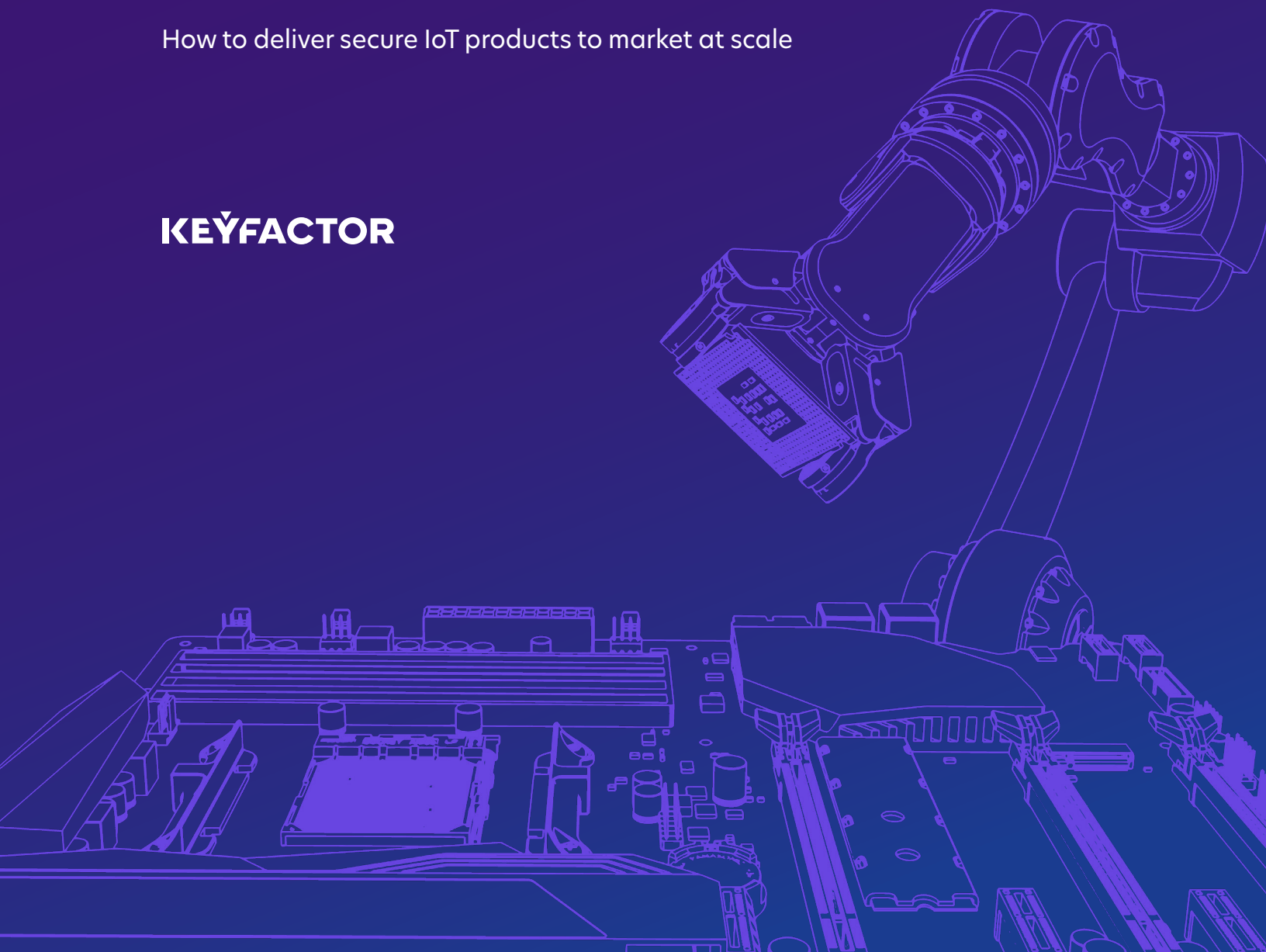
WHITE PAPER

PKI: The Solution for Building Secure IoT Devices

How to deliver secure IoT products to market at scale

KEYFACTOR



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Introduction

This white paper will discuss the security challenges that IoT developers and device manufacturers face, how PKI can address these challenges, and the unique considerations for design, deployment, and management of PKI for IoT devices.

