

HARVARD EXTENSION SCHOOL

The IoT Application of the Nest Cam Indoor

Brett Bloethner

7/22/2018

Homework 2

CSCI S-78/Wearables and IoT

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1. Introduction

A home intrusion happens in the United States every thirteen seconds. Often times these intrusions lead to much more than only theft. In fact, one out of every three residential assaults occur as a result of a burglary. If these facts aren't alarming enough, realize that police only solve fewer than 14% of reported burglaries due to a lack of physical evidence or witnesses. Without the proper security measures in place, residential properties are far more susceptible to burglaries. Properties without security systems are three times more likely to be broken into and according to the FBI, home intrusions are the most common threat to American's homes. The public knows this and so does the IoT market. (Security Statistics, 2010)

One popular solution to this problem is the connected security camera. With features such as remote viewing and virtually indestructible video evidence of home intrusions, connected cameras promise to protect our houses, belongings, and loved ones from criminals. The market leader in connected security cameras is Nest and their Nest Cam Indoor (NCI) along with their industry leading cloud service known as Nest Aware.

In this paper we'll show how the NCI benefits residents everywhere. We'll also get into the nitty gritty details regarding how the camera, Nest Aware, and other products in the Nest ecosystem interact together. To wrap it up, we'll discuss some of the challenges the device faces in the market from social aspects to legal and regulative troubles.

2. Benefits of the Nest Cam Indoor (NCI)

2.1 Handle Intrusions Safely and Remotely

The NCI's main value add is that it gives a user observability over their residence when they're away from home but it provides a few additional useful features as well. Alerting and recording capabilities enable the NCI to provide an entirely new user flow for detecting and handling home intrusions. With the NCI, users can get notified of an intrusion, view the intrusion in progress, talk to the intruders via the NCI's speaker, and call the authorities to have them respond to the incident, all in a matter of minutes and all remotely from their mobile devices. Video footage from the NCI is also recorded 24/7 and kept for up to 30 days, allowing you to use the video as evidence in case your residence is broken into.

2.2 A Deterrence and Sense of Security

The NCI also provides a much-needed sense of security for home owners when they're away. With 3rd party integrations from companies such as Petnet and Mimo, and made possible by Nest's innovative Weave standard, users can monitor their pets and children in addition to their residence. Users can even see who's on camera using Nest's Familiar Face facial recognition feature, that way they're not alarmed when a trusted individual arrives home. Like many other security devices, the NCI also comes with a window sticker showing a NCI is on site so that its presence alone can serve as a deterrent for would be home invaders.

2.3 Extend the Capabilities of Your Smart Home

Nest's Weave standard enables the Nest ecosystem of products to convert a user's home into a truly smart home. Each Nest device is designed to contribute holistically to the functionality of what Nest envisions a smart home to be. Using Weave, the NCI can talk to other Nest devices and even third-party devices that are designed to conform to Works with Nest standards. This gives the user the benefit of feeling like they're interacting with their smart home rather than just each individual IoT device alone.

