the transmitter.

3 NODE: EXTRACTING TRANSMITTER'S CURRENT FROM RECEIVER VOLTAGE

All desktop computers today are mandated to have built-in power PFC circuits in their power supply units to reduce harmonics. Importantly, these PFC circuits result in prominent high-frequency current ripples between 40kHz and 150kHz , whose amplitude changes with the computer's power consumption — the higher power consumption, the taller ripples, and vice-versa. These high-frequency current ripples also produce high-frequency voltage ripples at other power outlets, which are referred to as switching noises. Thus, by properly filtering the received voltage signals at a power outlet, switching noises can be retained and the receiver is able to successfully extract information about the transmitter's modulated current amplitude. Further, for different computers, the switching noise frequencies are typically different, which allows simultaneous data exfiltration attacks from multiple computers by a single receiver without strong interference.

We empirically validate the feasibility of extracting the transmitter's current amplitude information. We first show in Fig. 2(a) the transmitter's CPU load and current amplitude. Next, Fig. 2(b) shows the frequency components of the voltage signal at the receiver. We see large frequency components between 40kHz and 80kHz due to different computers' PFC switching operations, and the components around 67.3kHz are caused by our transmitter. The temporal variation of the power spectral density spikes created by the transmitter is shown in the frequency spectrum in Fig. 2(c), where we can easily identify the transmitter's high current periods. Next, we filter the collected voltage signal with a passband of <67.28kHz, 67.34kHz> and show the filtered voltage signal in Fig. 2(d) where the filtered voltage signal closely resembles the current ripples.

4 EVALUATION

We evaluate NoDE using seven computers with different hardware and software configurations at five different locations with various numbers of computers (e.g., Lab#1 has 30+ computers) in two different buildings. Table 1 lists the transmitter computers and their distances from the receiver at different locations along with the resulting bit error and bit transfer rates. We demonstrate NoDE can simultaneously exfiltrate data from four transmitters using a single receiver. We also test NoDE's transmission accuracy under different background applications and tasks (e.g., MS Word), different number of CPU cores used by NoDE, and different data frame settings. We generally observe very low error and high bit transmission rates across different settings.

Table 1: Summary of Experiments on Different Computers.

Transmitting Computer	Location	TX-RX Distance	Bit Error Rate	Bits Per Second
Dell Optiplex 9020, Windows 10	Lab #1 (Building A)	~55 feet	0.0%	28.48
Dell PowerEdge R630, Ubuntu 14.04	Office (Building B)	~90 feet	0.0%	28.48
Dell XPS 8920, Windows 10	Lab #1 (Building A)	~55 feet	0.0%	28.48
Acer G3-710, Ubuntu 16.04	Lab #2 (Building A)	~20 feet	10.1%	25.60
Custom Built with Corsair, Windows 10	Lab #1 (Building A)	~55 feet	8.1%	26.17
Custom~Built with EVGA, Windows	Lab #3 (Building A)	~15 feet	9.2%	25.85
Apple iMac Model A1419 (27-inch)	Lab #1 (Building A)	~55 Feet	16% (50ms/sym)	15.79
			2% (100ms/sym)	9.21

5 DEFENSE

To identify possible safeguards against NoDE's data exfiltration, we evaluate different hardware and software based defense approaches such as using a UPS to mask transmitter's power variation, adding power line noise filter to restrict PFC switching noise from entering the power network, and suppressing malware activity by randomizing computer's power consumption. Based on our study, we recommend the installation of power noise filters as a hardware-based defense and power randomization as a software-based technique.

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