The Internet of Things (IoT) is transforming the world we live in — and fast. Companies are now deploying billions of network-connected devices into mission-critical environments such as medical devices, industrial and manufacturing control systems, and built-in vehicle sensors.

Manufacturers increasingly enable network-connectivity in their products to improve features, functionality, ease of use and installation. For all the advantages these connected devices bring, inadequate security practices during design and manufacturing can quickly undermine trust and safety of end users.

As more stringent customer requirements and industry regulations emerge, manufacturers need a scalable solution to address critical security concerns, such as authentication, data encryption, and integrity of software and firmware on their devices. Ensuring that IoT solutions meet these key requirements is critical, not only for today's threats, but future product and security lifecycle challenges.

PKI has been the foundation of internet security for decades through the widespread use of SSL/TLS certificates. With the emergence of IoT, it's also become an instrumental tool in securing the next generation of industrial and consumer-driven connected devices.

Digital certificates allow manufacturers to implement strong authentication, encryption, and integrity into each device right from design through deployment. Digital certificates are not only cost-effective and efficient, but also lightweight and scalable. This makes PKI an ideal fit for resource-constrained devices and high-volume production.

While PKI is the foundation of security in most enterprises today; implementing a PKI that can support IoT deployments differs significantly from a typical enterprise PKI. Product engineers and developers must address complex hardware supply chains and product lifecycles, often with limited or no knowledge of PKI or cryptography.

IoT Market Opportunities

Beyond the buzzword, IoT is defined as a network of physical objects that can interact with other internet-enabled systems and devices to share information and perform actions. In other words, IoT bridges the gap between our physical world and the digital world.

While the practical application of IoT is just beginning, product innovators are leading the way. A range of Internet-connected 'things' have already been deployed across various industries — from wearable consumer devices and smart home appliances to mission-critical systems such as driverless cars, electrical power grids, and medical devices.

Connected Vehicles

Ironically, one of the most appealing benefits of connected cars is enhanced safety, whether through predictive maintenance of critical components, accident avoidance courtesy of sensors and AI, or precision control of safety features such as airbags and brakes. In reality, though, these connected systems have proven to be vulnerable to hacking, leading them and the entire vehicle to be viewed as a target.

Medical Devices

Real-time monitoring and over-the-air (OTA) updates offer patients, physicians, and healthcare providers significant advantages. However, medical IoT poses security risks on multiple fronts. Attackers can compromise a medical device to breach connected networks, or worse, alter or modify the controls of the device itself, causing potentially fatal results.

Hardware OEMs

IoT is not a new concept to hardware manufacturers — network routers, smart locks, Wi-Fi enabled thermostats and security cameras are just a few examples of connected products that have been on the market for years. However, many of these devices still have little to no security features in place, leaving them ripe for the picking by hackers seeking to build a botnet or compromise data.

Industrial IoT (IIoT)

The IIoT (known as Industry 4.0) delivers many benefits for utilities, transportation, and industrial manufacturing. The applications are endless, as more connected sensors, actuators and controllers are being deployed into manufacturing plants, energy grids, planes and high-speed trains. If attacks by nation-states and persistent threat groups are any indication, IIoT security is lagging far behind.

Technology advancement such as 5G networks, low-cost sensors, miniaturized batteries, and the proliferation of cloud and big data continue to drive market growth and opportunity for the IoT.

As hardware and device manufacturers continue to introduce network stacks into their products, engineers that have not previously had to think about secure communications and systems design now face serious challenges as they attempt to integrate security controls.

IoT Security: Risks & Regulations

Current threats to IoT devices have moved beyond proof of concepts to practical and feasible attacks, as both hackers and manufacturers seek to capitalize on IoT opportunities. Most IoT devices deployed today have poorly implemented security, as manufacturers continue to ship devices with default passwords or shared cryptographic keys across all devices — hack one, and you can hack them all.

Recent examples of IoT device compromises are relatively easy to find online, and serve as reminders that security best practices must be implemented when launching a new IoT product. It is critical that manufacturers perform a full risk assessment to understand how the device will be used throughout its lifecycle, and how to mitigate current and future risks it will face.

Here are some of the most common security risks related to poor implementation of IoT identity and authentication:

Weak Authentication

Attacks such as the Mirai botnet have proven existing safeguards ineffective, using weak default credentials to brute force access to devices at massive scale and deploy malware that turns them into remotely controlled "bots" to launch distributed denial of service attacks.