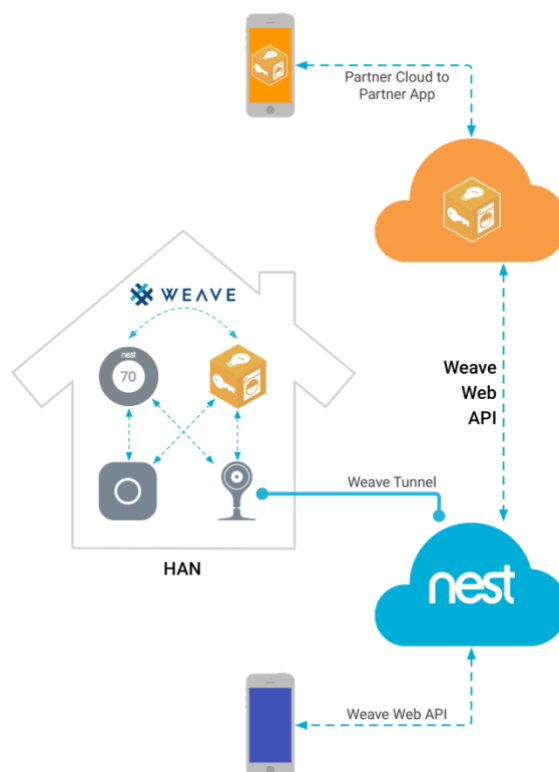
3. System and Network Architecture

The NCI requires wireless internet connectivity. Once connected and configured, Wi-Fi is used to send and receive commands, data, and video streams, using Weave technology, to and from the Nest and Nest Aware apps as well as other devices and apps in the Nest ecosystem. Nest takes advantage of common and custom middleware and architecture standards, which we will discuss in these subsequent sections.

3.1 Nest's Custom IoT Standard

Nest began building IoT devices and noticed the industry had no concrete standard they could take advantage of. Their innovative products required security, connectivity, reliability, efficiency, and redundancy that could support daily smart home use cases. No one provided a blueprint for this. Their solution was to create "a secure and reliable communications protocol that works with a wide range of hardware" (Nest Labs, 2018). Nest used Thread Group's private network protocol, known as Thread, to create their own open source version known as OpenThread. Nest went one step further by using OpenThread to create Weave, the standard that powers all Nest devices. In this paper we'll look at Weave and OpenWeave, Nest's open source variant of Weave.

Weave was carefully built after years and years of in house product development and close consideration of the problems they faced when creating smart home IoT devices without Weave technology. The company's main goals were to use compact message formats, provide secure communication methods, and only send data when absolutely necessary. What came out was an energy efficient standard capable of backing some of Nest's most processor and memory constrained products; the Nest Thermostat and the Nest CO alarm. Weave also solves one of the biggest problems facing IoT devices today; what happens if the internet goes down? Weave enables devices to communicate directly with each other through a mesh network, bypassing the cloud when it's not available.



(Nest Labs, 2018)

Weave enables a gatekeeper sort of cloud server app to make requests into and out of the smart home system via a Weave Tunnel. Devices used for direct interaction of Weave enabled products

communicate with the home area network (HAN) through this tunnel via the Weave API. Without HAN access to the Weave tunnel, devices on the HAN can still interact with each other via a mesh network created using the Thread protocol. In the above example, Nest's cloud infrastructure provides API access to the Weave Tunnel and ultimately, Weave IoT devices on the HAN. The Nest apps and third-party apps controlling Nest products communicate with the Weave API via their respective internet connectivity capabilities. On the other hand, edge devices may have direct internet access to the Weave Tunnel via their internet connectivity capabilities or they may use the Thread protocol to connect to the internet and Weave Tunnel through another Weave device.

3.2 Weave/OpenWeave in Detail

Nest recently decided to take a huge step forward with their Weave standard by publishing the technology and calling it OpenWeave. OpenWeave's purpose is to give everyone the ability to painlessly create reliable and safe smart home IoT devices. It also helps promote Nest as a leader in the IoT space and promote compatibility with Nest devices across the market.

Weave/OpenWeave is built with six core tenets in mind; low overhead, pervasive architecture, robustness, security, ease of use, and versatility. We'll refer to Weave/OpenWeave as Weave throughout the rest of this paper.

3.2.1 Low Overhead

Weave is designed from the ground up to tackle ones of IoTs greatest obstacles; constrained specs on edge devices. According to OpenWeave, many current IoT standards and approaches revolve around the concept of creating server-based technologies in such a way that they can be adapted and scaled down for execution on IoT devices. OpenWeave took a contrarian approach and built their technology to best suit the constrained energy and processing capabilities of IoT edge devices. This equates to a much more efficient use of the energy and processing power

available in the smallest edge devices as well as scalability up to the demands of larger more capable edge devices. (Openweave, 2018)

3.2.2 Pervasive Architecture

From the beginning, Nest realized the importance of one standard to not only address the limitations of IoT devices, but also to glue together all technical aspects of a connected device's platform including those edge devices as well as the cloud services backing them. Weave accomplishes this 'one standard for all IoT' goal by building the standard on top of the already battle tested Internet Protocol design. According to OpenWeave, this approach enables "end-to-end addressability, reachability, and security, making it easier on developers" (Openweave, 2018) in any part of the stack by only requiring knowledge of IP and Weave.

