Ben-Gurion University
of the Negev

המכון לחקר ביטחון החברה והמדינה
Homeland Security Research Institute

The Air-Gap Jumpers

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About Me

- Computer scientist (PhD)
- Head of R&D Cyber-Security Research Center, BGU
- Co-founder of Morphisec Endpoint Security
- Research focus
  - Advance Persistent Threats (APTs), Rootkits
  - Security of embedded systems
  - Low-level attacks/defense
  - Mobile security
  - Air-gap security
- A profile on my research at WIRED by *Andy Greenberg*: https://www.wired.com/story/air-gap-researcher-mordechai-guri/

- Papers and videos of this presentation can be found in my **air-gap research page** [1]

  https://cyber.bgu.ac.il/advanced-cyber/airgap

Agenda

- Background
- Threats, attack-vectors
- Air-gap jumping techniques (‘covert channels’)
  - Demo videos

- Evaluation
- Countermeasures

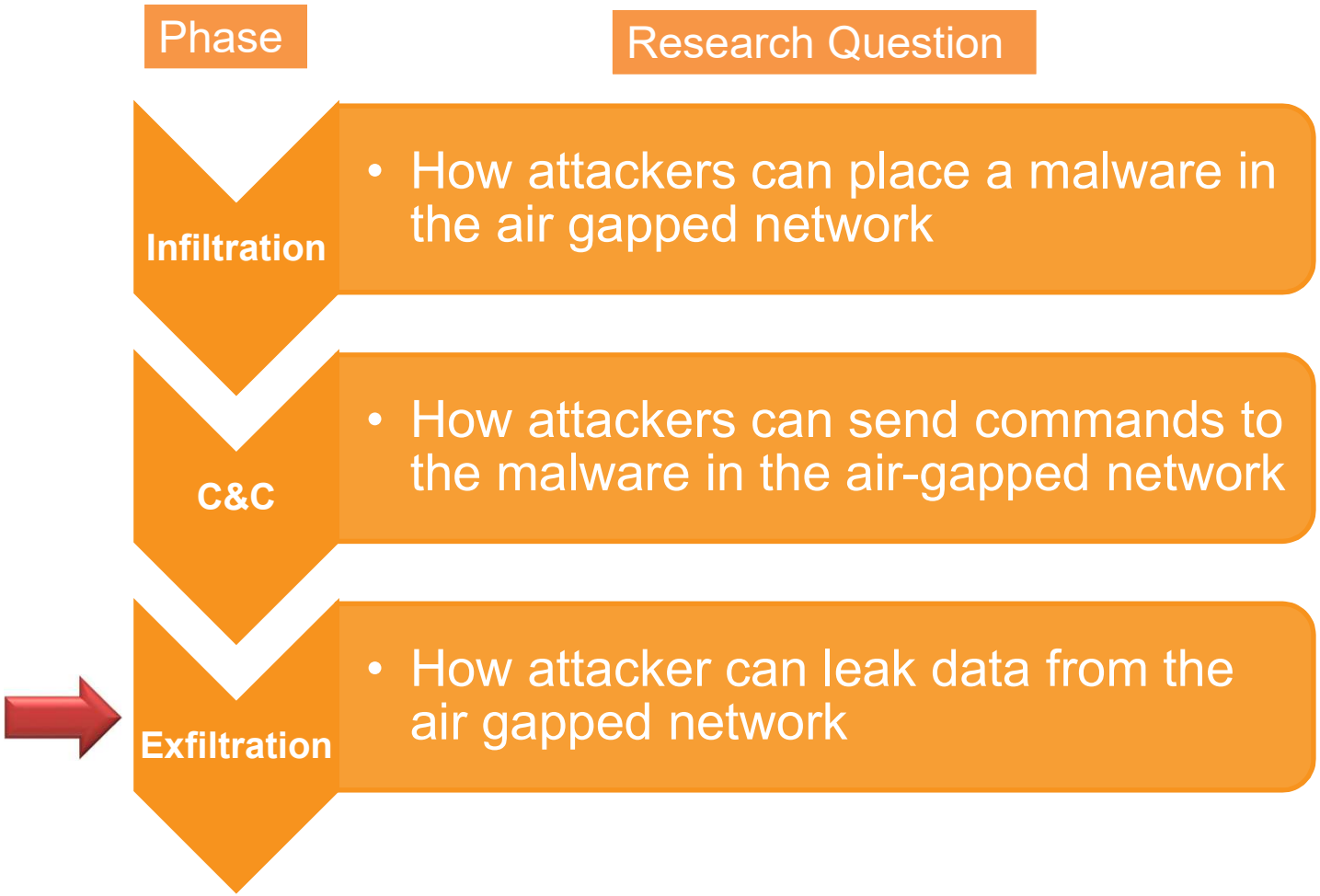
Air Gap

Definition: A cyber security measure that secures computer network by *physically* isolating it from unsecured networks, such as the Internet or another unsecured local area networks.

Examples of the types of networks or systems that may be air gapped:

- Military defense system
- Critical infrastructure command and control centers
- Computerized medical equipment and healthcare
- Banking and finance sectors
- Cryptocurrencies air-gapped (‘cold’) wallets, blockchain

Threats – Chain of Attack



Infiltration

- Despite the level of isolation, air-gapped networks are not immune to breaches
  - Supply Chain Attacks
  - Malicious Insiders
  - Deceived Insiders

Infiltration (1)

07.2018:

Security ▸ Insider threat

No big deal... Kremlin hackers 'jumped air-gapped networks' to pwn US power utilities

'Hundreds' of intrusions, switch could be pulled anytime, where have we heard this before?

By Richard Chirgwin 24 Jul 2018 at 05:28 80 SHARE ▼

The US Department of Homeland Security is once again accusing Russian government hackers of penetrating America's critical infrastructure.

Uncle Sam's finest reckon Moscow's agents managed to infiltrate computers networks within US electric utilities – to the point where the miscreants could have virtually pressed the off switch in control rooms, yanked the plug on the Yanks, and plunged America into darkness.

