IoT Alliance Australia

INTERNET OF THINGS SECURITY GUIDELINE

Internet of Things Security Guideline V1.2

This *Guideline* was developed by Workstream 5 *Security and Network Resilience* of the IoT Alliance Australia (IoTAA) – http://www.iot.org.au/

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INTRODUCTORY STATEMENT

The purpose of the *Internet of Things Security Guideline* is to provide comprehensive, top-level guidance to:

- promote a 'security by design' approach to IoT;
- assist industry to understand the practical application of security and privacy for IoT device use;
- be utilised by the IoT industry and digital service providers which use or provide support services for IoT deployments; and
- assist industry to understand some of the relevant legislation around privacy and security.

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1. GENERAL

1.1 Introduction

1.1.1 The development of this *Guideline* has been facilitated by Workstream 5 Security and Network Resilience of IoT Alliance Australia (IoTAA). Workstream 5 comprises representatives from the IoT and telecommunications industries, government, privacy advocates and consumer groups.

1.1.2 The *Guideline* should be read in the context of other relevant codes, guidelines, standards and documents.

1.1.3 The *Guideline* should be read in conjunction with related legislation, including:

(a) the *Telecommunications Act 1997*;
(b) the *Telecommunications (Interception and Access) Act* 1979;
(c) the *Radiocommunications Act 1992*; and
(d) the *Privacy Act 1988*.

1.1.4 Compliance with this *Guideline* does not guarantee compliance with any legislation. The Guideline is not a substitute for legal advice.

1.2 Scope

1.2.1 This *Guideline* covers security and privacy of:

(a) data generated by IoT devices;
(b) data carried to and from IoT devices;
(c) data stored in IoT devices;
(d) consumers using IoT devices; and
(e) actuators driven by IoT systems.

1.2.2 This *Guideline* covers resilience of:

(a) IoT device communications; and
(b) wide area IoT transit communications.

1.2.3 This Guideline deals with IoT devices associated with, but not limited to:

(a) home use by consumers;
(b) business use in the office environment;
(c) business use in operational systems; and
(d) critical infrastructure use.

1.2.4 This *Guideline* deals with:

(a) the general principles applicable to IoT security and user privacy;
(b) specific interpretation of standard security and privacy controls in the IoT context;
(c) guidance on the use and storage of information obtained through IoT devices;
(d) resilience of networks to and from the IoT device; and
(e) the application of relevant legislation.

1.3 Objectives

1.3.1 The objectives of the *Guideline* are to:

(a) assist industry in their understanding of the practical application of security and privacy for IoT device use;
(b) be utilised by the IoT industry, carriers, and carriage service providers which use or provide support services for IoT deployments; and

(d) assist industry in understanding the application of relevant legislation.

1.3.2 The *Guideline* brings together sources of information relating to the security, privacy, and resilience of IoT to assist the IoT industry in delivering quality products and services. It does not endorse any specific technology or approach for use in Australia.

1.4 *Guideline* review

This *Guideline* is a living document. Subsequent to this version, Communications Alliance intends to publish a second version. Following a public consultation process Communications Alliance intends to republish the document as an Industry *Guideline* which can be further reviewed and updated over time, as significant developments and potential risks become evident.

2. ACRONYMS, DEFINITIONS AND INTERPRETATIONS

2.1 Acronyms

For the purposes of the *Guideline*:

3GPP:	The 3rd Generation Partnership Project
ACL:	Access Control Lists
AES:	Advanced Encryption Standard
AES/CBC:	AES with Cipher Block Chaining Mode
AES/CCM:	AES with Counter-CBC Mode
AES/CTR:	AES with Counter Mode
APP:	Australian Privacy Principles
CANbus:	Controller Area Network Bus
CoAP:	Constrained Application Protocol
CSP:	Carriage service provider
DTLS:	Datagram Transport-Layer Security
GSMA:	Groupe Speciale Mobile Association
IEEE:	Institute of Electrical and Electronics Engineers
IETF:	Internet Engineering Task Force
IIC:	Industrial IoT Consortium
IIOT:	Industrial IoT
IoT:	Internet of Things
IoTSF:	IoT Security Foundation
IPSec:	IP Security Protocol
LPWAN:	Low Power Wide Area Network
LR-WPAN:	Low Rate Wireless Personal Area Network
MAC:	Media Access Control
mDNS:	Multicast DNS Service
NB-IOT:	Narrow Band IoT
NFV:	Network Function Virtualisation
NGN:	Next generation Network
NIST:	National Institute of Standards and Technology, US
OAIC:	Australian Information Commissioner
OIC:	Open Interconnect Consortium
OWASP:	Open Web Application Security Project
PLC:	Programmable Logic Controller
SABSA:	Sherwood Applied Business Security Architecture
SCADA:	Supervisory Control and Data Acquisition
SDN:	Software Defined Networking

SLA: Service Level Agreement

SSL: Secure Sockets Layer

TLS: Transmission Layer Security

UAV: Unmanned Aerial Vehicle (drone)

UDP: User Datagram Protocol

WSN: Wired Sensor Networks

2.2 Definitions

For the purposes of the *Guideline*:

Australian Privacy Principle

has the meaning given by Schedule 1 of the Privacy Act 1988 (Cth).

Carriage Service Provider (CSP)

has the meaning given by Section 87 of the Telecommunications Act 1997 (Cth).

Carrier

has the meaning given by section 7 of the Telecommunications Act 1997 (Cth).

Equipment

means apparatus or equipment used in connection with a Telecommunications Network.

Telecommunications Network

means a system, or series of systems, for carrying communications by means of guided or unguided electromagnetic energy or both, but does not include a system, or series of systems, for carrying communications solely by means of radio communication.

Telecommunications System

means a telecommunications network that is within Australia; or a telecommunications network that is partly within Australia, but only to the extent that the network is within Australia; and includes equipment, a line or other facility that is connected to such a network and is within Australia.

2.3 Interpretations

In the *Guideline*, unless the contrary appears:

(a) headings are for convenience only and do not affect interpretation;
(b) a reference to a statute, ordinance, code or other law includes regulations and other instruments under it and consolidations, amendments, re-enactments or replacements of any of them;
(c) words in the singular include the plural and vice versa;
(d) words importing persons include a body whether corporate, politic or otherwise;
(e) where a word or phrase is defined, its other grammatical forms have a corresponding meaning;
(f) mentioning anything after include, includes or including does not limit what else might be included; and
(g) a reference to a person includes a reference to the person's executors, administrators, successors, agents, assignees and novatees.

3. THE INTERNET OF THINGS

3.1 Background

From a network of connected computers to a network with billions of connected static and mobile devices, the internet is becoming the connectivity fabric for an increasingly diverse array of things – ranging from home furnishings and white-ware to human implants. The mobile revolution saw the number of end-point devices exceed one billion in 2002, and the introduction of smart phone technology and tablets means that now the vast majority of these devices are online.

Over the last twenty years, cars have become highly networked and are increasingly being connected to the internet for safety, navigation and entertainment purposes. A modern car now has multiple networks and dozens of microprocessors. The emergence of vehicle ethernet means that these microprocessors are increasingly becoming directly internet-accessible. Connected traffic management is used to improve driver experience, in-vehicle connectivity allows better fleet management, and public transport systems have become connected to provide schedule notifications. Smart parking and smart paying are emerging as standard in-car services. Intelligent transport systems are continuing to leverage connectivity. Smart driving systems will improve safety by assisting drivers in braking and avoiding incidents.

Hospitals are adopting operational health technology which can be remotely accessed to deliver the eHealth capability, within the hospital confines and through implanted and wearable devices. This is extending into the sports space with online recording of athletes' performance. Such systems are not only becoming connected, but increasingly leveraging cloud-based applications.

Utilities are major users of IoT devices, with the electricity sector increasingly adopting the SmartGrid technology. Water utilities are also deploying monitoring devices; the ability of sensing technology to pinpoint leaks is driving this demand.

Homes are becoming intelligent, with smart home technology appearing in the basic house infrastructure such as lighting and heating, as well as in appliances such as fridges and cookers. Technology companies are responding with delivering the central connectivity through devices such as Google's OnHub, while new start-ups are delivering a bewildering array of sensors all controlled remotely over the internet using smart phone applications.

Agriculture is not immune from the march of progress, with an increasing dependence upon connected sensors for always-on monitoring of crops and environmental conditions, and the vision of smart-farming. The concept of precision agriculture, and indeed intelligent decision agriculture, depends upon telematics and advanced sensing technologies. Unmanned aerial vehicles (UAVs), are increasingly being used to perform aerial monitoring of crop growth. The use of big data collected across the whole farming operation over time enables intelligent navigation of climatic variation, but depends upon connectivity and agility.

Strategically, smarter cities are essential if the world is to respond effectively to the rapid growth in urban living, with development occurring on a strategic roadmap rather than through piecemeal, tactical developments. Cities need to operate much more energy-efficiently, cater for the continuing demand for bandwidth, enable online service delivery across a wide variety of services, and to do this requires highly resilient utilities. Emergency services will also benefit from rapid access to connected data when responding to incidents.

Industrial control systems are increasingly connected to business networks, not only feeding data into those networks but also responding to decisions made by those systems, causing changes in the environment they control.

In summary, there is major potential in many industries for IoT products and services, with significant focus currently on the following application domains:

- Agriculture including autonomous equipment and herd management
- Automotive, including autonomous operation and service management
- Healthcare, including clinical diagnostic equipment and personal devices
- Manufacturing and plant automation equipment
- Retail and customer data management
- Smart City, including built environment devices and infrastructure monitoring
- Smart Home, environment monitoring and control
- Utilities & mining, monitoring, measurement and management.

The complexity and pace of change is a challenge which requires integrated systems across what has traditionally been a siloed set of service solutions, integrating also with humans and physical systems. This requires a smart city framework, along the lines of that documented by the British Standards Institution[1].

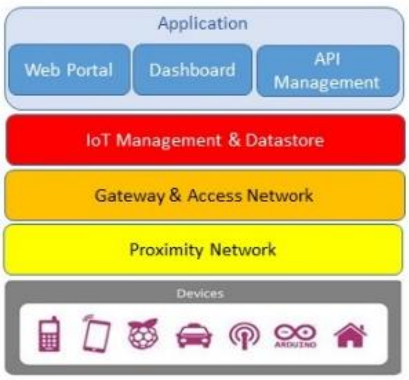
The increasing connectivity of physical, digital, and human systems has become known as the IoT. This connectivity brings with it a plethora of risks, and three critical success factors are resilience, privacy and security.

3.2 IoT Architecture, Protocols and Standards

The IoT security architecture is a component of the wider IoT reference architecture. It starts with the business outcomes and derives security requirements and controls traceable to those outcomes. Given the universal applicability of IoT, case specific security architecture viewpoints will need to be developed on demand using standard building blocks. The nature of IoT technology will place unusual demands on the architecture such as low power cryptographic algorithms and low latency communications. Identity and access management is another challenge which requires quite different solutions to traditional enterprise deployments. Secure interoperability will drive the need for security protocol and profile standardisation.

There is no one accepted architectural model for IoT, and the rapid evolution of all areas of the end-to-end technology continues to drive new changes to architectural models. However, for the purposes of this document, we can consider a high-level reference architecture for IoT as shown in Figure 1.