3.2.3 Robustness

Weave gives IoT devices the reliability customers demand from tried and true technologies. Our textbook points out the difficulty of building IoT device failsafes to account for intermittent connectivity and complete loss of internet access. Weave solves this problem by incorporating another open Nest standard, adapted from the Thread Group's Thread protocol, known as OpenThread. This protocol uses the network layer of IoT edge devices to create a mesh network with no single point of failure in the smart home system. This allows Weave devices to communicate with each other to reroute internet access when one device fails or when there is a complete loss of internet access across the network, enabling some system features to continue functioning despite outages. (Openweave, 2018) (Thread Group, 2018)

3.2.4 Security

Standard AES encryption is incorporated into the OpenThread protocol underneath the Weave standard. A product install code system is featured and requires that devices must be authorized before they can join an OpenThread/Weave network. OpenWeave also claims to incorporate

cyber defense with end-to-end application security and “tiered trust domains with application specific groupwise keys.” (Openweave, 2018)

3.2.5 Versatility and Ease of Use

Weave was designed with scalability in mind, with support for smart home networks with only a few Weave devices as well as smart home networks with well over 100 Weave devices. Weave is also designed to be versatile by allowing the standard to support many models and platforms whether it’s device-to-mobile, device-to-PC, device-to-device, or device-to-service, just to name a few. All of this equates to an easier job for engineers and designers building the product as well as users who are blessed with a more robust and reliable smart home IoT system. (Openweave, 2018)

3.3 Network Efficiency

Usually network usage and energy efficiency are closely coupled when it comes to the design of connected devices. However, when the device is afforded constant power from a reliable power source, network efficiency is much less of a concern. The Weave standard allows for network efficiency, promoting small messages and recommending communicating only when necessary. The NCI opposes these concepts though primarily because the device is designed to constantly record video and save it on the cloud. The NCI is sort of an anomaly in this sense, since many of its competitors store partial videos only after activity has been detected. In fact, Nest prides themselves with the fact that their camera is constantly recording. It seems as though network efficiency isn’t a huge concern for Nest and their line of connected cameras.

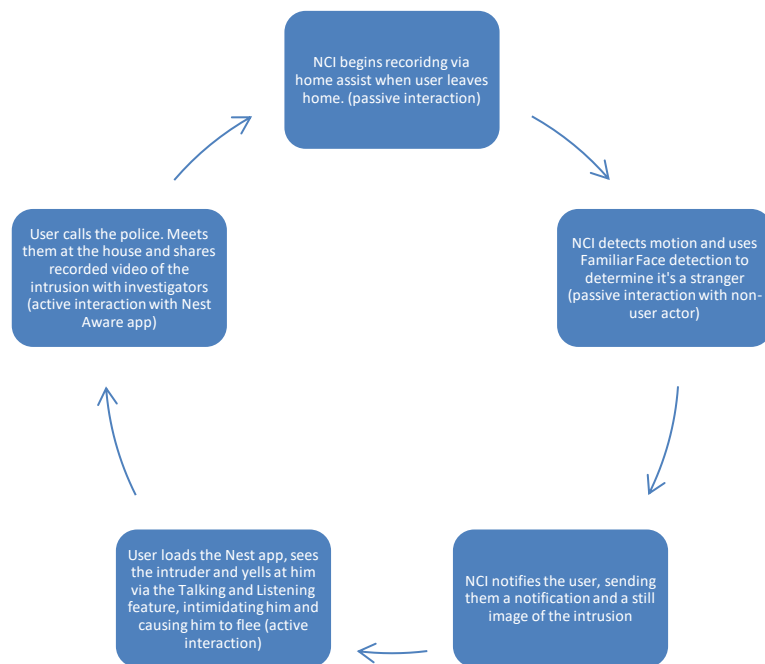
“Some cameras can’t stay on all the time because they rely on batteries, so they only start recording when they sense motion. But if they miss something, you do, too. With a Nest Aware subscription, Nest Cam continuously records 24/7. And saves up to 30 days of footage securely in the cloud. So you never miss a thing.” (Nest Labs, 2018)