Many low-cost IoT devices such as connected insulin pens, routers, or cameras have limited data and capabilities, so manufacturers often invest little into security. However, the device itself is not nearly as important as what the device has access to. These products should never be shipped with default or static passwords that cannot be easily changed by the end user.

Hardcoded Credentials

Manufacturers also commonly hardcode passwords or keys into software or firmware on IoT devices to simplify deployment at scale. Developers may also embed credentials in plain text into source code to access them easily when they need it. If these embedded passwords or keys are discovered or published to the Internet, anybody with knowledge of the credentials could access the device.

> **Weak, guessable, or hardcoded credentials are the biggest IoT security problem, according to the OWASP Top 10 IoT Vulnerabilities.[1]**

Shared & Unprotected Keys

Some IoT devices use symmetric encryption, where identical keys are used to encrypt and decrypt data. While more secure than static or hardcoded credentials, problems often arise in securely provisioning and storing these keys. If the key is leaked on either the device or other connected endpoints, the entire system is compromised. This is further complicated when an ecosystem contains millions of endpoints. At this scale, key management becomes costly and complex to maintain, without the right toolset.

[1] https://www.owasp.org/images/1/1c/OWASP-IoT-Top-10-2018-final.pdf

Asymmetric encryption addresses the issue of shared keys, since it uses a pair of different, but mathematically related keys. The public key can be openly distributed — only the private key needs to be protected. However, if the private key isn't stored securely, the device can still be compromised. Developers with tight timelines often do not understand the importance of protecting these keys — until it's too late.

NOT SO PRIVATE KEYS

In January 2020, developers at network equipment manufacturer Netgear embedded signed TLS certificates and private keys in device firmware, which was publicly available for download on their site, and shipped with devices. The leak raised serious concerns about the potential misuse of keys by hackers to intercept connections or tamper with devices.[2]

Weak Encryption

Encryption is only as strong as the cryptographic keys and algorithms that underpin it. If implemented correctly, encryption is virtually impenetrable, but the use of weak algorithms and poor entropy sources continue to undermine the cryptography used in IoT devices today.

The problem largely centers around lightweight devices with limited power that are unable to generate enough entropy, or random input, needed to produce strong encryption keys. This lack of sufficient random number generation makes it possible for attackers to derive the private key and compromise the device.

THE RISK OF PREDICTABLE RANDOMNESS

Keyfactor analyzed 75 million RSA certificates collected from the Internet and found that 1 in every 172 certificates is vulnerable to attack due to poor random generation. Using a single Microsoft Azure virtual machine, at a cost of about $3000, the team was able to break nearly 250,000 RSA keys in about 18 hours. Most of the vulnerable keys were found in embedded IoT devices.[3]

Unsigned Firmware

Software developers have adopted code signing to verify the authenticity and integrity of code they push into production. The problem is that IoT devices often lack the same security checks and balances that we take for granted in traditional IT devices. Many IoT products in the market do not verify that firmware is properly signed with a trusted public/private key before running the code.

In a 2016 proof-of-concept hack, researchers were able to compromise the electronic systems of a Tesla Model S vehicle from 12 miles away. The hack targeted the controller area network (CAN Bus), a collection of connected computers found inside modern vehicles that control everything from indicators to brakes. Tesla released an update following notification of the attack, requiring all new firmware updates to be digitally signed.[4] Despite efforts by automotive manufacturers like Tesla, the industry has seen a 94% year-over-year growth in hacks since 2016.[5]

[2] https://www.hackread.com/netgear-vulnerability-exposed-tls-certificates-to-public/

[3] https://www.keyfactor.com/resources/factoring-rsa-keys-in-the-iot-era/

[4] https://www.wired.com/2016/09/tesla-responds-chinese-hack-major-security-upgrade/

[5] https://www.cnet.com/roadshow/news/2019-automotive-cyber-hack-security-study-upstream/

Evidently, it's not just malicious hackers that manufacturers are concerned about. Security researchers and white-hat hackers continue to disclose IoT vulnerabilities to the public, putting pressure on manufacturers to respond.