Figure 1: Reference Architecture for IoT



Example Communications Stack

Application (Core CoAP)
Network Routing (IPv6)
Adaption (6LoWPAN)
MAC (IEEE 802.15.4)
Physical (IEEE 802.15.4)

The end-to-end IoT pathway consists of five main components: IoT devices, a proximity network, gateways and access network, IoT Management and message repository, and end user applications and APIs. This is a logical architecture which doesn't represent the complexity of physical deployment, as many deployments are blurring the layers by moving

1 PAS181: 2014: Smart City Framework

application code out to the network edge, in the gateways, or even out to the devices themselves.

Major technology vendors are developing services for IoT. AWS has released their AWS IoT Platform, Microsoft has developed their Azure IoT Suite, IBM has released Watson IoT Platform, CISCO provides a seven-layer reference architecture for IoT, which also includes an edge or fog layer for element analysis and transformation and has separate layers for data aggregation and for data storage. Academic papers proposing three, five, and six-layer reference architectures have also been published. This space will evolve.

There are a number of key technical protocols and standards that are being used in the IoT space. As with any new technology, not all will survive, but those that do will be reconciled into the detailed IoT reference architecture.

- Embedded devices connect via a proximity network to their local gateway using short distance protocols such as ZigBee, ZWave, Thread, Bluetooth and Bluetooth LE, and WiFi. There are also a number of long-range IoT protocols such as LoRa, LTE and NB-IoT, as well as newer protocols in development such as 6LoWPAN. Gateways connect the proximity network to the wider internet either directly or using various access or backhaul network links.
- The IEEE has published a proximity network protocol standard called IEEE802.15.4: Low Power Wireless Access Network, and this is used as foundation of higher level protocols such as 6LoWPAN and Zigbee.
- In the home automation sector, the Home Network Automation Protocol (HNAP) is being adopted by many vendors for device management. The protocol was patented originally by Pure Networks, but is now owned and is being further developed by Cisco.
- The Constrained Application Protocol (CoAP) is an IETF protocol which is designed for RESTful applications and uses HTTP semantics (and feeds into HTTP in the wider network) but with a much smaller footprint and a binary rather than a text-based exchange. CoAP is designed to be used over UDP. MQTT, the Message Queue Telemetry Transport, is an alternative to CoAP and has been deployed as a publish/subscribe messaging protocol for wireless sensor networks.
- The multicast DNS service (mDNS) is commonly used by IoT devices to resolve host names to IP addresses within small networks that do not include a local name server.
- NB-IoT is a 3GPP standard for narrow band IoT, based on the use of LTE cellular technology. The US National Institute of Standards and Technology (NIST) has released their publication SP800-187: Guide to LTE Security.

The UK Government has promoted the development of an IoT interoperability standard known as Hypercat. This standard aims to improve data discoverability and interoperability and to enable a catalogue of devices and capabilities to be published as a web repository of devices with associated metadata. This is currently one of the preferred interoperability options[2].

3.3 Privacy and Security in IoT

There are two core requirements for an IoT environment: privacy protection for personal identifiable data collected and stored within the environment, and system security ensuring that data is protected, both in transit and at rest, and that appropriate authentication is applied to any system providing data collection or device control. The level of privacy protection will vary for each of the categories indicated in Section 3.1. Sectors in which privacy is prevalent are Healthcare, which protection of patient data is paramount, Automotive, where vehicle ownership or driver identification must be protected from inadvertent release, Retail, in which customer identity must be removed before data is made

2 IoT Alliance Australia has recommended that the Hypercat Standard be considered by Standards Australia for adoption as an Australian Standard.

available for data analysis, and Smart Home, in which identity attributes such as address must be obfuscated before data is stored or made available for analysis purposes.

Security is equally important for Healthcare and sectors such as Automotive, where vehicle control must be protected from compromise, Manufacturing, in which access control to system control functions, and Utilities, where protection from unauthorised access is paramount.

Given the commodity nature of many IoT devices and the implications of security and privacy, a robust trust framework which is incorporated into the design of products is necessary. It is recommended that IoT deployments are based on a sector-appropriate open business model, a service-oriented IT architecture, and a user-centric trust model. Data should be made available to the desired business processes with privacy and security protection built into the system configuration.

For Privacy, a guiding principle should be the inability to match an individual to a transaction or data record.

For Security the principles are:

- Data should be adequately protected when in use, in transit and at rest
- System access should be appropriate to the sector; unauthorised persons must not be able to gain access to a protected resource.
- The integrity of device functionality should be protected

The evolution of the IoT requires an approach to security and privacy which is agile and supports unforeseen changes, across a wide range of technologies and applications. It requires an approach which recognises a global ecosystem consisting of different sectors using common solutions developed independently, compliant with a common set of principles but implementing a sector-specific interpretation of security and privacy.

3.4 IoT Resilience

As all sectors of government, industry, and society take advantage of the benefits that can be realised through the IoT, so dependence upon real time connectivity increases. This means that networks must be made resilient to enable continued operation in the event of infrastructure failure or cyber-attack.

IoT communications offers some specific challenges with the need to ensure business continuity from remote devices, sometimes installed in inhospitable environments, to supervisory systems under strict access control restrictions. Recent developments in ultra-low-power equipment and improving battery technology have significantly improved device resilience and the increasing convergence of operational technology environments and information technology systems is improving the management of supervisory systems.

The approach to resilience is detailed in Section 6.

3.5 5G Considerations

The impact of the launch of 5G technology on network architectures and security requirements should not be underestimated. 5G networks are expected to serve vertical markets with many distinct types of service, each with differing service requirement characteristics. These can broadly be described as:

- xMBB: massive broadband that delivers gigabytes of bandwidth on demand
- mMTC: massive machine-to-machine communications that connects billions of sensors and machines
- uMTC: critical machine-to-machine communications providing minimal latency and high reliability to enable, e.g., remote control over robots and autonomous driving

All major carriers will offer 5G services to a wide eco-system of carriage providers, network equipment vendors and manages service providers, and in doing so will require not only improved networking solutions but also a sophisticated integration of massive computing and storage infrastructures. 5G traffic streams can be individually optimised to support specific traffic characteristics by allowing service providers access to the underlying virtual network and computing infrastructure.

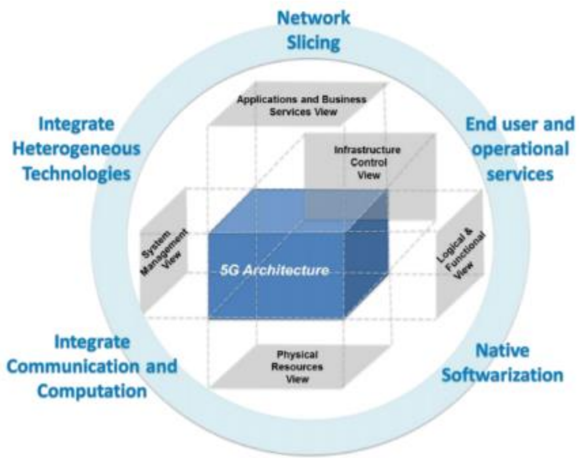
Carriers will need to manage multi-tenancy and multi-service support through network capability orchestration, delivering logical networks in "network slices".

5G networks will enable faster service instantiation, which in turn will require new security models to support them in an increasingly hostile cyber-threat landscape.

5G will require the support of new technology approaches such as software defined networking and network function virtualisation resulting in self-adapting networks. A network architecture is recommended that separates the user and control planes, and possibly, redefinition of the boundaries between the network domains (e.g. radio access network and core network). 5G will introduce new concepts such as network-controlled device-to-device (D2D) communication over point-to-point, multi-cast and broadcast protocols, and device duality schemes, where a device can act both as a "normal" end user device or sensor and as a network node extending the infrastructure, as in some existing IoT deployments.

A 5G top level architecture has been proposed by the 5G PPP[3] as shown in Figure 2.

Figure 2: 5G Architecture



5G is the continuing evolution of mobile technology, but the distinctly different nature of 5G networks will inevitably require different and more sophisticated approaches to security. The key considerations for internet of things security in a 5G environment are:

- multi-domain and multi-service models;
- re-definition of operator, user and device roles;
- new service delivery models based on virtualization, network slicing;
- more serious consequences for cyber attack on critical infrastructure services;
- increasing concerns for user privacy from mass surveillance; and
- the need for lighter and faster encryption systems and algorithms.

3 5G PPP Architecture Working Group View on 5G Architecture, July 2016

4. PRIVACY

This section will deal with some of the legal issues around privacy given the paramount importance of privacy and data sharing considerations in an IoT context. However, IoT may involve other legal challenges some of which will be discussed in Section 8 of this *Guideline*.

4.1 Privacy Principles

In 2014, a new set of Privacy Principles were enacted[4]. These are set out in the *Privacy Act 1988* and shown in Table 1.

Table 1: Australian Privacy Principles (APPs)

Principle	Description
1	Open and transparent management of personal information
2	Anonymity and pseudonymity
3	Collection of solicited personal information
4	Dealing with unsolicited personal information
5	Notification of collection of personal information
6	Use or disclosure of personal information
7	Direct marketing
8	Cross border disclosure of personal information
9	Adoption, use or disclosure of government-related identifiers
10	Quality of personal information
11	Security of personal information
12	Access to personal information
13	Correction of personal information

The APPs are legally binding principles which are the cornerstone of the privacy protection framework in the *Privacy Act 1988*. They set out standards, rights and obligations in relation to the handling, holding, accessing and correction of personal information. They are technologically neutral, principles-based law and apply to:

- most Australian government agencies
- private sector and not-for-profit organisations with an annual turnover of more than $3 million
- all private sector health service providers, and
- some small businesses such as businesses trading in personal information.

Personal information is information or an opinion about an identified individual or an individual who is reasonably identifiable, whether or not the information or opinion is true or the information or opinion is recorded in a material form. For example, in the IoT context, information from a sensor that indicates the presence of a person in a building may be personal information if that individual is reasonably identifiable in the particular circumstances.

The most applicable principles to IoT are:

- Collection of identity information that is not required for the business purpose, collecting data just because you can is not permissible.
- Sharing private identity information with agencies for which consent has not been granted. If a banking app provides account holder PII it must not be made available to the bank's insurance branch.

4 https://www.oaic.gov.au/agencies-and-organisations/guides/app-quick-reference-tool

- Use or disclosure of PII for purposes for which consent has not been given. If an owner of a vehicle has not consented to the release of their PII data to a service centre, it must not be provided.
- Cross-border disclosure of PII – it must be kept in a jurisdiction with similar regulation to the home country
- PII data must be periodically refreshed or deleted. A privacy policy is required that states how long data will be maintained.
- The opportunity to review and correct PII, if necessary, must be provided. A mechanism for a user to view the PII that's being maintained on them is required.

Many of the APPs will be relevant in the IoT context. Particularly relevant to new IoT projects that involve handling personal information, will be APP 1 on open and transparent management of personal information. APP 1 lays down the first step in the information lifecycle – planning and explaining how personal information will be handled before it is collected. APP entities will be better placed to meet their privacy obligations if they embed privacy protections in the design of their information handling practices. APP entities are required to take reasonable steps to implement practices, procedures and systems to ensure compliance with the APPs or a registered APP code that binds the entity (APP 1.2). The intention of APP 1.2 is to ensure that privacy compliance is embedded in the design of entities' practices, procedures and systems. APP entities will be better placed to meet their privacy obligations under the *Privacy Act 1988* if they embed privacy protections in the design of their information handling practices.