3.4 Works with Nest

The “Works with Nest” program takes advantage of the Weave API to extend the Nest ecosystem beyond the smart home product line and services only Nest provides. Works with Nest devices are officially approved by Nest for compatibility with specific Nest products and software. Through the Works with Nest program, Nest is able to further the reach of their platform to markets they have no real presence in such as smart lighting or smart home dimmers and switches. The robust Weave standard enables these 3rd party devices to interact with Nest products and services with certainty and reliability.

4. How it works. User Experience and Interaction.

The mission of the NCI is simple; allow users to observe their home remotely from their mobile device. In practice, the concept is much more complex, the user flows allow for many other added features but the mission of remote observability via video stays the same. The below diagram is a simple but powerful use case for the NCI device and system.



4.1 Interaction Design

One of the most intriguing aspects of the interaction design of the NCI is its lack of buttons. Like many other consumer IoT embedded devices, the setup, configuration, and interaction are done entirely via mobile app. Once the device setup is complete, the user experience and interaction are painless and simple. Since the initial setup is such a vital part of the design, we've discussed that in detail as well.

4.1.1 Initial Setup

Setup of the NCI requires the Nest mobile app. After the user chooses to add a NCI in the app, they're asked to scan the QR code printed on the back of the NCI. Next, they give their camera a location name and plug it in. The Nest mobile app will guide them through connecting their NCI to their Wi-Fi network after the NCI has finished booting. This obviously isn't conducted via Wi-Fi since the NCI has yet to be configured for the user's network. The Wi-Fi configuration is most likely done with the NCI's only other communications capability, Bluetooth 4.0 Low Energy (BLE). This is also suggested via a security flaw discussed later in this paper. (Nest Labs, 2018)

4.1.2 Watching and Sharing Camera Video

All of the interaction involved with watching and sharing video history is done in the Nest Aware app. They recommend using the mobile version, so we'll look at that platform here.

Nest Aware features a "Sightline" view which lets the user scrub through a timeline of what their camera has recorded. Features called "Activity Track" and "Activity Snapshot" allow the user to easily identify positions on the timeline where events occurred. Video clips can be created and shared by tapping a "New Clip" icon at a specific time position. The app will then take the next 2 minutes and 30 seconds after the selected position, wrap it into a video clip, and give you the option to download it to your phone or share a link to a copy of the video on the web. Only after

the video has been downloaded or a link created, can you watch the actual video on a mobile device unless you're using the Event History feature. This seems as though it could be an effort on Nest's part to limit bandwidth by restricting live video scrubbing capabilities on mobile devices.

The "Event History" mode highlights motion and sound activity that the camera has detected and provides a video, snapshot, activity name, and timestamp of when the activity occurred. Event clips may be saved in their entirety in the Nest app, after which you can save them to your phone or share them via a web link.

The primary use case for the NCI is viewing camera footage via a mobile device, which is why that's the only interaction method described in length in this paper. However, it is important to note that the capabilities are slightly different between the Nest Aware mobile app and the Nest Aware desktop web app. The most notable of which are the ability to create clips that are 1 hour in length rather than 2 minutes and 30 seconds and the ability to create timelapses of 6 second, 15 second, 30 second, 1 minute, or 2 minute intervals. (Nest Labs, 2018)

	Phone or tablet	Computer
Create clips	Up to 2 minutes 30 seconds per clip	Up to 1 hour per clip
Create timelapses	No	Yes
Share clips	Yes	Yes
Download clips	Only clips created with your phone or tablet	All clips and timelapses
Watch clips	Only clips downloaded to your phone or tablet	All clips and timelapses

from (Nest Labs, 2018)

Of course, NCI video can also be watched live. This is done by simply tapping on the “Go Live” button while in Sightline or Event History mode. Zooming on video is done via the standard pinch action. A calendar feature is also provided and allows the user to easily jump from one day’s video to another’s (Nest Labs, 2018).