Similar vulnerabilities in connected medical devices such as pacemakers and insulin pumps have led to recalls and warnings as early as 2011. In 2017, the US Food and Drug Administration (FDA) recalled 465,000 pacemakers after discovering security flaws that could allow hackers to drain batteries or send malicious instruction to modify a patient's heartbeat.

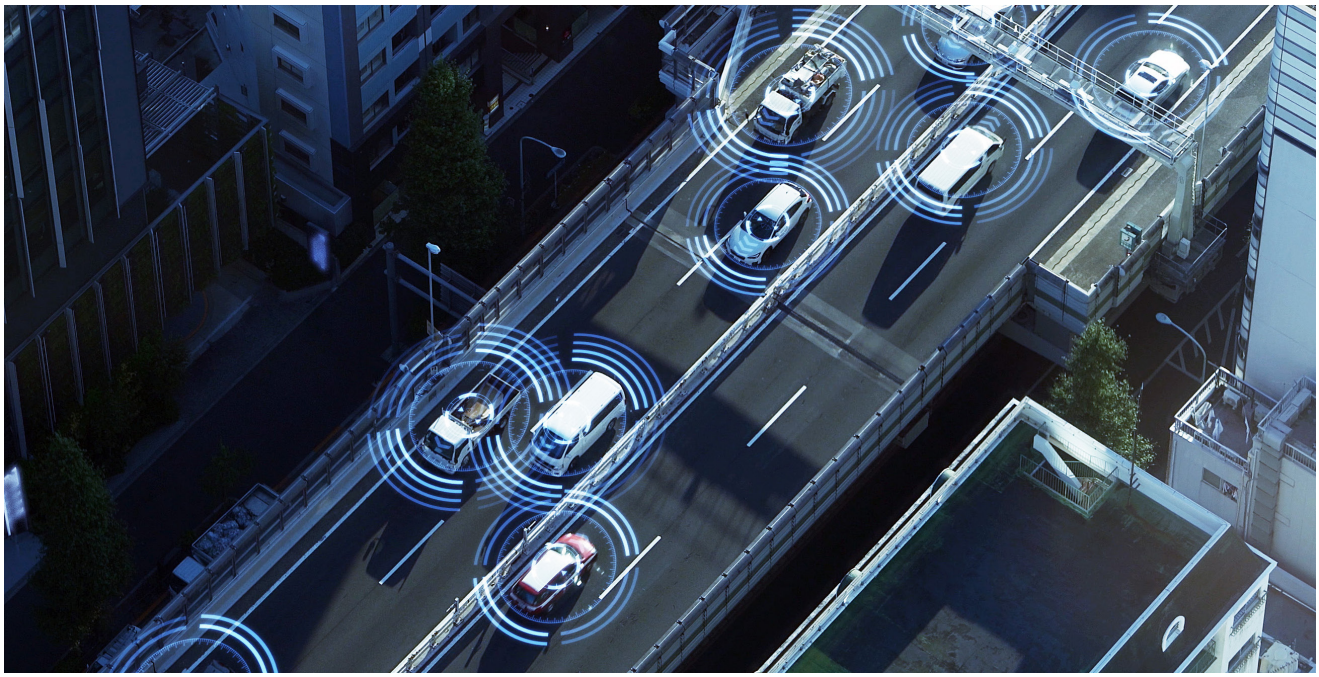
The financial impact of these incidents can reach into the millions — including warranty costs, incident response and remediation efforts, and long-term impacts to brand reputation.

IoT Regulations on the Horizon

As IoT devices become ubiquitous, industry regulators are becoming more aware of the potential risks to data privacy and the safety of end users. IoT products are already falling under increased scrutiny when it comes to reliability and overall cybersecurity preparedness — the Californian IoT security regulation bill SB-327 (put into effect on January 1st 2020) now requires that all connected device manufacturers use unique credentials for each device.

Other industries and regions are in the process of defining frameworks and guidelines to help align manufacturers with security best practices. The FDA has released pre- and post-market guidance for medical device manufacturers to meet cybersecurity requirements for market submissions. The Industrial Internet Consortium (IIC) and the IoT Security Foundation (ISF) have also developed security frameworks to address foreseeable problems.

While current laws and regulations are relatively lax, the landscape is changing quickly. It's therefore critical that device manufacturers regularly assess their regulatory requirements, and ensure that devices currently in design and development are intended to live up to standards today, and into the future.