The hackers, dubbed Dragonfly and Energetic Bear, struck in the spring of 2016, and continued throughout 2017 and into 2018, even invading air-gapped networks, it is claimed.

This seemingly Hollywood screenplay emerged on Monday in the pages of the Wall Street Journal (paywalled) which spoke to Homeland Security

Infiltration (2)

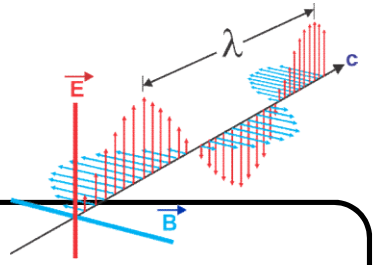
- US military base in the Middle East
- A USB flash drive infected with a worm (Agent.BTZ) was left in the parking lot
- Inserted into a laptop that attached to the United States Central Command network
- From there it spread undetected to other classified and unclassified networks
- The Pentagon spent nearly a year cleaning the worm from military networks

Air-Gap Jumping Research

- So, attackers *can* infect air-gapped networks
- We assume that an attacker already has a foothold (APT) in the air-gapped network
- The attacker want to *exfiltrate* data from the network
  - No internet

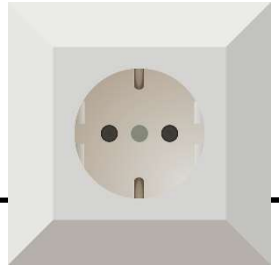
Physical Media

Acoustic



Electromagnetic

Magnetic



Electric

Optical

Thermal

Air-Gap Jumping

- **Electromagnetic**
  - AirHopper [3], GSMem [4], USBee [5]
- **Magnetic**
  - ODINI [6], MAGNETO [7]
- **Electric**
  - POWERHAMMER [8]
- **Acoustic**
  - MOSQUITO [9], Fansmitter [10], Diskfiltration [11]
- **Optical**
  - LED-it-GO [12], xLED [13], aIR-Jumper [14]
- **Thermal**
  - BitWhisper [15]

Physical Media

- Many developed APTs are able to jump over air gaps via USB ([2]).
  - Turla,
  - MiniDuke,
  - RedOctober
  - Fanny
  - Remsec
  - …

- Use USB flash drives to jump into air-gapped networks

- Use USB flash drives to exfiltrate data from air-gapped networks

Physical Media - Countermeasures

- Physical media is forbidden (policy)
- USB I/O activities are monitored
- USB port blocks (hardware/software)
- Write protected USB

Acoustic

ACOUSTIC

Ultrasonic

Ultrasonic

BeatCoin demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

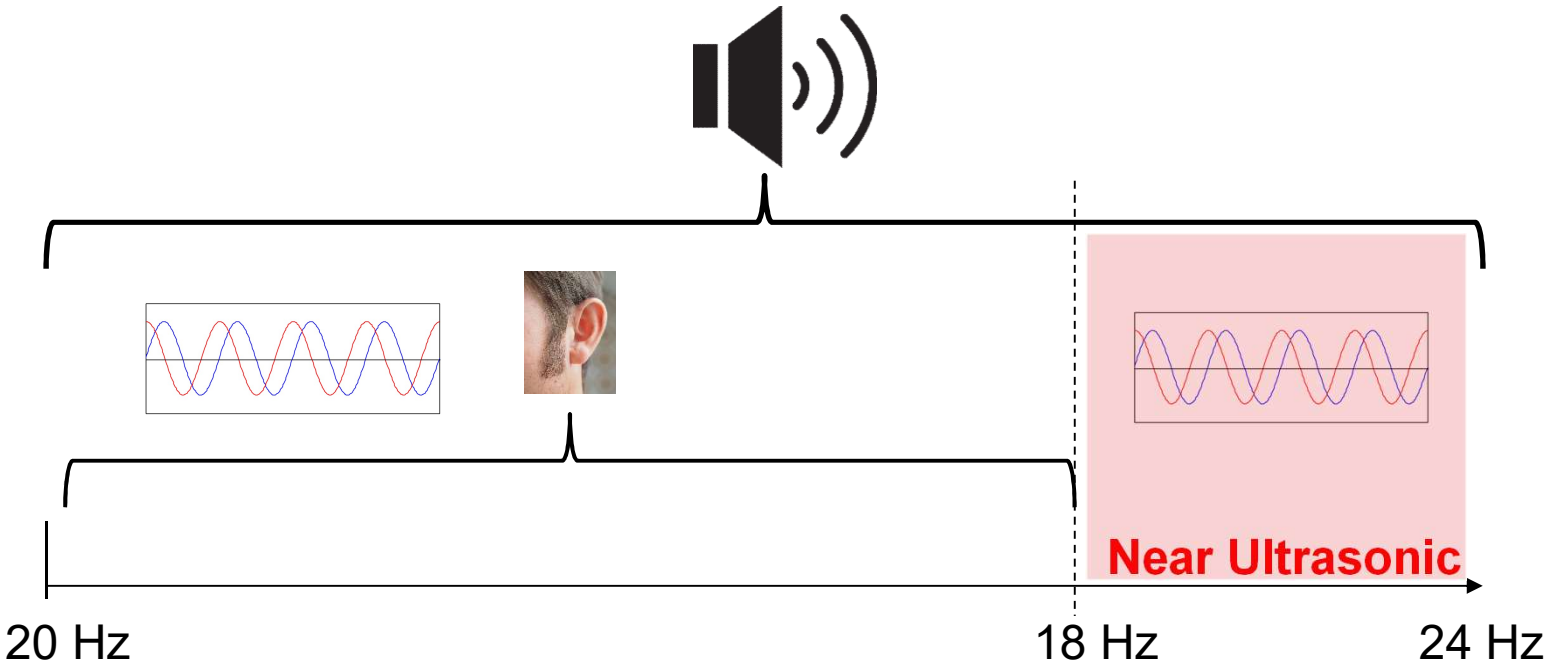
Ultrasonic

	Range
Humans	20 Hz to ~18 kHz
Cats	55 Hz up to 79 kHz (a range of 10.5 octaves)
Dogs	40 Hz to 60 kHz
Bats	1 kHz - 200 kHz
Mice	1 kHz to 70 kHz.
Dolphins	110 kHz