The Office of the Australian Information Commissioner (OAIC) has published a range of relevant guidance on its website, www.oaic.gov.au. These include:

- *Privacy Management Framework* (and *Privacy Management Plan Template*), which provides a comprehensive approach to creating integrated and robust privacy governance systems.
- a *Guide to undertaking privacy impact assessments* assists entities undertaking a privacy impact assessment of a project, in order to identify the project's impact on the privacy of individuals and to develop recommendations for managing, minimising or eliminating that impact.
- a *Guide to securing personal information: 'Reasonable steps' to protect personal information*, which provides guidance on the reasonable steps entities are required to take under APP 11.1 to protect the personal information they hold from misuse, interference, loss and from unauthorised access, modification or disclosure. It also includes guidance for the destruction or de-identification of personal information under APP 11.2. The guide is not legally binding, but provides a detailed explanation of the reasonable steps an entity may take, with specific explanation of how this applies in the ICT context.
- *Australian Privacy Principles guidelines*, which outline the mandatory requirements in the APPs, provides examples of how the APPs apply in particular circumstances, and includes suggestions for good privacy practice.

4.2 Trust Framework

Protection of personal information can be viewed in terms of a trust framework, an example of which has been proposed by the Online Trust Alliance[5]. This provides a framework covering security and privacy. The privacy requirements appear in Table 2 in the next section.

Not all of the trust framework requirements will be required by all products and services, but a statement of which requirements are applicable and which are not. Some requirements

5 https://otalliance.org/

may need to be interpreted against sector-specific IoT trust requirements, and some requirements may be replaced in the IoT context, for example passwords may be reset rather than recovered.

Entities covered by the *Privacy Act 1988* will separately need to ensure that their personal information handling practices comply with the legal requirements in *Privacy Act 1988*. For example, an entity must have a privacy policy that includes certain prescribed information, must comply with the notice requirements in APP 5 and must only use and disclose personal information in certain limited circumstances set out in APPs 6 and 8.

5 SECURITY

5.1 IoT Trust Framework

The IoT Alliance has released version 2 of their Trust Framework, covering device, application and cloud services; user access and credentials; privacy, disclosures, and transparency; and notifications and best practices. It provides thirty mandatory requirements and seven recommended practices. These have been included verbatim as Table 2 for easy reference.

Table 2: IoT Alliance Trust Framework

No.	Description
Security – Devices, Apps, and Cloud Services	
1	Ensure devices and associated applications support current generally accepted security and cryptography protocols and best practices. All personally identifiable data in transit and in storage must be encrypted using current generally accepted security standards. This is including but not limited to wired, WI-FI, and Bluetooth connections.
2	All IoT support web sites must fully encrypt the user session, from the device to the backend services. Current best practices include HTTPS or HTTP Strict Transport Security (HSTS) by default, also known as AOSSL or Always On SSL. Devices should include mechanisms to reliably authenticate their backend services and supporting applications.
3	IoT support sites must implement regular monitoring and continual improvement of site security and server configurations to acceptably reduce the impact of vulnerabilities. Perform penetration tests at least annually.
4	Establish coordinated vulnerability disclosure including processes and systems to receive, track and promptly respond to external vulnerabilities reports from third parties including but not limited to customers, consumers, academia and the research community. Remediate post product release design vulnerabilities and threats in a publicly responsible manner either through remote updates and/or through actionable consumer notifications, or other effective mechanism(s). Developers should consider "bug bounty" programs, and crowdsourcing methods to help identify vulnerabilities that companies' own internal security teams may not catch or identify.
5	Must have a mechanism for automated safe and secure methods to provide software and/or firmware updates, patches and revisions. Such updates must either be signed and/or otherwise verified as coming from a trusted source. Updates and patches should not modify user-configured preferences, security, and/or privacy settings without user notification. Automated (vs automated) updates provide users the ability to approve, authorize or reject updates
6	Ensure all IoT devices and associated software, have been subjected to a rigorous, standardized software development lifecycle process and methodologies including unit, system, acceptance, regression testing and threat modeling, along with maintaining an inventory of the source for any third party/open source code and/or components utilized. Employ generally accepted code and system hardening techniques across a range of typical use case scenarios and configurations, including preventing any data leaks between the device, apps and cloud services. Developing secure software requires thinking about security from a project's inception through implementation, testing, and deployment. Devices should ship with reasonably current software and/or on first boot push automatic updates to address any known critical vulnerabilities.
7	Conduct security, and compliance risk assessments for all service and cloud providers. (See resource guide for recommendations).
8	Develop and maintain a "bill of materials" including software, firmware, hardware and third party software libraries (including open source modules and plug ins). (This would apply to

	the device, mobile and cloud services to help quickly remediate disclosed vendor or open source vulnerabilities)
9	Design devices to minimum requirements necessary required for operation. For example, USB ports or memory card slots should only be included if they are required for the operation and maintenance of the device. Unused ports and services should be disabled.
User Access and Credentials	
10	Include strong authentication by default, including providing unique, system-generated or single use passwords; or alternatively use secure certificate credentials. As necessary, require use of unique passwords for administrative access, delineating between devices and services and the respective impact of factory resets.
11	Provide generally accepted recovery mechanisms for IoT application(s) and support passwords and/or mechanisms for credential re-set using multi-factor verification and authentication (email and phone, etc.) where no user password exists.
12	Take steps to protect against 'brute force' and/or other abusive login attempts (such as automated login bots, etc.) by locking or disabling user and device support account(s) after a reasonable number of invalid log in attempts.
13	Provide users notification of password reset or change utilizing secure authentication and /or out-of-band notice(s).
14	Authentication credentials including but not limited to user passwords shall be salted, hashed and/or encrypted. Applies to all credentials stored to help prevent unauthorized access and brute force attacks.
Privacy, Disclosures, and Transparency	
15	Ensure privacy, security, and support policies are easily discoverable, clear and readily available for review prior to purchase, activation, download, or enrollment. In addition to prominent placement on product packaging, on their website, it is recommended companies utilize QR Codes, user friendly short URLs and other similar methods at point-of-sale.
16	Disclose the duration and end-of-life security and patch support, (beyond product warranty). Such disclosures should be aligned to the expected lifespan of the device and communicated to the consumer prior to purchase. *(It is recognized IoT devices cannot be indefinitely secure and patchable. Consider communicating the risks of using a device beyond its usability date, and impact and risk to others if warnings are ignored or the device is not retired).*
17	Conspicuously disclose what personally identifiable and sensitive data types and attributes are collected and how they are used, limiting collection to data which is reasonably useful for the functionality and purpose for which it is being collected. Disclose and provide consumer opt-in for any other purposes.
18	Disclose what and how features will fail to function if connectivity or backend services becomes disabled or stopped including but not limited to the potential impact to physical security. *(Consider building in controls to disable connectivity or disable ports to mitigate potential threats, while maintaining core product functionality, based on the device usage, balancing out potential life/safety issues).*
19	Disclose the data retention policy and duration of personally identifiable information stored.
20	IoT devices must provide notice and/or request a user confirmation when initially pairing, onboarding, and/or connecting with other devices, platforms or services.
21	Publically disclose if and how IoT device/product/service ownership and the data may be transferred (e.g., a connected home being sold to a new owner or sale of a fitness tracker).
22	Only share consumers' personal data with third parties with consumers' affirmative consent, unless required and limited for the use of product features or service operation. Require that third party service providers are held to the same polices including holding such data in confidence and notification requirements of any data loss/breach incident and/or unauthorized access
23	Provide controls and/or documentation enabling the consumer to review and edit privacy preferences of the IoT device including the ability to reset to the "factory default."
24	Commit to not sell or transfer any identifiable consumer data unless it is a dependent part of the sale or liquidation of the core business which originally collected the data, providing the

	acquiring party's privacy policy does not materially change the terms. Otherwise notice and consent must be obtained.
25	Provide the ability for a consumer to return a product without charge after reviewing the privacy practices that are presented prior to operation, provided that such terms are not conspicuously disclosed prior to purchase. The term (number of days) for product returns shall be consistent with current exchange policies of the retailer, or specified in advance.
26	Whenever the opportunity is presented to decline or opt out of any policy, the consequences must be clearly and objectively explained, including any impact to product features or functionality. It is recommended the end-user value of opting in and/or sharing data be communicated to the end-user.
27	Comply with applicable regulations including but not limited to the Children's Online Privacy Protection Act (COPPA) and international privacy, security and data transfer regulatory requirements.
28	Publicly post the history of material privacy notice changes for a minimum of two years. Best practices include date stamping, redlines, and summary of the impacts of the changes.
29	Provide the ability for the user or proxy to delete, or make anonymous personal or sensitive data stored on company servers (other than purchase transaction history) upon discontinuing, loss, or sale of device
30	Provide the ability to reset a device and application to factory settings, providing the ability for erasure and zeroization in the event of transfer, loss or sale.
Notifications and Related Best Practice	
31	End-user communications including but not limited to email and SMS, must adopt authentication protocols to help prevent spear phishing and spoofing. Domains should implement SPF, DKIM and DMARC, for all security and privacy related communications and notices as well as for parked domains and those that never send email.
32	For email communications within 180 days of publishing a DMARC policy, implement a reject or quarantine policy, helping ISPs and receiving networks to reject email which fail email authentication verification checks.
33	IoT vendors using email communication must adopt transport-level confidentiality including generally accepted security techniques to aid in securing communications and enhancing the privacy and integrity of the message.
34	Implement measures to help prevent or make evident any physical tampering of devices. Such measures help to protect the device from being opened or modified for malicious purposes after installation or from being returned to a retailer compromised.
35	Consider how to accommodate accessibility requirements for users who may be vision, hearing and or mobility impaired to maximize access for users of all physical capabilities.
36	Develop communications processes to maximize user awareness of any potential security or privacy issues, end-of life notifications and possible product recalls, including in app notifications. Communications should be written maximizing comprehension for the general user's reading level. Consider multi-lingual communications recognizing that English may be the "second language" for users (see related principles regarding security and message integrity).
37	Enact a breach and cyber response and consumer notification plan to be reevaluated, tested and updated at least annually and/or after significant internal system, technical and / or operational changes.

The trust framework requirements form a good basis for evaluating an IoT system for best practices in security and privacy, and form the basis of the IoTAA Security and Privacy Trustmark.

5.2 Security Principles

The confidentiality, integrity and availability (CIA) framework for enterprise security is a good starting point for evaluating IoT requirements but a richer lexicon may be required to accommodate the categories outlined in Section 3.1 Background. The SABSA[6] model has been adopted by the Open Group Architecture Forum, and provides a full framework for

6 Sherwood Applied Business Security Architecture, www.sabsa.org/white_paper

capturing security requirements and architecting security solutions. A subset of the enterprise architecture will rely on the IoT, and IoT devices will need to meet the relevant enterprise security requirements.

There is no one best design for security in an IoT device or solution, and the selection of which device to use will in part be driven by how well its security functionality meets the security requirements identified in the enterprise security architecture. The IoT Security Foundation[7] has defined a number of principles for IoT security which together cover many of the common requirements that vendors may come across. These are grouped into seven areas, as shown in Table 3.