Product & Operational Requirements

Polished standards or not, the IoT train has left the station. Manufacturers can no longer design today and deploy with the hopes of securing equipment and devices later. Unlike our experience in the world of traditional IT, the inherent nature of IoT devices means that a deploy first, secure after approach would be costly, ineffective, and in most cases, just not possible. Those factors include the sheer magnitude of IoT deployments, where 100,000 devices can be a modest starting point. The diversity of hardware, software and protocols is another factor, as is the reality that most IoT devices are headless, deployed broadly, and never touched again.

Digital Certificates — A Good Fit for IoT

PKI is the de facto standard for IoT identity. Digital certificates issued from a trusted PKI offer a secure identity layer that is both scalable and lightweight to enable authentication, encryption, firmware signing and verification on millions of embedded IoT devices.

Authentication

Every device needs a trusted and unique identity to verify authenticity and securely connect within the IoT ecosystem.

Device Integrity

Firmware updates must be digitally signed to prevent tampering and ensure only authorized code runs on the device.

Data Encryption

Encrypting sensitive data at-rest and in-transit is becoming increasingly important to comply with data privacy requirements.

> "PKI provides highly-proven certificate provisioning standards that match IoT requirements like automation, volume, and on-device or on-server key generation."
>
> Gartner, Architecting Identity for the Edge of IoT Innovations, 2019

PKI: The Solution for IoT Security

Public key infrastructure (PKI) addresses the complexity and diverse security challenges of designing and delivering IoT products to market — enabling unique identity, authentication encryption, and secure over the air updates for millions of connected devices.

PKI is a trust framework composed of hardware, software, policies and procedures needed to manage trusted digital certificates and public key encryption. For decades, PKI has served as the backbone of internet security, now emerging as a flexible and scalable solution uniquely capable of addressing the data and device security needs of the IoT. The real advantage of PKI is manufacturers can implement these safeguards with minimal footprint on the device and at massive scale.

Advantages of PKI for IoT

Unique Identity

By embedding a cryptographically verifiable identity into each device, you can enable secure network access and code execution throughout the device lifecycle. Certificates can also be customized based on manufacturer policy and updated or revoked on a per-device basis.

Open & Flexible

PKI is an open standard that allows you to define a system cryptographically, with flexible options, trusted roots, revocation, and standard protocols for certificate enrollment and deployment — such as REST API, SCEP, and EST.

Highly Scalable

Using asymmetric encryption means that all certificates can be issued from a single trusted sub-CA that is tightly controlled. This disconnected verification model allows devices and applications to authenticate to one another without the need for a centralized server.

Robust Security

Digital certificates issued from a well-managed PKI offer much stronger protection than other authentication methods. Cryptographic keys can also use secure hardware elements and have validity periods that far exceed the usable lifetime of passwords or token.

Minimal Footprint

Even devices with low computational power and memory can use asymmetric keys. Elliptic Curve Cryptography (ECC) is quickly becoming the algorithm of choice for IoT, using smaller key sizes ideal for networked devices and sensors.

Proven & Tested

PKI is a proven and time-tested tool used to secure most networked devices and applications today. Industry experts now recognize PKI as a practical and scalable solution for IoT devices that require strong protection against device hijacking, data theft, or ransomware attacks.

PKI for Product Security vs Enterprise PKI

PKI is a fundamental security tool used by most organizations today, but enterprise PKI is far different from a PKI required to fit within complex hardware supply chains and IoT device lifecycles, especially for device manufacturers with little to no knowledge of cryptography.

Innovators that can provide strong security at scale will be able to differentiate their products, protect their brand, and prevent warranty claims or device recalls that can cost millions. PKI — if properly designed and implemented — can be a compelling solution for scalable IoT security, but there are still some significant considerations that need to be addressed.

Scalability & Availability

The volume and velocity of certificate issuance required for the IoT is typically much higher than most enterprise PKI deployments. Certificate enrollment and issuance for IoT devices often occurs at a rate of thousands per minute, or even per second. All PKI components such as issuing CAs, revocation infrastructure, and HSMs must be configured to meet intended availability and performance levels.

Setting up a PKI requires that the manufacturer understand how to define architecture based on their use cases and operational requirements. They must also implement a PKI hierarchy and ensure that appropriate security policies and algorithms are used. Managing a PKI, especially without in-house expertise, is not for the faint of heart. Product leaders should consider a trusted managed PKI solution to address these needs.