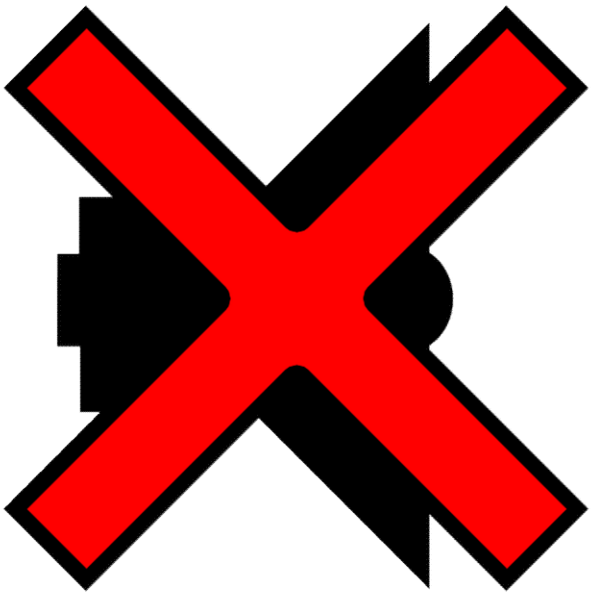

Ultrasonic



An ordinary computer can produce sound at a frequency band of 0-24kHz

Audio-Gap

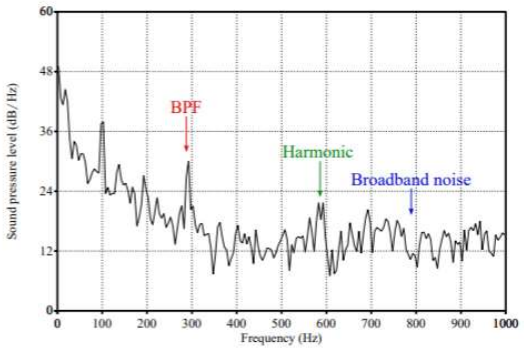
- The solution to the ultrasonic covert-channels: Maintaining ‘Audio-Gap’
- Common practices and security policies may prohibit the use of speakers [16]
- Disable the audio hardware
- A ‘hermetic’ solution?



Fansmitter

- Computer fans
  - CPU cooling fans
  - Chassis fans
  - Power-supply fan
  - GPU fans

- The Blade Pass Frequency (BPF)
  - Number of blades
  - Rotation speed



- Malware can control the fan speed (RPM)
  - Control the BPF

Fansmitter

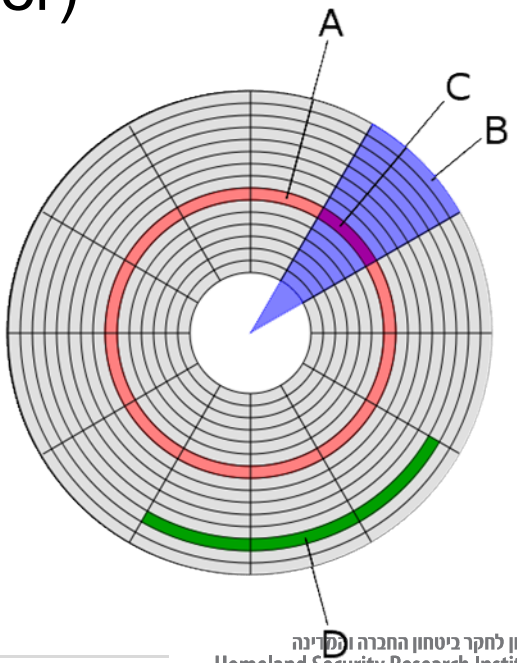
Fansmitter demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

Fansmitter

- Move to a “water cooling”?

Diskfiltration

- The *actuator arm* is controlled by a motor that moves the hard drive head arm
- Can be controlled by malware by performing I/O between tracks (read/write)
- With user level privileges (temp folder)



DiskFiltration

DiskFiltration demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

MOSQUITO

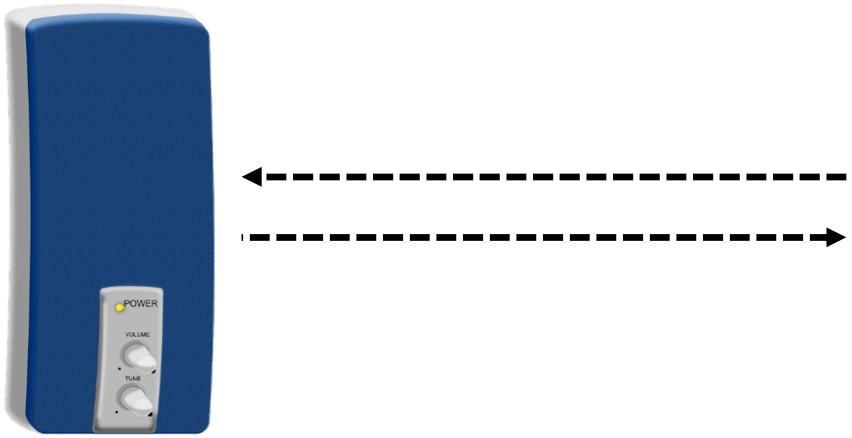
- Ultrasonic covert channel requires
  - Speakers (transmit data)
  - Microphones (receive data)