4.1.3 Talking and Listening with the NCI

A microphone and speaker on the NCI device allow users to listen to live audio from the device while speaking into their mobile phone with their voice coming out of the NCI’s speaker. This could serve as a scare tactic against intruders if a user receives an alert that an intruder has entered the home. A fun use case for this feature is using it as a way to command a pet remotely to behave or get off of furniture, a use case Nest uses in their marketing materials.

4.1.4 Sharing and Family Accounts

Nest gives users a few options in regard to how they’re able to share video. A family account can be created by inviting members to your account via the Nest app. As long as the inviter has a Nest Aware subscription, the invitee will get nearly all the access to the NCI that the inviter has. Users can also share their NCI’s live video stream via a password protected link and, oddly enough, a completely open public link. The latter shows that Nest understands there may be use cases for the NCI beyond only home security (Nest Labs, 2018).

Sharing method	What's shared	View live stream	View video history	Alerts	Control cameras
Family Account	All cameras	yes	yes	yes	yes
	(and other Nest products in the home)				(and other Nest products in the home)
Public	Selected cameras	yes	no	no	no
With password	Selected cameras	yes	no	no	no

from (Nest Labs, 2018)

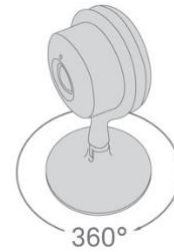
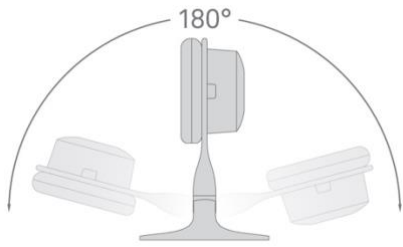
5. Industrial Design Overview and Energy Considerations

5.1 The Nest Hinge

A prominent hinge is noticeable where the NCI stem meets the base. At first sight this looks like a simple hinge and an obvious feature for any camera similar in form factor. However, according to Nest Engineering & Design, the agility of the NCI hinge is one of the main features which enabled their product to dominate the market.

After an in-depth evaluation of our own indoor camera and user trends, one of our top insights was that offering huge hinge articulation was one of the key differentiators that made our Indoor Cam so successful in the market.
(Tristin, 2017)

The powerful hinge on the NCI allowed camera users to take advantage of an increased range of articulation. This meant users could place and mount the NCI in positions, places, and angles that competing products simply couldn't go.



(Nest Labs, 2018)

5.2 More Articulation

Nest designers realized the importance of articulating the NCI to the perfect angle, so they didn't stop their effort for versatility at the NCI's hinge. The NCI also features a 360-degree rotation feature at the lenses mount location and if that still isn't enough, the NCI can be removed from the chassis entirely and attached to mounts from third part manufactures.



(Amazon.com, 2018)

5.3 Requirements and Operating Context

The NCI requires and operates primarily via a Wi-Fi internet connection and is compatible with 802.11 a/b/g/n (2.4GHz & 5GHz) standards. Setup and configuration require and are completed via the NCI's only other communication capability, Bluetooth Low Energy. The only remaining requirements are the Nest app (Nest also recommends the Nest Aware app), a Nest account, and an active power outlet. The device is designed for indoor use only (32 degrees to 104 degrees / 10% to 90% humidity) and, despite its various mounting capabilities, has no certifications or ratings for ruggedness or reliability.

5.4 Hardware and Capabilities

A 1/3-inch 3MP color sensor is featured on the NCI and is coupled with a 130 degree wide-angle glass lens and destructive live 8x digital enhancing zoom as well as a non-destructive 8x digital non-enhancing post-zoom for video history. The live 8x enhancing digital zoom will zoom into and enhance a spot in the viewing field while also cutting out all the peripheral viewing area.