Table 3: Areas of IoT Security Foundation Security Principles

Group	Question	Principle
1	Does the data need to be private?	Be designed with security, appropriate to the threat and device capability, in mind from the outset.
		Offer appropriate protection for all potential attack surfaces (e.g. device, network, server, cloud etc.)
		Inform users what private data is required in order for the device to function.
		Allow users and security products to review sensitive data to verify the device is maintaining privacy.
		Ensure identifiers are removed or anonymised where necessary.
		Manage encryption keys securely.
2	Does the data need to be trusted?	Integrity of software is verified (e.g. secure boot).
		The device or system uses a hardware-rooted trust chain.
		Authentication and integrity protection are applied to data.
		Compromised or malfunctioning devices can be identified and revoked.
		Data is isolated from other systems or services where applicable.
		System testing and calibration ensures data is handled correctly.
		Device metadata is trusted and verifiable.
		Re-using existing good security architectures rather than designing brand new ones.
3	Is the safe and/or timely arrival of data important?	Data is accurately time-stamped.
		Integrity of data in the device, server and other parts of the system is designed in from outset.
		Devices should provide failure handling and status monitoring to meet availability requirements.
		Carriers and device managers can identify safety and timeliness needs in a secure, trusted fashion.

[7] https://iotsecurityfoundation.org/

		Any reliance on other systems or devices for availability is clearly detailed to the user.
		Devices should identify themselves to a network using a secure identifier.
		Be clear what functionality the device is offering and its intended use. Make users aware of any restrictions or limitations.
4	Is it necessary to restrict access to, or control of, the device?	Defences against hacking are designed in from the outset.
		Development processes incorporate secure coding standards, penetration testing etc.
		Service management occurs over an authenticated channel.
5	Is it necessary to update software on the device?	The vendor update and management process follows best security practice.
		Only authenticated sources are able to provide security updates or patches.
		Users and managers are easily able to see a device's patching update status.
6	Will ownership of the device need to be managed or transferred in a secure manner?	Provide a secure method to transfer ownership of the device to another user.
		Be clear which system components (devices, data, network etc.) are owned by the user.
		Ensure that change of ownership does not impact security updates.
7	Does the data need to be audited?	Managed access to IoT data (for example at a local hub).
		Policy controls to disable unwanted features.

The questions which form the groups in the IoT Security Foundation Principles provide a good start point or IoT security and should be considered at the outset of any IoT development and deployment projects, and the specific principles associated with them applied where relevant. In the longer term, these principles may form the foundation from which sector specific IoT security profiles and controls can be developed.

5.3 Application Layer

The application layer is a rapidly evolving space in IoT, with vendors such as IBM with its Watson for IoT service, Microsoft with Azure IoT, and Amazon with AWS IoT offering full cloud based IoT application and IoT management solutions.

The application layer is solution specific. It can be implemented simply as a dashboard, may involve a web portal to access messages, may use an API through which messages may be pushed or pulled, or may be a fully contained application. The application layer may contain a storage repository in which messages are kept temporarily or as a longer term archive. While the underlying infrastructure may provide security features, the application layer may also extend out to devices to deliver full end-to-end security.

There are two popular application level protocols: the Constrained Application Protocol (CoAP) and the Message Queue Telemetry Transport (MQTT). CoAP is a one-to-one protocol, whereas MQTT supports a one-to-many architecture.

5.3.1 Constrained Application Protocol

RFC 7252: Constrained Application Protocol (CoAP) has become widely adopted as a low cost method of communications between devices and their applications.

CoAP uses the Datagram Transport-Layer Security (DTLS)[8] to secure CoAP messages – this is a variant of TLS which can accommodate the unreliable nature of UDP communications. It has a small number of mandatory minimal configurations defined, as appropriate for constrained environments. This provides support for Confidentiality, Authentication, Integrity, Non-Repudiation and protection against Replay Attacks.

CoAP has four security modes to support key management: NoSec, PreSharedKey, RawPublicKey, and Certificates. The cipher suites used in these specifications are shown in Table 4.

Table 4: CoAP Cipher Suites

Mode	Cipher Suite
NoSec	-
PreSharedKey	TLS_PSK_WITH_AES_128_CCM_8 and Elliptic Curve Cryptographic
RawPublicKey	TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 and Elliptic Curve Cryptographic
Certificate	TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 and Elliptic Curve Cryptographic

The DTLS handshake for authentication and key agreement can pose a significant impact on the resources of constrained devices, particularly with the requirement for elliptic curve cryptography. Investigations continue into optimisations of DTLS in IoT environments and the incorporation of elliptic curve cryptography in hardware. A new protocol, DTLS+, has been proposed as a standard lightweight variant.

Research is underway to consider the employment of alternative approaches to secure CoAP communications, in particular the employment of object security rather than transport layer security. This may be achieved by integrating security into the CoAP protocol itself using new security options. This approach enables granular security on a per-message basis, and supports the secure transversal of different domains and the usage of multiple authentication mechanisms.

5.3.2 Message Queue Telemetry Transport

ISO/IEC 20922: Message Queue Telemetry Transport (MQTT) is a publish/subscribe messaging protocol designed for lightweight machine-to-machine communications. It was originally developed by IBM and is now an open ISO standard.

MQTT has a client/server model, where every sensor is a client and connects to a server, known as a broker, over TCP. It is message oriented, where every message is a discrete chunk of data, opaque to the broker.

A message is published to an address, known as a topic. Clients may subscribe to multiple topics. Every client subscribed to a topic receives every message published to the topic.

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8 RFC 6347: Datagram Transport Layer Security v1.2

Topics are arranged in a hierarchical manner and can be accessed individually or as a group using wildcards requests.

MQTT brokers provide authentication using username/password credentials, and confidentiality and privacy through the use of encrypted SSL/TLS protocols.

5.4 IoT Management Layer

The management layer of the IoT reference architecture is where all the activity occurs to enable the devices to interact with the applications successfully. This is where registration of devices occurs. It's also the point of data flow management, and may be the end point for receiving device data, storing it in a management layer repository for applications to access.

Device configuration and modelling may take place at the management layer, as well as security control for issuing and validating certificates.

In traditional networks, there are separate data, control, and management planes, as described in ITU X.805[9]. Research on applying X.805 in the IoT context has been carried out by Raheem et al[10].

5.5 Gateway and Access Layer

The purpose of the gateway and access layer is to provide an upstream connection for the proximity network and pass the data to the access network, typically an IP based backhaul, and vice versa. The requirements of a gateway go beyond being just a firewall. As this is the closest point to the devices, the gateway may also be used as the point of device access control, determining whether the device can connect using its proximity communications. Beyond that, a network gateway serves many needs, including management of traffic and meeting service level agreements or regulatory requirements, and is itself a critical device that must be protected.

In the WiFi scenario, the device will typically authenticate by presenting the network key through the WPA/WPA2 security protocol. In a LoRa network, the device key will have been prepositioned into the network server and the network key will either be pre-positioned also by the service provider or may be negotiated through over the air keying. For NB-IoT, an inserted or embedded sim module will provide authentication to the network.

Communications from the gateway through the access network to the application will be deployment specific. Standard IP protocols such as IPSec are often used to achieve integrity and confidentiality on the access network.

The security of the gateway is a critical part of any IoT end-to-end solution, as it is exposed both in the proximity network to rogue devices and in the access network to internet delivered attacks. ETSI TR 103421: Network Gateway Cyber Defence provides a good overview and set of recommendations concerning cyber defence capabilities at network gateways.

5.6 Proximity Layer

One of the fundamental aspects of the IoT is the manner low-powered devices self-organise and share information (route and data information) among themselves. Even though these sensors are energy constrained, they need to store and process data, dynamically connect to the network, and possibly interoperate with other devices. Some of the devices may act as internal or border routers.

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9 https://www.itu.int/rec/T-REC-X.805-200310-I/en

10 Supporting Communications in the IoTs using the Location/Id Split Protocol: A Security Analysis, Raheem et a, Middlesex University, December 2013

Some proximity network protocols may connect devices directly to the access gateway, while some may connect via other devices. In the latter case, for a route to be established, route information may be transmitted from node to node (multi-hopping) until the desired destination is found. Throughout the route maintenance phase, nodes can add, delete or needlessly delay the transmission of control information (selfish or misbehaving nodes). It is during route discovery or forwarding that malicious nodes can attack. For example, a node can introduce a routing table overflow attack by transmitting a large amount of false route information to its neighbours in a manner that will cause its neighbour's routing table to overflow or be poisoned. A malicious node can advertise a false route with the smallest hop count and with the latest sequence number, hence other nodes, seeing this as a route update, quickly invalidate their old route to innocently accept the new false route. IoT networks require adequate security to enable seamless operation and for users to build confidence. A full set of routing protocol attacks has been identified by David Airehrour, Jairo Gutierrez and Sayan Kumar Ray[11].

Secure routing plays an essential role in the safe and seamless functioning of the entire network, yet finding a universal solution applicable to all the routing attacks is proving to be very difficult. Protocol designers must ensure protection from the known attacks, while minimising the impact on sensor and network performance. There are five key issues to address: secure route establishment, automatic secure recovery and stabilisation, malicious node detection, lightweight or hardware-supported computations, and node location privacy.

At the higher data rates, Ethernet, WiFi and WiMax are well known physical layer standards. In the cellular space, the current 2G-4G standards are deployed and 5G is emerging as a real option for IoT use. At the same time, Narrowband IOT (NB-IOT) has been developed and is in trials as a technology that can co-exist with existing cellular networks to provide IOT solutions now.

It should be noted that security at the physical and media access control layer requires a certain amount of computing power and this may not be available to very constrained devices, for example in devices such as micro/nano-technology enabled sensors. Energy efficiency and sufficiency for IoT sensors is an active research area. Where possible, symmetric cryptography should be implemented in hardware level in order to achieve acceptable performance.

5.6.1 IEEE 802.15.4

IEEE 802.15.4 defines the physical layer and media access control for low-rate wireless personal area networks, or LR-WPAN. This is the standard used in personal and industrial applications where there are many sensors and a low-cost, low-speed network approach can be used in the proximity segment. It operates at about 250Kb/s at up to 10 metres. Other standards such as WirelessHART, DigiMesh, ISA100.11a also exist as low power physical layer standards. ZigBee is built on IEEE 802.15.4, as is 6LoWPAN.

IEEE 802.15.4 does not require security, but it can be applied to enable device authentication, payload protection, and message replay protection. An access control list is used to specify the security configuration based on the destination address, and from this the symmetric cryptography for payload protection. Where security is specified, an auxiliary security header will be used. The cryptographic security modes that can be employed in an IEEE 802.15.4 system are as shown in Table 5.

The Advanced Encryption Standard counter mode (AES-CTR) can be used where confidentiality of the link layer encryption only is required, with message integrity being handled at a higher level. However, there are some concerns regarding this mode's

[11] *Secure routing for Internet of Things: A survey*. Airehrour, Gutierrez and Ray, Journal of Network and Computer Applications, (66) 2016

susceptibility to denial of service attacks through use of forged packets, and its use is discouraged.

Table 5: IEEE 802.15.4 Security Modes

Mode	Description
No security	-
AES-CBC-MAC-32	Data is not encrypted, uses a 32-bit integrity code.
AES-CBC-MAC-64	Data is not encrypted, uses a 64-bit integrity code.
AES-CBC-MAC-128	Data is not encrypted, uses a 128-bit integrity code.
AES-CTR	Data is encrypted, no integrity code.
AES-CCM-32	Data is encrypted, uses a 32-bit integrity code.
AES-CCM-64	Data is encrypted, uses a 64-bit integrity code.
AES-CCM-128	Data is encrypted, uses a 128-bit integrity code.

The CCM mode combines the counter and CBC modes of operation to provide confidentiality, authenticity and integrity at the link layer.