- What if microphones are
  - Banned
  - Disconnected
  - Muted
  - Taped

- Speakers-only environment

MOSQUITO

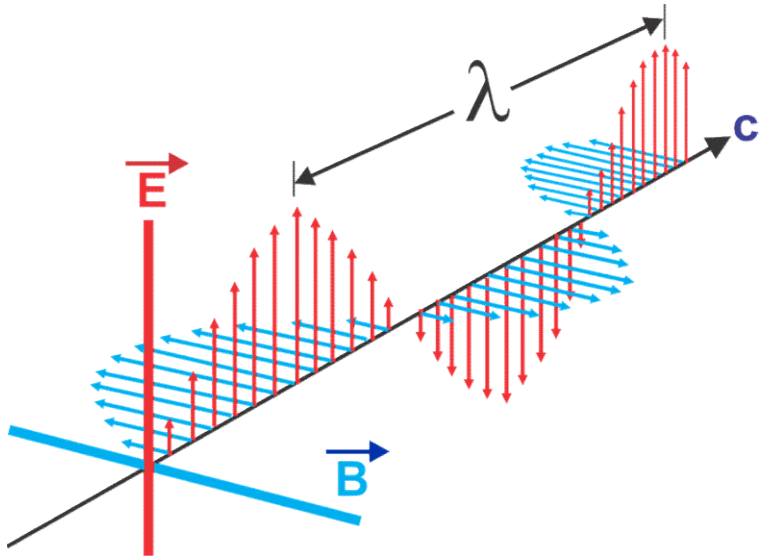
- A malware that exploit a specific audio chip feature
- *Reverse* the connected speakers from *output* devices into *input* devices
- Turn speakers/headphones/earphones to microphones
- Speaker-to-Speaker communication



MOSQUITO

MOSQUITO demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

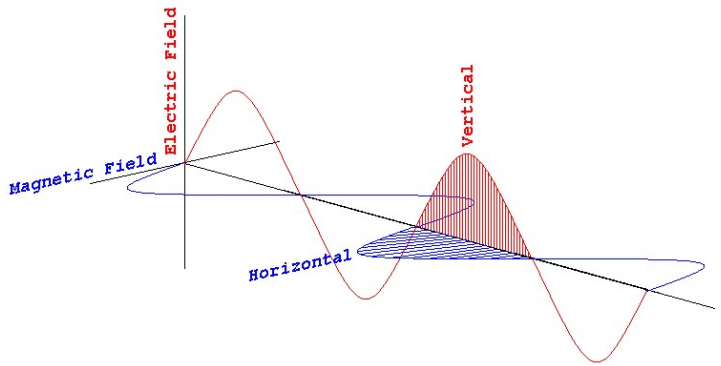
Electromagnetic



ELECTROMAGENTIC

Electromagnetic - Basics

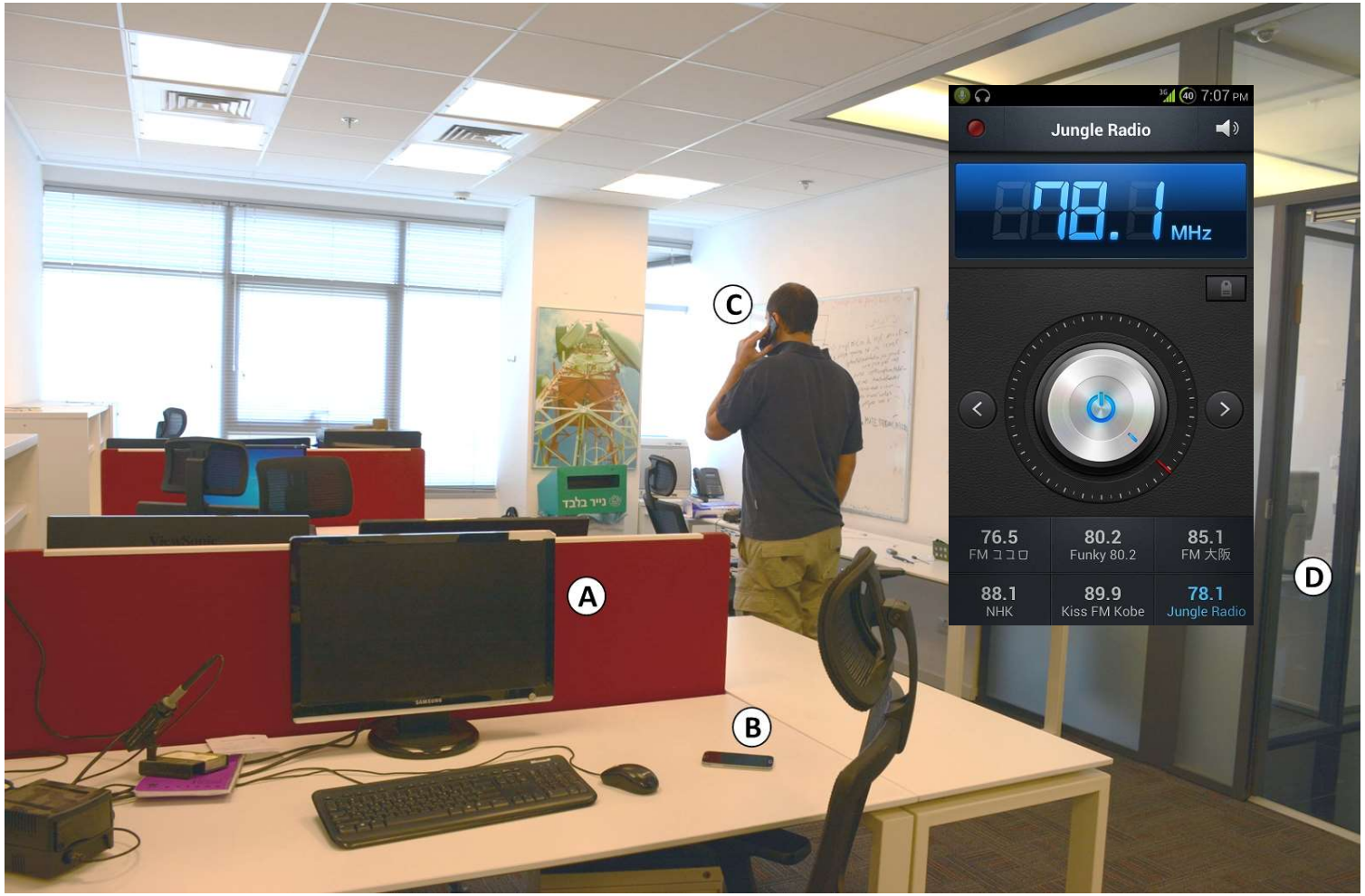
- Electric current in a wire produces an electromagnetic field
- The electromagnetic field depend the current pass through the wire
- If we control the current in a wire, we control the electromagnetic emission
  - Frequency
  - Amplitude