Private Key Generation & Storage

Unlike web servers hosted in a physically secured and protected datacenter, IoT devices are typically deployed into places that are physically accessible to the public. Private keys must be kept on the device to ensure that it can authenticate to gateways, applications, and cloud services, but for PKI to work effectively, manufacturers need a way to protect them.

> "Internet of Things (IoT) authentication is the mechanism of establishing trust in the identity of a thing (for example, a device) interacting with other entities such as devices, applications, cloud services or gateways operating in an IoT environment."
>
> Gartner, Hype Cycle for Identity and Access Management Technologies, 2021

In the best case, private keys are generated within a secure hardware component and never exposed outside the device. It's not uncommon though for vendors to design devices unable to generate or store keys securely and then ship the product to another facility that knows little about the device or its security requirements. These considerations need to be defined upfront to avoid unintended risks down the road.

Certificate Policy

Certificate policy is not unique to IoT, but the need to adhere to policy is much greater, given the disparate nature of IoT ecosystems. Trust and assurance levels are defined by policy, in accordance with RFC 3647, and contained within the certificate. This is the part of a certificate that confirm what policy it adheres to, which proves why it is trusted. This kind of documentation is not only important for regulatory and audit requirements, it is also helpful for partners within the IoT supply chain to establish trust with one another.

Lifecycle Management

IoT has significant differences from enterprise PKI when it comes to certificate lifecycle planning. Manufacturers need to analyze the full device lifecycle to understand how identities will be provisioned and updated over time. This should also include response plans for cryptographic incidents such as algorithm degradation or a compromised root of trust.

Considerations for PKI in IoT:

- Where the certificate root of trust is hosted — determine if certificates are issued from an internal PKI, public CA, or managed PKI
- Where the certificates are stored — depending on capabilities they may be stored in a TPM or secure element embedded in the device
- Connectivity at the factory — whether certificates are generated locally, via a signed CA at the factory, or in advance
- Risks and regulations — determine the length of certificate validity, key sizes, algorithms, and required audit trails

Use Cases & Recommendations

Companies that provide strong identity for their IoT devices at scale can deliver to market faster and more securely, differentiate their products, and increase visibility across the IoT supply chain.

1 Trusted Device Identity & Provisioning

Securely provisioning an initial set of credentials to IoT devices can be challenging, but it is essential to ensure the authenticity of products that leave the manufacturing line. Using unique digital certificates for every device allows for granular management and tracking, since each one can be identified. With a private/public key pair and certificate embedded in secure chips that are manufactured into the device, identity is an integral part of the product.

Every certificate eventually ties into a root of trust, which is the foundation for PKI. A properly established root certificate authority (CA) is paramount to ensure trust is maintained throughout the product lifecycle. The root CA establishes trust within the IoT devices and all other entities that are authorized to create secure connections with the device. From the second the root is created, a chain of custody is established, which must remain intact from the minute it's incepted throughout its lifetime. If this chain of custody is broken at any time, every device is potentially at risk.

> "Unique passwords are better than static passwords, but passwords have no place at all within greenfield IoT solutions. Gartner recommends organizations instead use HRoTs — a type of secure key storage — and asymmetric cryptography to full trust IoT devices."
>
> Gartner, Architecting Identity for the Edge of IoT Innovations, 2019

DESIGN	MANUFACTURING	COMMISSIONING	LIFECYCLE	END-OF-LIFE
Define unique ID policy and determine appropriate crypto-libraries based on hardware or design restrictions.	Embed credentials, preferably using on-device key generation and a hardware root of trust (HRoT) to store private keys.	Authenticate the device with other trusted devices and applications using the digital certificate.	Manage the lifecycle of keys and trust anchors, and enable digital signature verification for firmware updates and secure boot.	Revoke or replace digital certificates during a change of ownership or device end-of-life.

2 On-Device Key Generation

Most organizations deploy a PKI quickly to address a specific project requirement, without consideration for proper policies and procedures. Fortunately, PKI has a well-defined structure for policy and practices defined in the form of Certificate Policy and Certificate Practice Statements (CP/CPS). Drafting a CP/CPS is optional, but your environment will benefit from a high assurance level through the enforcement of these policies. Not every enterprise needs a CP/CPS, but the best secured and managed PKIs usually do.