5.6.2 6LoWPAN

6LoWPAN environments route traffic using the Routing Protocol for Low-power and Lossy Networks (RPL) protocol. Rather than providing a generic approach to routing, RPL provides a framework that is adaptable to the requirements of particular classes of applications. This suits the richer attribute approach to security.

In the most typical setting various 6LoWPAN nodes are connected through multi-hop paths to a small set of root devices responsible for data collection and coordination. RPL defines secure versions of the various routing control messages, as well as three basic security modes: unsecured, pre-installed, and authenticated and adopts AES/CCM as the basis to support security. A secure RPL control message includes a security field after the ICMPv6 message header. The information in the security field indicates the level of security and the cryptographic algorithms employed to process security for the message.

Incorporation of a timestamp and a nonce in a 6LoWPAN message can also protect against fragmentation attacks. Hash chains and purging of messages from suspicious senders can also help protect replay attacks between sensors and 6LoWPAN devices.

6LoWPAN inherits its security model from IEEE 802.15.4. No security mechanisms are currently defined in the context of the 6LoWPAN adaptation layer. RFC 4919, however, discusses the possibility of using IPSec at the network layer, although this may be too processing intensive for smaller IoT devices.

5.6.3 ZigBee

ZigBee specifies an IEEE 802.15.4-based set of high-level communication protocols used to create personal area networks using low-power digital radios. It is intended to be low power, lower cost and simpler to implement than Bluetooth and WiFi. It uses 128-bit encryption keys and is typically used where the end-point device requires long battery life and secure networking. ZigBee devices have low latency and low data rates.

5.6.4 LoRaWAN

LoRaWAN is a Low Power Wide Area Network (LPWAN) specification intended for wireless devices which are battery powered, and provides secure bi-directional communication, mobility and localisation services. LoRaWAN is typically architected as a star-of-stars topology in which a gateway acts as a transparent bridge relaying messages between end-devices and a back-end server.

Communication between end-devices and gateways is spread spectrum, and devices are not IP addressable, both of which provide significant security advantages.

LoRaWAN incorporates the ability to authenticate the node in the network and to protect the payload using AES encryption. LoRaWAN has comprehensive and well-designed security at both the network and application layer and uses two keys, one at the network layer for message integrity and one at the application layer for confidentiality. LoRaWAN does not allow for the device key to be changed, but does create a unique session key for payload encryption when the device joins a network. AES counter mode (AES-CTR) is used for payload encryption. It uses AES128 as its encryption algorithm, with the base encryption key referred to as the AppKey. The AppKey is stored in a network server, and also stored in the device.

This is used to generate two working keys:

- unique 128-bit network key to ensure security at the network level (NwkSKey)
- a unique 128-bit application key to ensure end-to-end security at the application level (AppSKey)

Encryption uses the AES-CCM (Counter with CBC-MAC) mode of operation which provides counter-based integrity.

The activation of a LoRa service depends upon the service provider, however the protocol allows for both Activation By Personalisation (ABP) where the service provider provides the session keys, and Over The Air Activation (OTAA) where these are dynamically created.

5.6.5 Sigfox

SIGFOX is a cellular style system that enables remote devices to connect using ultra-narrow band, UNB technology. It is aimed at low cost machine-to-machine applications where wide area coverage is required and cellular is too costly. The overall SIGFOX network topology has been designed to provide a scalable, high-capacity network, with very low energy consumption, while maintaining a simple and easy to rollout star-based cell infrastructure. SIGFOX allows up to 140 messages per device per day, with the message payload of 12 bytes and a wireless throughput of up to 100 bits per second and is ultra-low power. The SIGFOX network is radio-based using unlicensed frequencies. Data is not delivered directly to the user from the radio system. When data is received from the radio network, a message is sent to user's server or an aggregator which in turn will dispatch it to the user.

5.6.6 LTE-M and NB-IoT

Another cellular technology being deployed for IoT is LTE Cat-M1, or LTE-M, the enhanced fourth generation long term evolution of the 3G GSM/CDMA cellular technology. LTE is already used in 4G cellular services, so it does not need a completely new infrastructure and can be deployed as a software upgrade to an existing 4G services. LTE-M solutions operate at around 1Mb/s and can support easy handoff for mobile devices in the transportation sector.

LTE solutions can also be deployed in an enterprise form, operating as a radio network with backhaul to an IoT management platform.

The 3GPP began work on a new variant of LTE, LTE Cat-M2 or NB-IoT, in September 2015, and initial results of this work have been strongly supported by Industry. NB-IoT operates at about 200Kb/s. By December 2015, the first pre-commercialisation trial was successfully completed in Spain by Vodafone, Huawei, Neul and U-blox and NB-IoT is now being deployed by carriers.

NB-IoT is designed as a resilient network which is power-efficient and has deep in-building penetration, wide area ubiquitous coverage, and can manage high volumes of small data packets. NB-IOT utilises the security and privacy features that already exist in mobile networks, such as support for user identity confidentiality, entity authentication, confidentiality, data integrity, and device identification. It includes network access security, network domain security, user domain security, and application domain security. Three algorithms exist to protect the air interface: the SNOW stream cipher designed by cryptographers at Lund University in Sweden; AES; and the ZUC stream cipher designed by the Chinese Academy of Sciences. EPS-AKA is used for authentication and key agreement. Backhaul may be physically protected, or protected by IPSEC and may include a Security Gateway (SEG) to provide protection for the Evolved Packet Core (EPC). It is a sim-based deployment ensures full hardware-based, tamper-proof cryptography.

3GPP has published guidelines for the LTE security architecture in its technical standard TS33.401, and NIST has provide guidelines on LTE security in SP800-187.

5.6.7 5G

3GPP is currently developing standards on the next cellular network technology, known as 5G. Pilot trials of 5G have been successfully completed, and the first production deployments with IoT slices are expected by the end of 2018. A technical report on 5G security has been released by 3GPP as TR89.331. As noted in section 3.5 5G Considerations, 5G technology allows network slices to be optimised for specific uses, and software defined networking developments are tailoring communications to specific IoT requirements.

5.7 Device Layer Security

5.7.1 Security Threats

Security threats to hardware and embedded systems are a well-known concern and care is needed to reduce the opportunity for hardware to incorporate flaws or to be a vector for malicious attack. Embedded systems do provide a level of security in that firmware is less prone to compromise, but if patches are made available a testing regime is recommended prior to release to production.

Defending against potential threats requires an approach to security testing of hardware components particularly where the product depends upon hardware based random number generators, encrypted bit streams, key storage elements, secured flash memory, anti-tamper features and other controls. Unless these controls are trustworthy, higher level security controls will be compromised.

A key element in hardware security is the supply chain, and the opportunity and motivation for actors in the supply chain to embed backdoors or malicious circuits at the hardware level. Research related to hardware injected Trojan circuits[12] has identified some solutions for detecting hardware Trojans.

Testing tools are increasingly starting to offer the capability to bridge directly to hardware, for example the latest release of the Metasploit framework includes the ability to link tests directly to hardware[13]. Early applications include automotive systems such as CANBus and industrial SCADA components.

5.7.2 Trusted Execution

Hardware provides a solution to some of the problems of IoT security, for example in having a hardware-based root of trust. ARM introduced its TrustZone architecture into its Cortex processors to provide system wide hardware isolation for trusted software. This has enabled

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[12] Addressing Hardware Security Challenges in Internet of Things: Recent Trends and Possible Solution. Koley S et al, http://ieeexplore.ieee.org/document/7518284/

[13] http://www.globenewswire.com/news-release/2017/02/02/913426/0/en/Rapid7-Enables-IoT-Hardware-Security-Testing-with-Metasploit.html

the deployment of what is commonly referred to as the Trusted Execution Environment (TEE – or QSEE on Qualcomm chips).

At this stage the TEE is typically used for vendor supplied secure storage mechanisms, trusted keyboard entry, and cryptography. The TEE is not yet available for consumers to deploy secure applications, although some vendors do enable 3rd party applications to be registered for secure operation.

6 DOMAIN VIEWPOINTS

Some domain specific guidance has been provided in the consumer, industrial, healthcare, smart cities, and automotive domains.

6.1 Consumer Domain

The IoT Security Foundation has developed a foundation of guidance on IoT security, with the first release focusing primarily on the consumer domestic – or home automation – domain. This includes a set of 33 principles for IoT security, in seven groups, as described in section 5.1.

In addition, the IoT Security Foundation has proposed a compliance regime for demonstrating security in IoT devices and systems. This classes an IoT product into one of five classes – Class 0 to Class 4 - as shown in Table 6.

Table 6: IoT Security Foundation Classes

Class	Impact of Compromise	Confidentiality	Integrity	Availability
0	Minimal	Basic	Basic	Basic
1	Limited impact on an individual or organisation	Basic	Medium	Medium
2	Significant impact on one or more individuals or organisations	Medium	Medium	High
3	Significant impact to sensitive data	High	Medium	High
4	Personal injury or damage to critical infrastructure	High	High	High

While there is no governance framework in which to apply a compliance regime, the IoT Security Foundation envisages that an audit process could lead to use of a "Trust Mark" as a qualified public symbol of conformance to best practice.

6.2 Industrial Domain

While many uses of the IoT will involve collection of data from sensors, IoT devices are also remotely activated and configured through central decision-making processes. The controlled devices may be as simple as a light switch, or as complex and expensive as aircraft control systems, nuclear reactors and mining systems. Many older systems continue to use SCADA or programmable logic controls (PLCs). SCADA is well known for security weaknesses, with the Stuxnet worm being the most notorious example of a successful and extremely damaging attack.

IoT control systems vary from the low-scale (a home lighting system) to the critical (power supplies for a large city). There are as yet no comprehensive guidelines spanning this range. Some guidelines, predominantly from the US, exist in specific areas such as SmartGrid.

The Industrial Internet Consortium (IIC) has published security guidance[14] on security in the industrial sector. The IIC see the industrial internet of things as being the convergence of information and operational technology across the internet, with a focus on the traditional

[14] Industrial Internet of Things: Volume G4 Security Framework IIC:PUB:G4:V1.0:PB:20160919

information security aspects of confidentiality, availability and integrity but also embracing privacy, safety, reliability and resilience to deliver a concept of trustworthiness for industrial IoT.

It is recommended that a model for delivering trustworthiness in the industrial IoT incorporates a risk management approach, taking into account the OWASP Top Ten IoT threats, and using a model such as Microsoft's STRIDE for evaluating threats and modelling risk. The concept of trustworthiness is applied from the component design through system building to operational use. This requires a clear identification of security requirements and the ability to trace how these requirements are being met through the supply chain to the end user. This can be achieved using a business security architectural approach such as that provided by the SABSA framework.

The functional viewpoint of the industrial IoT security framework comprises six interacting building blocks. It starts with the two basic blocks of security policy model and data protection and then incorporates four core security blocks of endpoint protection, communications & connectivity protection, security monitoring and analysis, and security configuration & management.

6.3 Healthcare Domain

Healthcare is a sector in which It is conceivable that failures in the IoT environment could potentially lead to not only reputational damage and expensive litigation but also loss of life.

The US Food and Drug Administration has produced guidelines for the security of medical devices and systems[15]. They consider both pre-market considerations to determine "recommendations for manufacturers to address cybersecurity during the design and development of the medical device" as well as post-market support: "... it is essential that manufacturers implement comprehensive cybersecurity risk management programs and documentation."[16]

A security architecture for healthcare[17] has been proposed by researchers at CISCO Systems, in which they identify both communications and physical devices as attack surfaces. The architecture paper identifies relevant standards activities.