AirHopper

- Screen cables are emanating electromagnetic radiation – depend on the ‘image’ transmitted in the cable
- We can control the electromagnetic radiation by transmitting specially crafted images
- We can adjust the electromagnetic radiation to the FM radio band! (88 MHz -108 MHz)
- Malware uses the video display as a FM transmitter to leak data
  - Screen cable function as an antenna

AirHopper


7:07 PM
Jungle Radio
78.1 MHz
76.5
FM ココロ
80.2
Funky 80.2
85.1
FM 大阪
88.1
NHK
89.9
Kiss FM Kobe
78.1
Jungle Radio
A
B
C
D

AirHopper

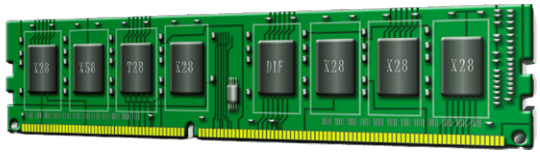
AirHopper demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

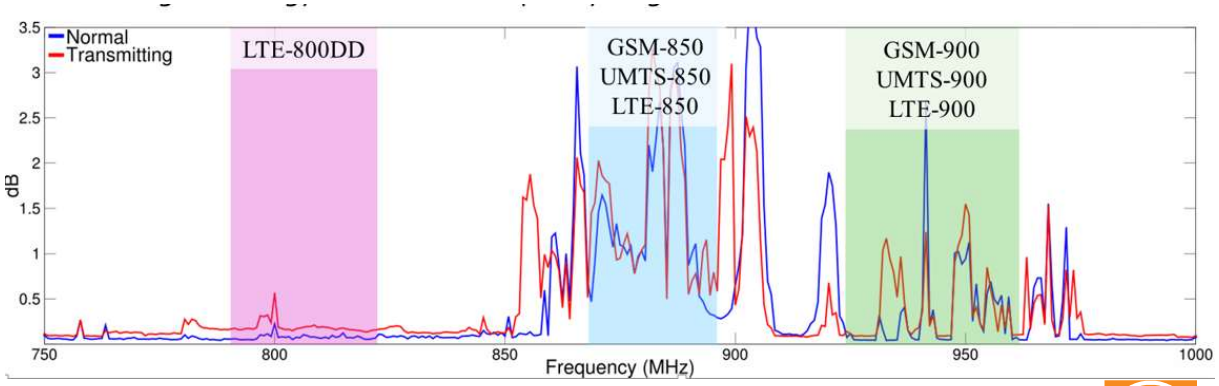
GSMem

- “feature-phones” might be allowed in some facilities
- No camera, Bluetooth, Wi-Fi, FM, etc.