(Nest Labs, 2018) Video is encoded at up to 1080p at 30 frames/sec in a standard H.264 codec.

Night vision is also an important capability for security cameras. Nest achieves this with their NCI by using high powered 850nm infrared LEDs to illuminate the viewing area in low light conditions. In bright conditions the NCI will engage an IR cut filter to preserve color and fight distortion caused by IR light in the daylight. (cctvgold, 2018)



(Nest Labs, 2018)

One speaker and one microphone are also built into the NCI body for the “Talk and Listen” feature and allow two-way communication via the app and device as well as audio recording. Various status LEDs are positioned on the front of the unit above the lens and reflect camera, network, and talk and listen status (Nest Labs, 2018).

5.5 Energy Considerations

The NCI requires constant power from a standard USB power adapter connected to the camera via a standard USB to USB-micro cable. (Nest Labs, 2018) Competing IoT camera devices feature backup battery operation but are target more toward a complex use case such as travel or outdoor remote monitoring. Nest markets the NCI as a simple entry level indoor camera designed to provide high quality video reliably, so it makes sense that the NCI would require constant power rather than compromising video quality or reliability for the cost of engineering a battery into the design.

6. Service Design

A user begins by purchasing the NCI at any electronics retailer. After the initial setup interaction is completed (see section 4.1.1), the user simply sets it and forgets it until a situation arises when they need to review video. Most of the interaction with the device is direct interaction, although the device can be configured to trigger or be triggered to provide alerts based on passive interaction from actors walking through the NCI's viewing angle. Access to some form the Nest Apps are required, although Nest specifically recommends using the Nest Aware app with a paid membership and via a mobile device. Configuration servicing and troubleshooting can be done by the user via the Nest app, which makes the user a technician to some extent. Like many other consumer electronics companies, Nest provides technical support via chat, email, phone, and social media, further enabling the user to serve the role of technician. Hardware issues are more complex and will most likely result in a warranty repair from a professional electronics technician by or on behalf of Nest. Once the user has reached the end of the user lifecycle, they simply recycle their NCI and delete of their Nest account, removing their stored videos.

7. The Nest Ecosystem

The Nest ecosystem includes numerous devices design to work with the NCI. Nest's public API and Weave standard also allow other manufactures to make devices designed to integrate seamlessly with the NCI. The table below outlines a few of the most popular devices in the Nest and Works with Nest ecosystem, each of these devices connects to the NCI over the internet using the IP protocol and Weave standard.

Device Name	Manufacturer	NCI Interaction
Nest Protect (Smoke & CO Alarm)	Nest Labs	<ul style="list-style-type: none">• Device triggers NCI to cut, process, and send a video clip once smoke or CO is detected
Philips Hue Lightbulbs	Philips	<ul style="list-style-type: none">• NCI triggers lights to turn off after prolonged motion inactivity• NCI triggers lights to turn on after it sense activity while you're away
LIFX Lightbulbs	Lifi Labs	
Garage Door Opener	Chamberlain	<ul style="list-style-type: none">• Device triggers NCI to begin recording once the garage door is activated
SmartFeeder	Petnet	<ul style="list-style-type: none">• Device triggers a snapshot from the NCI once it detects the pet is feeding
Mimo Baby Tracker	Mimo	<ul style="list-style-type: none">• Device triggers a snapshot from the NCI once it detects the infant has moved

7.1 Nest App Family

The Nest app provides the core functionality for the NCI including the initial setup flow as well as rudimentary access to the NCI's camera features and alerts. To experience all the NCI has to offer, Nest recommends downloading and using both the Nest app for whole home control and the Nest Aware app for advanced camera functionality. The Nest Aware platform is a subscription service and its pricing corresponds to the length of time that Nest will store your cameras recorded video for. Both of these apps are available on iOS, Android, and as a desktop

web app. All of the NCI's user interaction is conducted via Nest apps, so the experience is discussed throughout this entire paper rather than in this one subsection.

