IoT Goes Nuclear: Creating a ZigBee Chain Reaction

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WEIZMANN INSTITUTE OF SCIENCE

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The Joy of Tech™ by Nitrozac & Snaggy

The Internet of ransomware things...

HUNGRY? PAY UP AND I’LL UNLOCK MY DOOR!

ON STRIKE UNTIL YOU SEND MONEY TO MY HACKERS.

20 BUCKS IN MY PAYPAL ACCOUNT OR I’LL ONLY BREW DECAF!

I’LL BE BURNING THE TOAST IF YOU DON’T GET ME SOME DOUGH!

THE NEXT TIME YOU LEAVE, IT’LL COST YOU 100 BUCKS TO GET BACK INTO THE HOUSE, UNLESS YOU GIVE ME $75 NOW!

30 BUCKS IN BITCOIN, OR NEXT TIME I SMELL SMOKE, I MIGHT JUST LET YOU SLEEP.

WIRE MY HACKER $100 OR I’LL REVERSE MY MOTOR AND BLOW DIRT ALL OVER THIS PLACE!

YOUR DIRTY DISHES CAN WAIT, I’M BUSY MINING BITCOINS.

EXCUSE US WHILE WE PARTICIPATE IN A DDOS ATTACK.

I’M TURNING OFF THE HEAT UNTIL YOU WARM UP MY BANK ACCOUNT!

IF YOU DON’T SEND US CASH, YOUR REPUTATION WILL BE IN THE TRASH.

I’LL START YOUR CAR, BUT ONLY TO TAKE YOU TO YOUR BANK TO MAKE A TRANSFER.

SEND ME $25 OR I’LL TELL EVERYONE ON YOUR SOCIAL NETWORK THAT YOU WERE STUPID ENOUGH TO BUY AN INTERNET-CONNECTED BROOM!
Typical IoT devices: Philips Hue Smart Lights
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- Mature technology and standards, a relatively simple system
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- Mature technology and standards, a relatively simple system
- A high end product with high end security, but...
The underlying ZLL protocol
Each installed light is connected to a central controller using the ZigBee Light Link (ZLL) wireless protocol in a Personal Area Network (PAN).
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• The bridge is connected to a secure home/office network, and is controlled by a smartphone app via IP
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- Each installed light is connected to a central controller using the ZigBee Light Link (ZLL) wireless protocol in a Personal Area Network (PAN).
- The bridge is connected to a secure home/office network, and is controlled by a smartphone app via IP.
- It enables each authorized user to turn each light on or off, to change the light intensity, and to set its color.
Creating a lightbulb worm

• A question: Can hackers create a worm which spreads using only the standard ZigBee wireless interface?
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• A question: Can hackers create a worm which spreads using only the standard ZigBee wireless interface?
• Two main obstacles:
  • Taking over a preinstalled smart light
  • Spreading everywhere – finding a method for one smart light to infect nearby smart lights
Taking over a preinstalled smart light
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• ZigBee Light Link standard uses multiple cryptographic and security protocols to prevent misuse.
Taking over a preinstalled smart light

• ZigBee Light Link standard uses multiple cryptographic and security protocols to prevent misuse

• In particular, uses a proximity test to make sure that the only way to take control of an already installed Hue lamp is by operating it within 10-20 cm from its new controller
Protocol Outline

Controller

Scan Request (Transaction ID) → Lamp

Network Start (Transaction ID)

Reset to Factory New (Transaction ID)

Proximity Test
Protocol Outline

Controller

Scan Request (Transaction ID)

Scan Response

Lamp

Proximity Test

Network Start (Transaction ID)

Reset to Factory New (Transaction ID)
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Scan Request (Transaction ID) → Lamp

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Reset to Factory New (Transaction ID)

Proximity Test
Protocol Implementation Bug
Protocol Implementation Bug

• We want to cause the light to Reset to Factory New
Protocol Implementation Bug

- We want to cause the light to Reset to Factory New

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<tbody>
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Figure 37 – Format of the reset to factory new request command frame

7.1.2.2.4.1 Inter-PAN transaction identifier field

The *inter-PAN transaction identifier* field is 32-bits in length and specifies an identifier for the inter-PAN transaction. This field shall contain a non-zero 32-bit random number and is used to identify the current reset to factory new request.
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Protocol Attack Outline

Controller -> Factory Reset (Transaction ID=0) -> Lamp
We bought a cheap and lightweight commercial Zigbee evaluation kit:
We then decided to take full control of all the smart lights in the same office building we attacked before. By launching a drone carrying a fully automated attack equipment 400 meters away.
Spreading everywhere
Packet #1 (first 16-byte packet) Processing using AES-CCM
New CPA attack on CCM

Nonce (unknown) Counter (m)

CBC State m -1 (CBC\textsubscript{M-1})

Plaintext (PT\textsubscript{M})

Block Cipher Encryption

Ciphertext (CT\textsubscript{M})

CBC State m (CBC\textsubscript{M})

Nonce (unknown) Counter (m+1)

CBC State m (CBC\textsubscript{M+1})

Plaintext (PT\textsubscript{M+1})

Block Cipher Encryption

Ciphertext (CT\textsubscript{M+1})
New CPA attack on CCM

Jaffe 07
Requires $2^{16}$ blocks
New CPA attack on CCM

O’Flynn & Chen
Chosen Nonce

Nonce (unknown) Counter (m)
New CPA attack on CCM

Nonce (unknown) Counter (m)

Block Cipher Encryption

Ciphertext (CTM)

Plaintext (PTM)

CBC State m-1 (CBCM-1)

ECB - modified key

Block Cipher Encryption

CBC State m (CBCM)

Nonce (unknown) Counter (m+1)

Block Cipher Encryption

Ciphertext (CTM+1)

Plaintext (PTM+1)

CBC State m+1 (CBCM+1)
New CPA attack on CCM

Nonce (unknown) Counter (m)

Block Cipher Encryption

CBC State $m - 1$ ($CBC_{m-1}$)

Ciphertext ($CT_m$)

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CBC State $m$ ($CBC_m$)
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Creating An Explosive Infection:
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• For a city such as Paris whose area is 105 square km, the critical mass is about 15,000 randomly located smart lights, which is surprisingly low.
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- The attack proceeds entirely via the ZigBee radio frequencies and protocols, which are not currently monitored, so it’s hard to locate the infection source.
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• The attack proceeds entirely via the ZigBee radio frequencies and protocols, which are not currently monitored, so it's hard to locate the infection source.

• It does not use any TCP/IP packets, and thus cannot be stopped by standard internet security tools.
What the Attacker Can Actually Achieve:
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- The attacker can permanently brick all the smart lights
- The attack can simultaneously turn all the city’s smart lights on or off, possibly affecting the electricity grid
- Cause epileptic seizures in photosensitive people
- The attacker can disrupt WiFi communication since WiFi and ZigBee share the same frequencies
Responsible disclosure
Responsible disclosure

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We contacted Philips and disclosed the vulnerabilities prior to publication.
- The protocol implantation bug was fixed and an update was rolled out.
- The software update process remains vulnerable.
What went wrong?
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• Without really thinking about it, we are going to populate our homes, offices and neighborhoods with billions of tiny transmitters/receivers.

• These new IoT devices have ad-hoc networking capabilities built in, which has the potential to create a new communication medium, in addition to the traditional mediums of telephony and the internet.
More information and videos

Paper site - iotworm.eyalro.net

Eyal Ronen - eyalro.net
Colin O’Flynn - colinoflynn.com