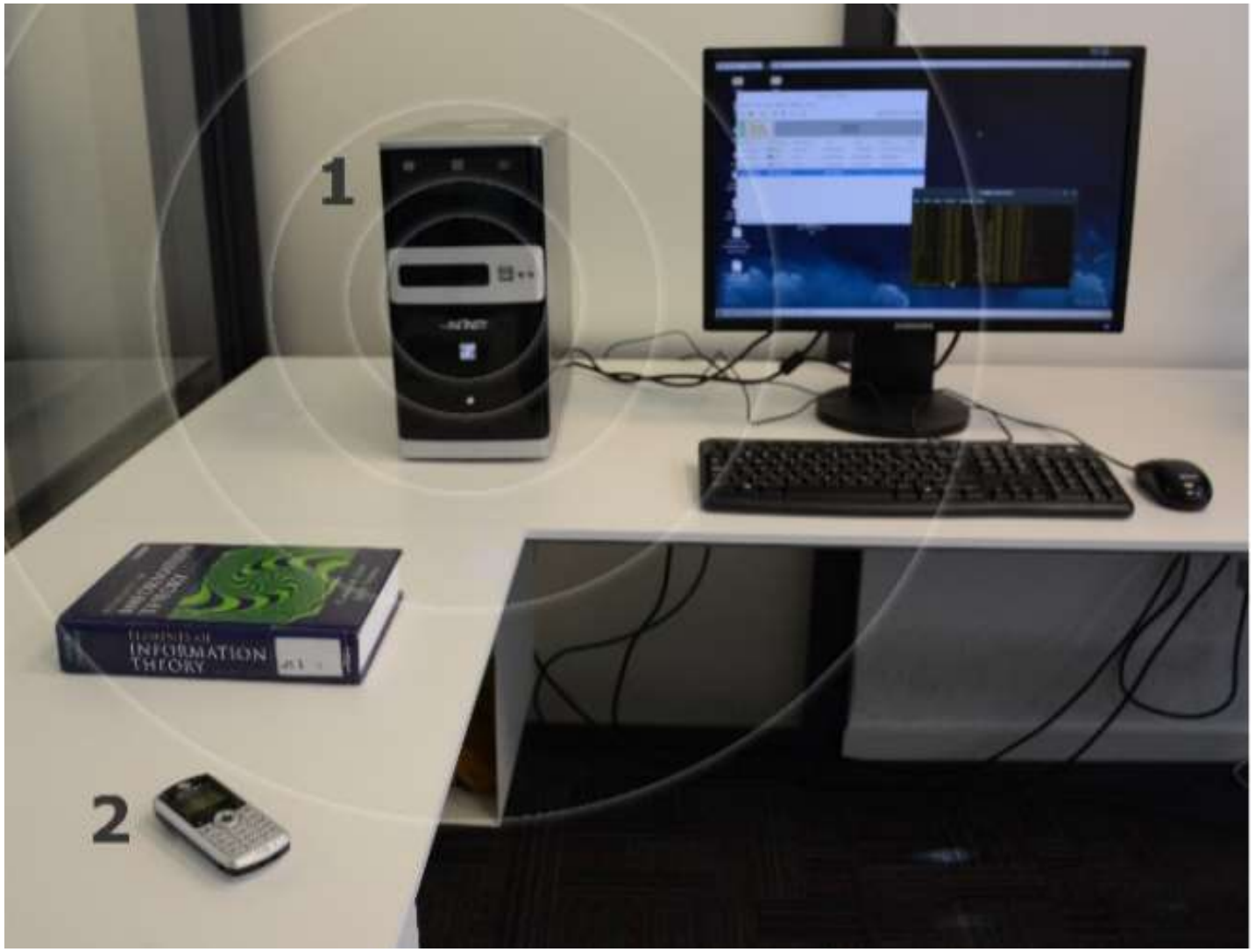
GSMem

- The CPU-memory bus emit electromagnetic radiation
- We can control the radiation by building special patterns memory transfers
- The radiation can be adjusted to the GSM, UMTS and LTE frequency bands (2G, 3G and 4G)
- We use multi-channels to amplify the transmission





GSMem

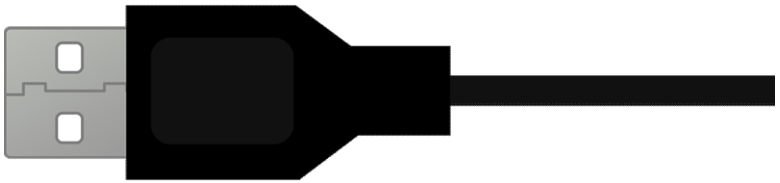


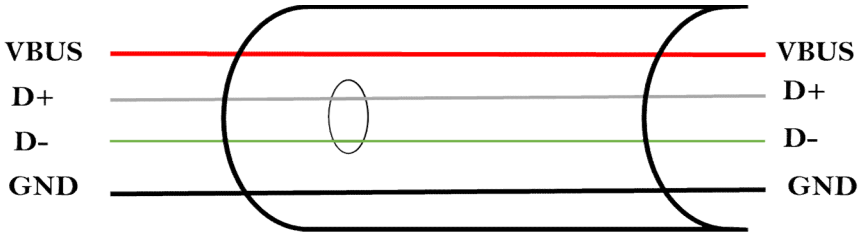
GSMem

GSMem demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

USBee

- Use the USB data bus to transmit RF signals
- D+/D- as small antennas
- Simple I/O operations (read/write)
- No special permission is required





USBee

USBee demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

Magnetic

MAGNETIC

ODINI

ODINI

- Jump air-gaps and bypass Faraday cages
- The ODINI method is based on an exploitation of the *low-frequency magnetic fields* generated by the computer's CPU
- Low frequency magnetic radiation propagates through the air, penetrating metal shielding such as Faraday cages
- E.g., compass still works inside Faraday cages

ODINI

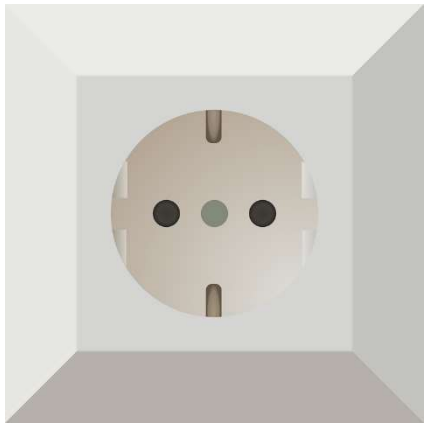
ODINI demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