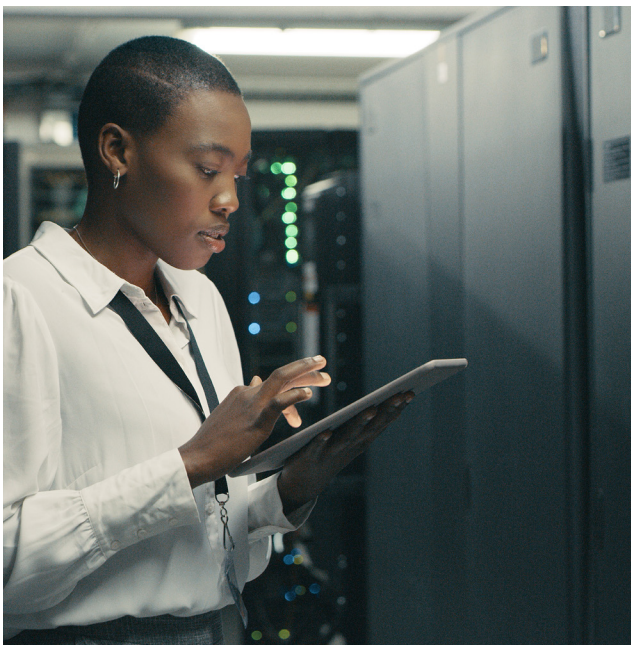
Once you've documented your use cases, you'll need to define your CP/CPS, which will guide you through the process of implementing controls for your PKI. Creating these documents can be a daunting task, but it's important to note that just copying another set of CP/CPS documents verbatim will not suffice. These tools only have value if they truly represent your organization's specific PKI requirements and operational processes. The NIST 7924 Draft CP/CPS can provide a solid starting point, but you will need to customize it to your organization.

Once the device generates and stores its private key, the next step is to generate a Certificate Signing Request (CSR) combined with customer-defined identifiable information. The manufacturing records system should also contain this information, which will be utilized upon registration at a later point.

3 Offline/Limited Connectivity Devices

Many IoT deployments include devices that are offline or do not have a continuous, reliable connection to the internet. This is either by design or unintended due to intermittent connectivity issues. In any case, the device manufacturer should bind authentication and authorization to a HRoT. At this point, devices within the same trust chain can authenticate, even without an internet connection.

Some IoT systems also incorporate a mobile device or tablet to interface with connected devices in the field to perform regular maintenance or updates. These intermediate endpoints can also be used for initial device commissioning and deployment. A technician's device simply registers with a backend IoT platform to verify the identity of the connected device, along with the certificate signing request (CSR), generated at the time of manufacturing. Once validated, the CSR is processed and the certificate and RoT are returned to the IoT device. While this may sound complicated, the process can be completely transparent to the end user.



4 Mutual Authentication

Authentication is essential to restrict access to only trusted users, applications and systems. As passwords become obsolete in the world of IoT, the use of PKI and digital certificates is one of the most effective ways to authenticate devices via standard protocols that are completely transparent to the end user and do not compromise interoperability.

Digital certificates allow mutual TLS authentication between any two entities which share a root of trust, ensuring data exchanges across open networks are secured. Most IoT devices communicate over protocols that can be secured using TLS, including HTTP, MQTT, AMQP, WebSockets, and OPC UA.

5 Secure Boot & Code Signing

With code signing, manufacturers can program devices to only permit execution of code that has a verified signature. Implementing secure code signing in conjunction with secure boot ensures that IoT devices will be protected from initial firmware flashing through every firmware update thereafter. This ensures that IoT devices will only be allowed to boot up or install updates once they have been signed by a trusted and known authority.

All firmware images should be digitally signed as well, using a code signing certificate that is sufficiently protected within a secure HSM. The signing process should integrate directly with a device manufacturer's development workflows and provide an audit trail of all signing activities and key access.

6 Crypto-Agility & Lifecycle Management

Renewable, replaceable, and revocable credentials, along with an updatable RoT, are non-negotiable requirements for IoT. Static systems are inherently insecure, and this principle applies to cryptography as well. Here are a few scenarios that highlight the importance of being able to quickly re-issue or revoke certificates from active devices, without interruption or delay.