6.4 Smart Cities Domain

Many current smart city initiatives are being deployed piecemeal and are based on custom systems that lack interoperability or portability between cities, and they are not extensible or cost-effective. In addition, the standards community has yet to converge on a common language and architecture. To address this problem, the US National Institute of Standards and Technology has convened a working group[18] to develop a common IoT-enabled smart city framework. This work is at an early stage of development but it is likely to have a significant impact on how smart cities apply IoT.

On 29 April 2016, the Australian Government launched its Smart Cities Plan[19]. The plan foresees the use of new technology in transport and communications, and looks to leverage real time open data driven solutions to support innovation.

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15 U.S. Dept of Health and Human Services Postmarket Management of Cybersecurity in Medical Devices http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM482022.pdf

16 Homeland Security, : https://ics-cert.us-cert.gov/Seven-Steps-Effectively-Defend-Industrial-Control-Systems

17 http://www.riverpublishers.com/journal/journal_articles/RP_Journal_2245-800X_133.pdf

18 https://pages.nist.gov/smartcitiesarchitecture/

19 https://cities.dpmc.gov.au/smart-cities-plan/

6.5 Automotive Domain

Automobile systems commonly use the controller area network (CAN) bus to interact with almost all systems. Access to the CANbus is required by automotive repair shops for diagnostic purposes, it is an obvious attack surface potentially giving access to the brakes and steering subsystems which introduces serious safety concerns. Remote control of a Jeep Cherokee travelling at 70mph was demonstrated at the 2015 Blackhat conference.

While alternatives to CANbus are appearing, replacement will be a long-term objective. In the meantime, advice by experts such as NXP's security architect, van Roermund is[20]

- Isolate in-vehicle electronics from external interfaces with firewalls;
- Apply strict access control to only allow known/trusted entities (partial) access to in-vehicle systems;
- Segment in-vehicle networks, in which systems with similar criticality are clustered in separate networks, to better isolate safety-critical systems from others;
- Protect message-exchange over in-vehicle networks using cryptography (digital signing and potentially encryption);
- Use intrusion detection/prevention systems (IPS/IDS) to detect and possibly counter attacks;
- Protect the ECUs (microcontrollers and their software) through secure boot, secure update, and other measures.

Almost every automotive system now comprises a sensor network and an actuator network. Many issues arising from sensor data can be managed at higher levels, but these higher levels and connectivity can lead to serious problems when they result in effects at the actuator level. While there are guidelines in many important cases, the scope of the IoT at present rules out generic solutions. Nevertheless, it is critical that attention be paid to these issues.

An active research area is Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X) communications. Although these developments can offer huge safety benefits, there are also substantial security and privacy concerns. Authorities in both the US and the European Union are working towards appropriate standards. Australia has adopted the C-ITS standard in the 5.9Ghz band[21], aligned with the EU, based on a number of ETSI TS 102 standards. The US has a different standard based on IEEE 1609.2.

A primary difference is that the EU model applies security at the network layer while the US model applies it at the application layer. The US model has better anonymity, with the potential for improved privacy, compared to the EU model. A further complication is that the Japanese and Korean standards do not align with either the US or EU standards, making import of cars (particularly used ones) from these countries problematic.

There are two principal sub-categories of V2X: Vehicle to Infrastructure (V2I) and Vehicle to Pedestrian (V2P). In general, V2I can be managed by the above standards although a failure of security can have more wide-reaching consequences. V2P is more complex as pedestrians cannot be guaranteed to carry appropriate devices and pedestrian detection systems may be needed. There do not appear to be specific cyber security related issues, but of course a failure in the vehicle's security is more likely to be fatal to the pedestrian.

Relevant organisations in Australia include Austroads, Intelligent Transport Systems Australia (ITS Australia) and the recently established Cooperative Research Centre, iMOVE.

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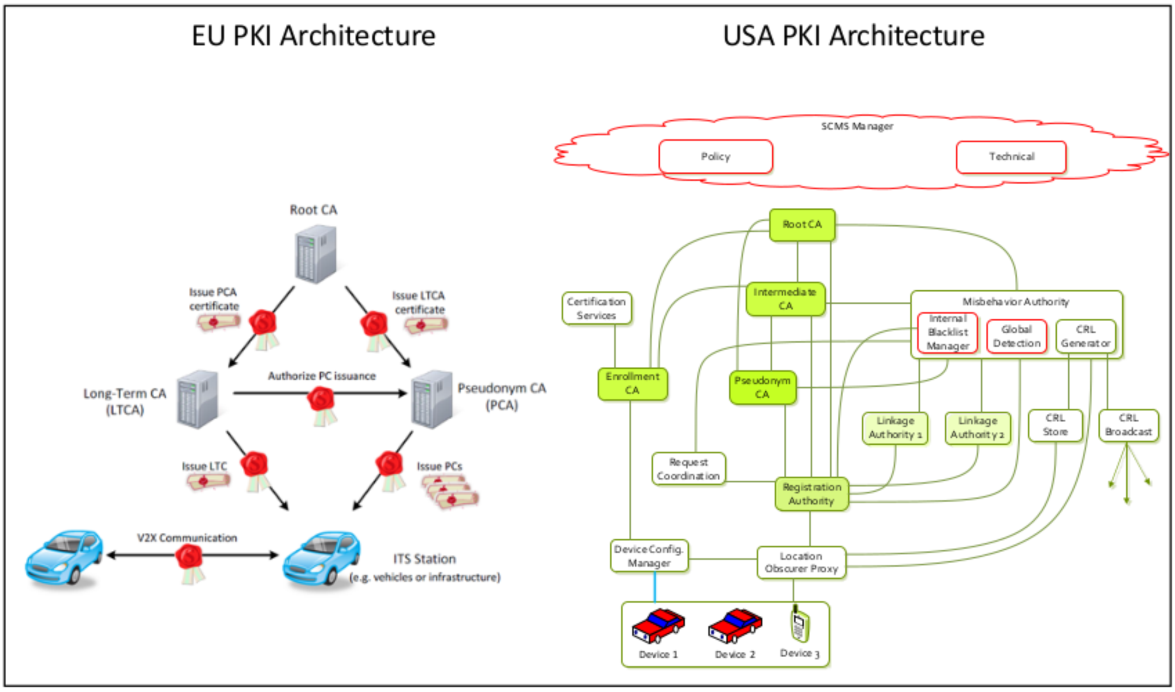
20 Junko Yoshida CAN Bus Can Be Encrypted, Says Trillium http://www.eetimes.com/document.asp?doc_id=1328081&page_number=3

21 Cooperative Intelligent Transport Systems (C-ITS) Standards Assessment by David Green, Dr Charles Karl and Freek Faber, Austroads Ltd



Source: From a presentation prepared by Dr. André Weimerskirch of the University of Michigan Transportation Research Institute (UMTRI) on 27 March 2014.

6.6 Agriculture Domain

Little attention has been given to the security of IoT products used in agriculture. However the American Farm Bureau Federation has drafted a set of Privacy and Security Principles[22] relating to the use of smart technology on farms, with a focus on enabling secure central repositories of precision agriculture and farm data. These have been incorporated in the *AG Transparency Evaluator*, a checklist approach to the application of the principles, as shown in table 7.

Table 7: Privacy and Security Principles for Smart Agricultural Technology

Principle	Description
Education	The industry should work to develop programs to create educated customers who understand their rights and responsibilities. Contracts should use using simple, easy to understand language.
Ownership	Farmers set the agreements on data use and sharing with the other stakeholders with an economic interest, such as the tenant, landowner, cooperative, owner of the precision agriculture system hardware, and/or technology provider.
Collection, Access and Control	The collection, access and use of farm data by technology providers should be granted only with the affirmative and explicit consent of the farmer through contract agreements.
Notice	Farmers must be notified that their data is being collected and about how the farm data will be disclosed and used. This notice must be provided in an easily located and readily accessible format.
Transparency and Consistency	Technology providers should notify farmers about the purposes for which they collect and use farm data, and provide contacts for inquiries or complaints. They should explicitly state the types of third parties to which they disclose the data and options for limiting its use and disclosure. The technology provider's

22 http://www.fb.org/issues/technology/data-privacy/privacy-and-security-principles-for-farm-data

	principles, policies and practices should be transparent and fully consistent with the terms and conditions in their contracts. Customer contract should not be changed without agreement.
Choice	Technology providers should explain the effects and abilities of a farmer's decision to opt in, opt out or disable the availability of services and features offered by the technology and services. If multiple options are offered, farmers should be able to choose some, all, or none of the options offered.
Portability	Within the context of the agreement and retention policy, farmers should be able to retrieve their data for storage or use in other systems, with the exception of the data that has been made anonymous or aggregated and is no longer specifically identifiable.
Terms and Definitions	Farmers should know the third parties, partners, business partners, or affiliates of their technology provider which have access to their data. Clear language should be used in terms, conditions and agreements.
Disclosure, Use and Sale Limitation	Technology providers must not sell and/or disclose non-aggregated farm data to a third party without first securing a legally binding commitment to be bound by the same terms and conditions that are in place with the farmer. Farmers must be notified if such a sale is going to take place and have the option to opt out or have their data removed prior to that sale.
Data Retention and Availability	The technology provider should provide for the removal, secure destruction and return of original farm data from the farmer's account upon the request of the farmer or after a pre-agreed period of time. Personally identifiable data retention, availability and disposal policies should be documented.
Contract Termination	Farmers should be allowed to discontinue a service or halt the collection of data at any time subject to appropriate ongoing obligations. Procedures for termination of services should be clearly defined in the contract.
Unlawful or Anti-Competitive Activities	Technology providers should not use the data for unlawful or anti-competitive activities, such as a prohibition on the use of farm data by the ATP to speculate in commodity markets.
Liability & Security Safeguards	Technology providers should clearly define terms of liability. Farm data should be protected with reasonable security safeguards against risks such as loss or unauthorised access, destruction, use, modification or disclosure. Polices for notification and response in the event of a breach should be established.

It is likely there will be some overlap with the automotive sector as smart farm vehicles and drones gain widespread adoption in the agricultural sector.