MAGNETO

MAGNETO

MAGNETO demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

Electric

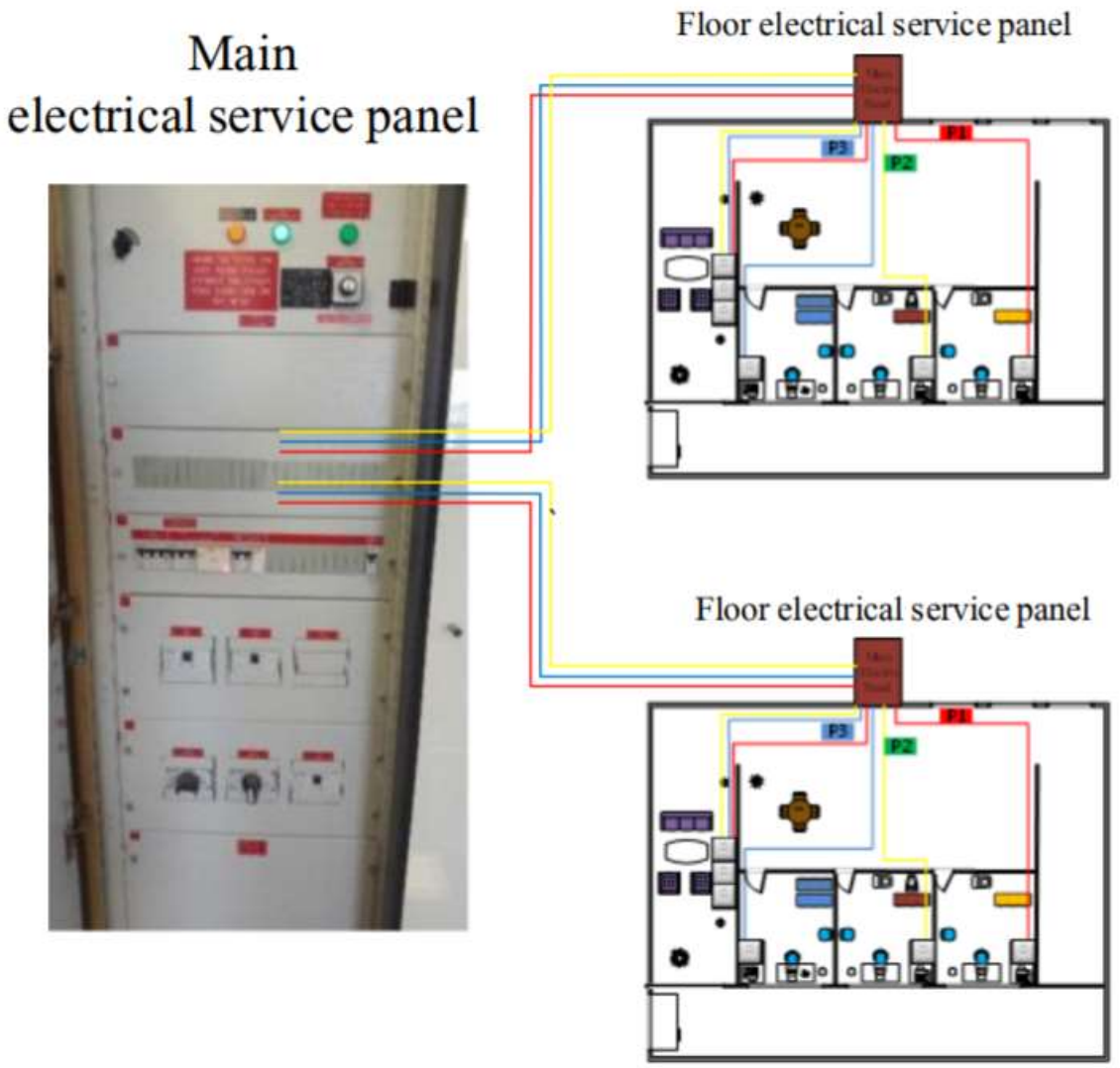


ELECTRIC

PowerHammer

- A malicious code running on a compromised computer can control the power consumption of the system by intentionally regulating the CPU utilization
- Data is modulated, encoded, and transmitted on top of the current flow fluctuations
- This it is conducted and propagated through the power lines
- This phenomena is known as a ’conducted emission’

PowerHammer



Optical

OPTICAL

Optical

- Computer and peripherals are equipped with LEDs indicators
- The LEDs are controllable from software/firmware level
- Malware can encode data on ‘blinks’
- Can be intercepted by local cameras or remotely (e.g., drones)

LED-it-GO

LED-it-GO demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

xLED

xLED demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

aIR-Jumper

- Security camera are equipped with IR LEDs
- Security cameras can ‘see’ IR
- Can not seen by humans

aIR-Jumper

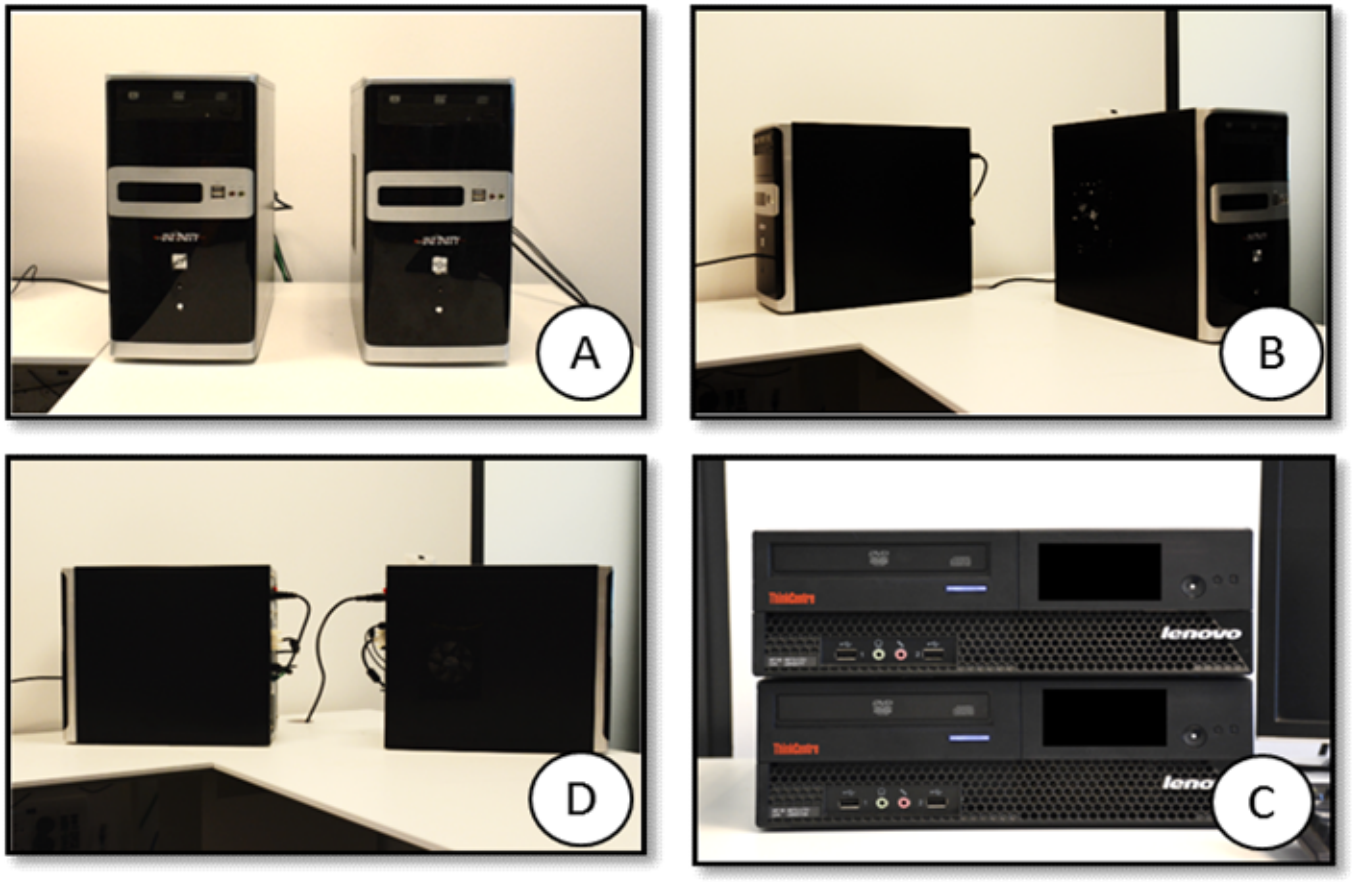
aIR-Jumper demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