Certificate expiration

Best practice for IoT certificate issuance is to set an expiration of no more than one to two years, dependent on the specific use case. Many IoT device lifespans reach 10-20 years or more, so tracking certificate expirations and renewals is not a nice-to-have — it's a mandate.

Changes in ownership

Devices that are deployed today may be sold or transferred to another entity in the future — especially in the industrial space where devices have longer lifespans. The devices' identity will need to be re-configured along with trust stores that define who trust it, and who it trusts.

Algorithm Deprecation

It's widely known that the cryptographic algorithms embedded into IoT today will likely become outdated or vulnerable and need to be updated at some point during the device's lifetime. As these algorithms evolve, new certificates and keys will need to be installed on all devices, including those already deployed.

Quantum Computing

In the near future, most public-key algorithms may be broken by increasingly available computing power. Existing devices will require immediate replacement of certificates, keys, and trust stores.

Keyfactor EJBCA

EJBCA Enterprise is a full PKI solution with all the necessary components to set up a complete deployment for industrial grade manufacturing supply chains or IoT product design and delivery.

PKI for Product Security

Secure connected products and IoT devices by design with unique certificate-based identities.

PKI for Manufacturing

Ensure trust in the manufacturing supply chain and industrial IoT (IIoT) environments

Deploy your way

EJBCA can be deployed as a turnkey SaaS PKI, in your AWS or Azure environment, or as a turnkey software or hardware appliance. It can also be deployed alongside Identity Authority Manager (IdAM) an industrial-grade registration authority.

Scale without limits

EJBCA can be scaled to handle billions of certificates. Spin up new certificate authorities, registration authorities, and validation authorities as needed to scale as your manufacturing environment grows.

Comply with requirements

EJBCA Enterprise also offers detailed, signed audit and transaction logs, role-based authorization and extensive support for HSMs.

Keyfactor Command for IoT

The end-to-end secure identity platform for connected devices.

IoT security begins with building a foundation of unique identity and trust. It is maintained by the ability to securely update devices throughout their operations. Keyfactor establishes trusted identity for your devices and provides complete identity lifecycle management for your IoT ecosystem.

Unique Identity Provisioning

Ensure that every device has a unique identity assigned, a proper RoT is established, and a secure identity is provisioned during device activation.

Secure Update / Management

Manage device identity centrally and remotely, replace certificates without disruption, and modify trust and key stores throughout the device lifecycle.

Ecosystem Integration

Integrate with popular IoT platforms such as ThingWorx, Azure IoT Hub, AWS IoT, SAP Leonardo, and others using flexible plug-ins and APIs.

Secure Code Signing

Enable secure code signing operations from end-to-end, with complete visibility and protection for sensitive code signing keys.

Trusted Manufacturing

Work with common ERP and MRP systems to establish "bootstrap" identities with information only known to the manufacturer.

Integrated with EJBCA

Get all the benefits of PKI without the complexity or cost of managing the infrastructure required to run it.

Conclusion

As the IoT landscape and security requirements evolve, device manufacturers need a cost-effective and scalable security solution to stay ahead of emerging threats and regulations. Yet, recent attacks and exploits have proven current solutions ineffective.

PKI is uniquely suited to address the complexity and diverse security requirements of IoT devices, enabling authentication, encryption and integrity for devices at scale. For all of its advantages though, PKI can be costly and complex to implement, particularly for device manufacturers with little to no knowledge of cryptography.

PKI must be integrated into the hardware supply chain and be made simple enough for developers and manufacturers to implement. With the right managed PKI solution, device manufacturers can deliver secure products to market faster, protect their brand, and prevent costly device warranty recalls — all without the need to deploy and run PKI themselves.

GET IN TOUCH

Learn how leading IoT manufacturers design and deliver secure IoT products to market with Keyfactor.

REQUEST A DEMO

KEYFACTOR

Keyfactor is the machine and IoT identity platform for modern enterprises. The company helps security teams manage cryptography as critical infrastructure by simplifying PKI, automating certificate lifecycle management, and enabling crypto-agility at scale.

For more information, visit www.keyfactor.com or follow us on LinkedIn, Twitter, and Facebook.

Built on a foundation of trust and security, Keyfactor is a proud equal opportunity employer, supporter and advocate of growing a trusted, secure, diverse and inclusive workplace.

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