6.7 Critical Infrastructure Domain

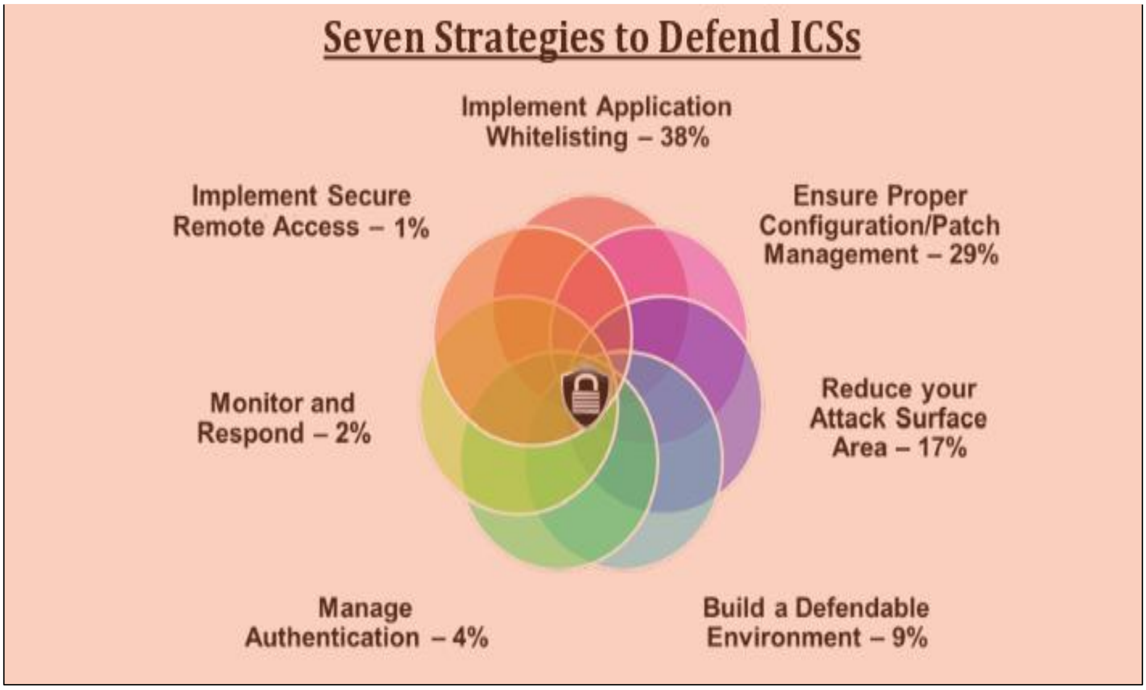
The US Government is developing principles and strategies for managing risk in the critical infrastructure domain[23]. IoT security strategies in this domain will have to align with the US Government principles and strategies. These are summarised in Figure 3, and include some of the strategies from the Australian Signals Directorate Essential Eight controls.

Patching and application whitelisting are top controls, whilst monitor and respond are key elements of NIST's Cybersecurity Framework. A key area to note in this domain is that of analysing and reducing the attack surface – a process which has much in common with the resilience work on single point failure analysis.

23 Homeland Security https://ics-cert.us-cert.gov/sites/default/files/documents/Seven%20Steps%20to%20Effectively%20Defend%20Industrial%20Control%20Systems_S508C.pdf

Building a defendable environment involves segmenting networks into logical enclaves and restricting host-to-host communications paths to those necessary. The use of network enclaves limits possible damage, as compromised systems cannot be used to reach and contaminate systems in other enclaves. Containment provided by enclaving also makes incident clean-up significantly less costly.

Figure 3: ICS-CERT Incidents Mitigated by Strategy



7. RESILIENCE AND SURVIVABILITY

7.1 Resilience

The resiliency of a system can be defined in general terms as its capability to resist external disruption and internal failures, to recover and gain stability, and even to adapt its structure and behaviour to constant change.

Laprie[24] has defined resilience as *The persistence of dependability when facing changes* and provides a view of how resilience, dependability and security interact (Figure 4).

Figure 4 Resilience and Other Attributes

The International Telecommunications Union considers the two key attributes of reliability and availability to be core characteristics of communications networks. This is true for existing fixed and wireless networks, as well as the emerging IP-based Next Generation Networks (NGNs).

RFC 6568 provides some early consideration of the possible approaches to resilience in the light of the characteristics and constraints of wireless sensing devices, and discusses threats due to the physical exposure of such devices which may pose serious demands for resiliency and survivability.

Much more work has been carried out on resilience since Laprie published his model. To be resilient, a system must also be fault tolerant, dependable, and trustable. Beyond this, diversity, adaptation, correlation, causation, and renewal are the most promising directions of research into resilience of complex systems.

The IoT will be so large as to be difficult to monitor effectively and control efficiently, and consequently the resilience of any IoT system will be important. The use of multi-homing on network devices is a common networking strategy to increase the overall resilience of a network. Such a strategy can usefully be applied to IoT devices, and can be seen in devices which can connect to multiple gateways and peer devices.

7.1.1 Reliability

Interpreting reliability is more critical for IoT than for traditional IT services. One attribute which can be critical for some IoT systems is latency – the delays that are experienced as traffic travels through the various network links from the IoT device to the destination. This is addressed by telecommunications providers in systems such as VOIP through providing a fit-for-purpose class of service. Customers of NB-IoT services should require a fit-for-purpose class of service offering from their telco providers.

24 “From Dependability to Resilience”, IEEE/IFIP 2008

7.1.2 Availability

Availability typically requires attention to three key attributes: built in whole-of-life power sources, the ability to access the internet through the IoT gateway, and the availability of transit paths from the gateway to the destination on either the fixed line internet or linked through mobile services to a handset data service.

Long-life devices are made possible through low power design, including the use of low power near connectivity, and low power wide area (LPWAN[25]) communications. Some solutions for energy harvesting, such as WSN-HEAP[26], enable greatly extended sensor lifetime. WSN-HEAP sensors can use environmental energy such as light, vibration, and heat using nano-collectors. Cellular networks and standard WiFi require significant power and are not always suitable for sensors. The IEEE has developed a standard 802.15.4 as a low power protocol. 6LoWPAN, as adopted by ARM and Cisco, is based on IEEE 802.15.4 and provides a low power connectivity solution. In the wide area, NB-IoT is designed to be a low power requirement protocol to support devices with lifetimes of 10 years or more.

Access to the wide area IoT transit service is usually through a near-area gateway device (also known as an edge node) such as a home hub, although wearable devices may look for direct connectivity with cellular services for mobility.

There are five key issues with the first-hop, i.e. the device to near-area gateway, access:

- Signalling, to ensure that data is delivered and meets performance criteria;
- Security, especially authorisation, encryption, and open port protection;
- Presence detection, to know when an IoT device loses connectivity;
- Scalability, ensuring bandwidth is available as massive scaling of the IoT takes place; and
- Protocol, whether the device connects using IPv4 and uses NAT across the gateway, or connects natively in IPv6 (6LoWPAN carries an IPv6 address and offers internet connectivity without significant additional overhead).

NB-IoT is different to other protocols as it is designed to connect directly with the cellular network and will avoid some of the device to gateway issues.

Where the service involves cloud applications, as was the case with the Wink smart home devices[27], any accidental or scheduled maintenance outage will result in availability issues. Wide-area transit path availability is a requirement that should be specified in SLAs and support for multiple diverse paths for critical IoT services should be specified if required.

7.2 Survivability

While not currently a significant consideration for telecommunications and cloud service providers, survivability will be increasingly important as the IoT places more always-on, real-time demands on IoT communications. A critical IoT class is emerging and will need ultra-reliable, and potentially survivable, services to be deployed. These include remote health care, smart grid automation, traffic safety and control, and industrial control. While product developers can do little to ensure survivability of the end-to-end service, these needs should be identified at the design stage and the risks around survivability should be taken into account in service planning.

One approach to achieving network survivability is to focus on the ongoing operation of lower layer connectivity, in the event of loss or degradation of one or more nodes or links,

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25 https://en.wikipedia.org/wiki/LPWAN

26 Seah & Chan, Challenges in Protocol Design for Wireless Sensor Networks Powered by Ambient Energy Harvesting, IEEE, Wireless Vitae 2009

27 www.wired.com/2015/04/smart-home-headaches/

through static or dynamic link redundancy. Survivability in this context is not applied to higher level services. In the military and critical infrastructure fields, it is common to consider survivability as it applies to the mission or service and, hence, look to end-to-end survivability at all levels. Key to this is establishing the concept of essential services, and ensuring that these are protected even at the cost of non-essential services if necessary.

Survivability is not just an issue of maintaining operational status. A service which has an operational core network and set of services is of little use if it cannot be accessed by those users who have a critical part of the business process to perform. For instance, a supervisory control and data acquisition (SCADA) system in a nuclear plant needs to be operational at all times, allowing relays, switches, and monitoring sensors to take commands and return status information. However, having the central control room and the remote termination unit both fully available is of little use if users lose network access.

One potential methodology for designing elements of critical infrastructure is the Risk Analysis and Probabilistic Survivability Assessment (RAPSA) Taylor et al[28]. RAPSA emerged from examining an increasingly significant threat of cyber terrorism to the SCADA systems used to control electrical infrastructure. The conclusions from this work hold also for malicious or inadvertent damage from malware, external and internal hacking, or system failures. The use of public distributed networks such as the internet makes it impossible to harden the complete end-to-end system, and there is a real possibility that at least part of the system is susceptible to damage through cyber-attack.

RAPSA has evolved from two separate disciplines – survivability systems analysis and in particular the Survivable Network Assessment (SNA) process[29] with its probabilistic risk assessments. It considers the issues associated with maintaining survivability in unbounded and hostile networks such as the internet, where attacks are frequent and may be zero day – i.e. hitherto unknown and with no countermeasures (e.g. a patch) available. When under attack, even if the attack is successful, the survivable network must maintain its essential services and a process to recover full capability must be commenced at the earliest opportunity.

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[28] Taylor C, Krings A., and Alves-Foss J. Risk Analysis and Probabilistic Survivability Assessment (RAPSA): An Assessment Approach for Power Substation Hardening. *Proceedings of ACM Workshop on Scientific Aspects of Cyber Terrorism.* (Washington DC), November 2002.

[29] Mead NR, Ellison RJ, Linger RC, Longstaff T, McHugh J. Survivable Network Analysis Method. *Technical Report CMU/SEI-2000-TR-013*, Carnegie-Mellon University, 2000

8 DEVELOPING IOT PRODUCTS AND SERVICES

The development environment for IoT spans many programming languages, operating systems, and networks. Hardware is specialised. The attack surface for IoT is enormous, there are no generic models for security across IoT, and there is a risk that security may become an afterthought due to the demands of getting products to market[30]. In addition, as information technology and operational technology systems continue to converge, particularly in mission and life critical solutions, security is becoming an increasingly important requirement and an underpinning foundation for safety.

8.1 Identifying Security Needs

Security is an important consideration when designing an IoT product or system, and a secure IoT framework such as that promoted by the Online Trust Alliance should be adopted to ensure that developers design security into their products while still allowing for rapid application development. The framework should incorporate security components which deliver security by default, transparent to deployment personnel. The Open Group enterprise architecture framework provides an approach to defining security requirements[31] based on identifying appropriate business classifications. Examples of business classifications include confidential, protected, private, available, and resilient. By defining which classification attributes apply, a risk profile can be determined and appropriate security controls applied.

Developing a risk profile for the deployment of IoT products helps ensure a product not only is secure from a cyber attack, but that it operates in a manner which promotes privacy and safety. In the same way as security is applied to traditional IT products, the level of rigour at which security is applied in the IoT domain should be proportional to the potential consequences should it fail.

Given the wide scope of IoT, there is no single solution which defines security for IoT. Designers need to identify the security requirements relevant to their products in the context of the design goals, the environment in which the product will be deployed, and with regard to any regulatory obligations that might apply.

8.2 Security Frameworks

8.2.1 Industrial Internet Consortium

The Industrial Consortium has produced a series of documents including the *Industrial Internet of Things Volume G4: Security Framework*. This is a very thorough document covering the business viewpoints of risk and trust and functional viewpoints including protecting endpoints, protecting communications and connectivity, monitoring and analysis, and configuration and management. This is summarised in section 6.2.

This document also pays particular attention to 'brown fields' systems where new solutions and components must co-exist and interoperate with existing legacy solutions. This is in recognition that there are many long-lived systems which are potentially "out of date," and solutions such as locked doors are no longer appropriate.

8.2.2 Open Connectivity Foundation

The Open Connectivity Foundation (formerly the Open Interconnect Consortium, OIC) has designed an open framework for the IoT. This provides detail down to the level of device

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30 www.networkworld.com/article/2909212/security0/schneier-on-eally-bad-iot-security-it-s-going-to-come-crashing-down.html

31 www.opengroup.org/subjectareas/security

descriptions, data types, network protocols, and includes an IoT security specification. The framework is still evolving.