Thermal

THERMAL

BitWhisper

Motivation

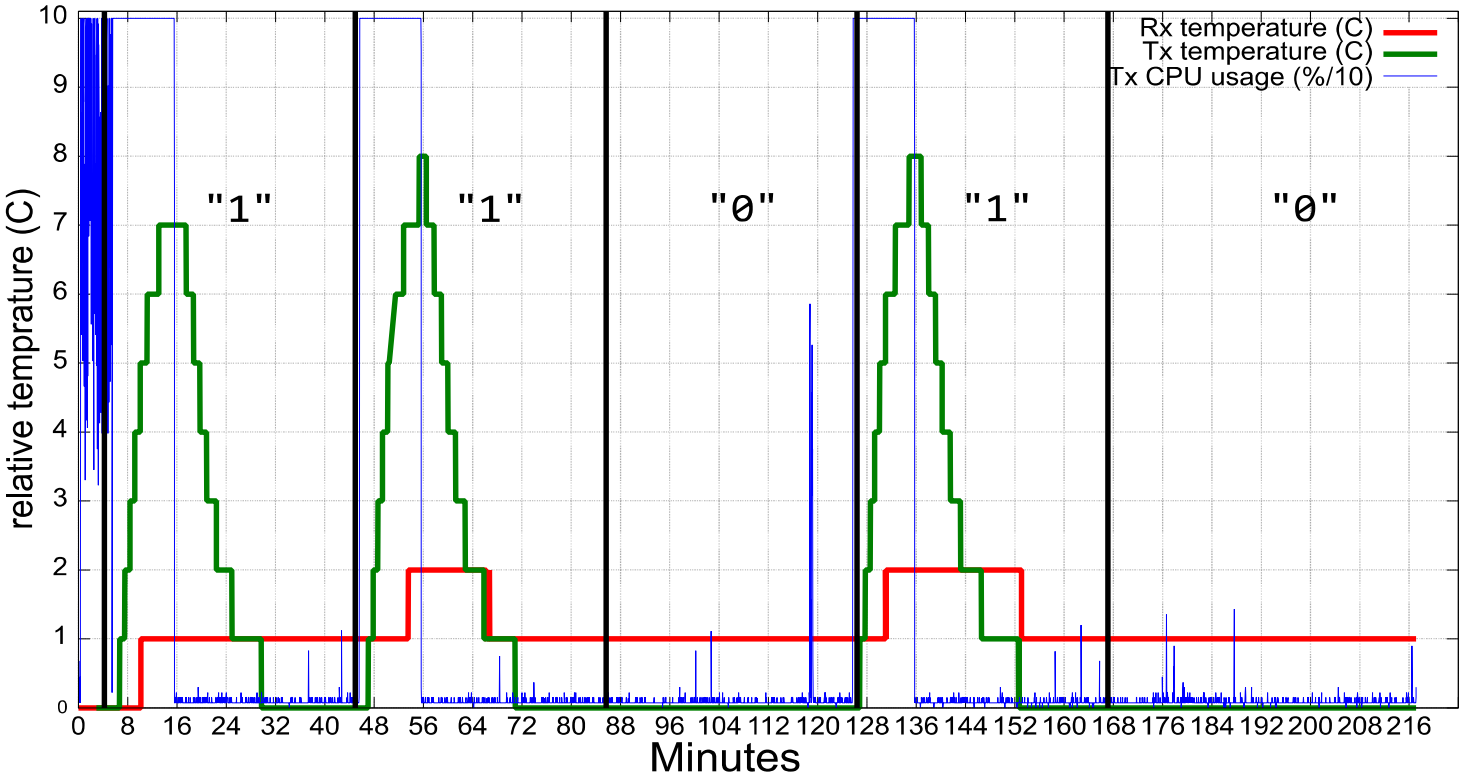


BitWhisper

- Computer are emitting heat from
  - CPU
  - GPU
  - HDD
  - Peripherals
- Computer are equipped with built-in thermals sensor
  - CPU/GPU
  - Motherboard
  - HDDs
- Bi-Directional communication based on heat

BitWhisper

- A computer can detect temperature change created by the adjacent computer
- Data is encoded via temperature changes



BitWhisper

BitWhisper demo: https://cyber.bgu.ac.il/advanced-cyber/airgap

Evaluation

	Channel Type			
	Acoustic	Electro magnetic /magnetic/electric	Thermal	Optical
Channel Characteristic				
Stealth	High	High	Medium (sensible)	Low / High
Channel Availability	High	High	Low (overnight attack)	Low (user absence)
Feasibility in Virtualization	Medium	Medium	Medium	Medium
Hardware Availability	Medium-low	High	High	High
Quality	Medium	Medium/low	Low	Medium
Required Privileges	Regular	Regular/Root	Regular/Root	Regular

Countermeasures

Method	Type	Relevancy to bridgeware types	Cost
Physical insulation/ Zoning/ Red/Black separation	Physical countermeasures	Acoustic, Electromagnetic, Thermal, Optical	High
Wires and equipment shielding	Hardware countermeasures	Electromagnetic (partial)	Low-Medium
Signal filtering	Hardware countermeasures	Acoustic, Electromagnetic (partial)	Medium
Signal jamming	Hardware countermeasures	Electromagnetic	Medium
Activity detection	Software countermeasures	Acoustic, Electromagnetic, Thermal, Optical	Low-Medium
Soft tempest	Software countermeasures	Electromagnetic	Low

Air-Gap Jumping

- **Electromagnetic**
  - AirHopper [3], GSMem [4], USBee [5]
- **Magnetic**
  - ODINI [6], MAGNETO [7]
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References

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[11] Mordechai Guri,Yosef Solewicz, Andrey Daidakulov, Yuval Elovici. "Acoustic Data Exfiltration from Speakerless Air-Gapped Computers via Covert Hard-Drive Noise ('DiskFiltration')". European Symposium on Research in Computer Security (ESORICS 2017) pp 98-115

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Thank you