8. Challenges

8.1 Legal Challenges in Illinois

One of the most useful features of the NCI is the Familiar Face detection system. This feature uses facial recognition software from Google to determine if the actor activating the camera is a known trusted individual or a stranger who may be a threat, then the Nest app alerts the user accordingly. Nest has faced some fierce opposition against the use of facial recognition technology, with one example being in the State of Illinois legislature. Illinois enacted legislation enforcing strict regulations on the collection of biometrics such as facial image data. As a result, Google's facial recognition software is not being made available in Illinois which means Nest's valuable Familiar Face alerting system is also unavailable in the Illinois (Townsend, 2017). Nest doesn't seem to be fighting this legislation, they simply state on the bottom of the marketing materials that Familiar Face is unavailable in the State of Illinois.

8.2 Cyber Security Challenges

Security challenges are a constant concern for any connected device manufacturer. Nest is no exception and the nature of the NCI, being a security measure and often placed in private areas, makes the device even more of a target. One prime example of a security flaw the NCI experienced was uncovered by a cybersecurity engineer named Jason Doyle, who claimed to have found three Bluetooth related security flaws regarding the NCI and other Nest cameras in 2016.

"The first two involve sending either a wi-fi SSID parameter or a wi-fi password parameter to the camera via Bluetooth. In either case, the camera will crash and reboot, giving a potential burglar about 90

seconds to enter a home undetected. The third vulnerability lets a hacker disconnect the camera from the network altogether by sending it a new, non-existent wi-fi SSID parameter via Bluetooth.” (Estes, 2017)

Nest did release a fix for this bug but cybersecurity will still be a constant battle for Nest, the NCI, and the Nest ecosystem. Programs such as bug bounties may help the company discover exploits before they’re made public but Nest will ultimately need to set security as a number 1 priority and enforce strict policies and sound engineering principals while developing new products and features if they hope to minimize their product’s and service’s exposure to cybersecurity threats.

8.3 Privacy

Most users don’t want to be recorded while they’re home, their primary concern is observability while they’re unable to monitor their residence in person. Nest and the NCI have two solutions to this challenge. With the Nest Aware app, a user can schedule their NCI to record only at certain times. The Nest Aware app also features a “Home/Away Assist” setting which uses the user’s mobile device’s location to determine if they’re at home, activating the NCI to record only while they’re away.

8.4 NCI’s Power Requirement

The NCI’s lack of a battery may allow for lower cost and better signal processing, video, and transmission of data, but it also has a few negative impacts on the user experience with the most obvious being that while there is no power there will be no recorded video. A user could easily fix this by using some sort of external backup battery to power the NCI during outages. Nest fails to address this downside in any of their marketing or support materials so one has to assume this camera shouldn’t be used for any sort of high profile security where attackers may think to cut the power to a residence before breaking in. Fortunately, Nest did address the NCI’s energy

efficiency, claiming their cameras never use more than 9 watts of power with the infrared LEDs active and far less than 9 watts while the infrared LEDs are off (Nest Labs, 2018).

9. Conclusion

The Nest Cam Indoor (NCI) is an extremely useful connected device. It serves a vital role in many households as one of the first lines of defense against intruders and does so using state of the art technology and engineering standards. As a connected device, the NCI serves as a perfect example of new connected technology fitting perfectly into the smart home/consumer applications niche and addressing a need many home owners have; safety. But there's a hidden benefit of the NCI and Nest ecosystem as well and that's the demand that the technology put on the market for the new cutting-edge Weave standard that backs the NCI and Nest ecosystem. The NCI and Nest products are unique in that respect since if it wasn't for these products, Weave may not exist and many future IoT consumers may have worse experiences with future products that wouldn't have had the luxury of taking advantage of Weave. It's entirely possible that future IoT consumers may be reaping the benefits brought on by the NCI and other Nest products without ever having actually purchased one.

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