8.3 Security Standards and Guidelines

8.3.1 Open Web Application Security Project (OWASP)

The Open Web Application Security Project was originally conceived as an initiative to develop the definitive security and testing guide for web services. OWASP subsequently extended its scope with the development of a framework for mobile device testing, and has now produced a similar framework and testing guide for IoT.

The OWASP IoT Security Principles, summarised at Appendix I, can be applied in various ways by manufacturers, developers and consumers as evaluation criteria for various forms of IoT products. These criteria provide the basis of a secure IoT development framework. Their adoption as part of the overall development framework substantially increases confidence in IoT deployments and will likely minimise the overall cost of developing a secure IoT environment.

8.3.2 Internet of Things Security Foundation

The Internet of Things Security Foundation (UK) has produced a set of *Principles for Security IoT*, based around privacy, trust, integrity, access control, ownership and auditing. The document provides a set of questions in each area which explore the extent of a target device's security. This guidance is summarised in section 6.1.

8.3.3 Online Trust Alliance

The Online Trust Alliance has produced a set of *Trust Principles*, based around security, access and credentials, privacy disclosures and transparency, and notifications. This guidance is detailed in section 5.1.

8.3.4 NIST IoT Security Model

The National Institute of Standards and Technology's *Special Publication 183* provides "an underlying and foundational science to IoT-based technologies on the realisation that IoT involves *sensing, computing, communication*, and *actuation*.[32]" The model is based on five primitives of sensor, aggregator, communications channel, eUtility, and decision trigger. It also has six elements or characteristics of an IoT device: environment in which it operates, cost, location, owner, identifier and snapshot.

NIST has also released *Special Publication 800-160: Systems Security Engineering*[33]. This is not a security standard for IoT per se, but represents a set of best practices for cybersecurity in product engineering in order to deliver a trustworthy product. It provides a systems security engineering framework, together with a set of technical and technical management processes.

NIST is also leading the work on development of an IoT-enabled smart city framework as referenced in section 6.5.

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32 http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-183.pdf

33 http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-160.pdf

8.3.5 GSMA Security Architecture

The GSMA has produced a set of four documents covering IoT security: a security guidelines overview, guidelines for IoT Service Ecosystem, guidelines for IoT endpoint system, and guidelines for network operators[34]. The goal of these guidelines is to resolve the security challenges inherent to its growth. These challenges are:

- Availability: ensuring constant connectivity between endpoints and their respective services in a way which provides security similar to that of cellular networks;
- Identity: authenticating endpoints, services, and the customer or end-user operating the endpoint;
- Privacy: reducing the potential for harm to individual end-users by understanding what privacy identifying information is processed, particularly relating to tracking of people; and
- Security: ensuring that system integrity can be verified, tracked, and monitored by understanding the security in its development lifecycle, whether it uses a trusted computing base, its ability to detect and contain malicious behaviour, and its incident management.

The guidelines provide a set of examples showing how security might be designed into solutions taking into account the challenges above. The guidelines do not provide a new security architecture, rather they identify the questions that should be posed, provide a list of frequently asked questions, and indicate existing standards that might address the solutions.

GSMA observes that IoT technology has collapsed into a predictable model composed of only several variants, with the IoT endpoint expected to take on one of three manifestations:

- the Lightweight Endpoint, e.g. wearables and home security sensors;
- the Complex Endpoint, e.g. appliances and SCADA systems; and
- the Gateway (or "Hub").

The GSMA security model considers five targets for endpoint attack: networks, network services, console access, local bus and chips.

The network security principles cover secure identification and authentication of users, applications, endpoint devices, networks, and service platforms; security of communications; and availability. The Guidelines list a set of best practice recommendations for service providers to consider.

The Guidelines provide a set of security recommendations for the endpoints and service ecosystem, which are shown at Appendix III.

8.3.6 Cloud Security Alliance

The Cloud Security Alliance has produced a document entitled *Security Guidance for Early Adopters of the Internet of Things*[35]. This covers the security controls which should be in place, across seven primary areas:

- Analyse privacy impacts to stakeholders and adopt a Privacy-by-Design approach to IoT development and deployment
- Apply a Secure Systems Engineering approach to architecting and deploying a new IoT System.
- Implement layered security protections to defend IoT assets
- Implement data protection best-practices to protect sensitive information
- Define lifecycle controls for IoT devices

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34 http://www.gsma.com/connectedliving/gsma-iot-security-guidelines-complete-document-set/
35 https://cloudsecurityalliance.org/download/new-security-guidance-for-early-adopters-of-the-iot/

- Define and implement an authentication/authorisation framework for the organisation's IoT Deployments
- Define and implement a logging/audit framework for the organisation's IoT ecosystem.

8.4 Designing Security into Products

8.4.1 Designing for Evaluation and Certification

Design of security for an IoT product should be based on the identified risks, with controls selected from the relevant control sets. A threat risk assessment based on the likely deployment scenarios will identify the risk level to which an IoT device or system is likely to be exposed, and the systemic risk which this introduces to the environment in which it operates.

When designing IoT products and services which are expected to be submitted for security evaluation and/or certification, it is useful to develop and maintain a current set of documents that will support the evaluation process. A key start point will be documenting an Initial Claims Document (ICD) which explicitly calls out the security functionality and a Target of Evaluation (ToE) description which documents the boundaries of the evaluation.

8.4.2 Application Services which Influence Design

There is an increasing number of vendor end-to-end solutions being delivered for IoT deployments. These are expected to produce solutions for a variety of use cases but will likely evolve quickly as new IoT technologies emerge. Some will be more open than others, and some will leverage and influence industry standards. When employing vendor end-to-end solutions, the security model should be investigated and understood.

An example of this at the component level is Microchip. Microchip and Amazon have collaborated to develop an integrated solution to help IoT devices quickly and easily comply with AWS's mutual authentication IoT security model. The new security solution will help companies implement security best practices from evaluation through production. This is delivered as a hardware chip which integrates with the AWS Software Development Kit.

At the system level, IBM promotes an architecture-based on their Bluemix platform at the application level, with the Watson IoT Platform working in conjunction with the HiveMQ Enterprise MQTT Broker to enable device integration.

Microsoft has released an Internet of Things Security Architecture which promotes a four zone model of Device, Field Gateway, Cloud Gateway, and Services. Each zone segments a solution, and often has its own data, authentication and authorisation requirements. Zones can also be used to isolate damage and restrict the impact of low trust zones on higher trust zones.

8.4.3 Design Patterns

The design and implementation of security controls can be time consuming and costly, requiring a high level of effort in the design and testing phases. Where similar products are being developed, their security solutions are likely to be substantively similar, and the re-use of an existing design can often provide an effective solution requiring little more than design integration and testing. A design pattern is a formalisation of this concept, and is a reliable implementation blueprint for a specific business use case scenario. A repository of software security design patterns has been developed through the Pattern Languages community and documented by the Carnegie-Mellon University Software Engineering Institute[36]. These are for general software security, but provide a foundation for more specific use cases. An

[36] CMU/SEI Report Number: CMU/SEI-2009-TR-010

increasing number of IoT design patterns are expected to become available as common approaches are adopted by vendors.

IoTAA will progressively develop and publish IoT security design patterns to support this *Guideline*.

8.5 Testing Security in IoT Products and Deployments

8.5.1 Testing Schemes

IoT product manufacturers may wish to submit their products for testing by an accredited test laboratory, either under the National Association of Testing Authority (NATA) scheme or under the Australian Government in the Australasian Information Security Evaluation Programme (AISEP)[37]. Formal testing will, if successful, result in the award of a test certificate and provide evidence of independent security assurance to customers.

Currently there is no mandated requirement for security testing, but the high profile of cyber attacks involving internet of things devices makes this a key area of consideration for users. Having evidence that a device has been security tested will be a competitive advantage.

In order to provide security and privacy confidence in IoT devices designed, manufactured, or deployed in Australia, the IoTAA will release a security testing procedure based on the Online Trust Alliance Framework which will be available for accredited organisations to use to recommend the issue of an IOTAA Security and Privacy Trustmark.

8.5.2 Assurance Levels

The threat risk assessment used to drive design considerations will also determine the depth of security testing required for the product, and this in turn will determine its assurance level – the extent to which the user can be confident that its security is effective. Assurance levels are commonly referred to as EAL1 to EAL7, where EAL1 is basically just a test that the documentation is correct, and EAL7 has a formally verified design and in depth testing. Commercial vendors will typically seek to achieve assurance levels of EAL3 or EAL4.

8.5.3 Testing Criteria

There are currently three sets of published criteria that can be used for testing IoT devices:

- The IoT Security Foundation has proposed a compliance scheme based on evaluation against their Security Compliance Framework. This has been described in section 6.1.
- OWASP has developed a testing guide for IoT products (see Appendix II) which covers 16 IoT Principles of Security and provides a framework for testing ten different vulnerabilities.
- The Online Trust Alliance framework provides measureable requirements which can be used as a start point for selecting security testing requirements.

IoT device manufacturers may wish to select the relevant criteria for their device from these three documents, in addition to any device specific functionality not otherwise covered. These criteria will then form the Initial Claims Document for the security testing.

For mission- and life-critical systems, security evaluation should be through, or as a minimum reflect the processes of, the globally recognised Common Criteria approach adopted by the AISEP.

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[37] https://www.asd.gov.au/infosec/aisep/

8.6 Cyber Security Insurance

The use of cyber insurance is becoming more prevalent and is a useful way for businesses to address the risks of cyber-attack, with a survey by the US Risk and Insurance Management Society in September 2016 finding that 80% of surveyed companies had bought cyber insurance.

When considering a business for insurance, the insurance company will assess the cost of cover based on the client risk exposure, and may offer premium reductions where security has been properly addressed.

When marketing and deploying IoT products and systems, the impact on insurance cover is a cost factor that must be taken into account. IoT products with security certification may result in lower premiums than those without.

9 LEGAL ISSUES

Privacy issues associated with IoT, as discussed in Section 4 of this *Guideline*, are covered by a number of relevant laws and principles. However, there are other areas of legal relevance that arise or are reinforced by the nature of the IoT. Some of these are related to security[38], including areas of national security and cooperation with law enforcement agencies.

9.1 IoT in Telecommunications Law

Section 4 of this Security Handbook discusses how personal information is regulated by the *Privacy Act 1988*. Another important body of security related regulation is imposed by telecommunications law.

If an IoT solution involves deployment of a wireless network and/or includes the sale of carriage services to customers, the solution will (very likely) be regulated by telecommunications law.

Services that provide or resell carriage have onerous security obligations. Information transiting the network must be protected. Use of it and use of the details of its customers is heavily restricted. Unless exempt, there is an obligation to ensure that messages can be intercepted by law enforcement and to retain and make available certain data.

Small changes in the design of a solution and/or making use of third party services can have a big impact on the regulatory obligations that may apply.

9.1.1 Overview of regulatory framework

In order to understand if an IoT solution is regulated by telecommunications law, it is important to understand whether a provider of such a solution is a carrier and/or whether the solution provided is a carriage service.

IoT networks are generally radio communication networks. Radio transmissions are strictly regulated in Australia by the *Radiocommunications Act 1992*.

Broadly speaking the *Radiocommunications Act 1992* permits:

- the operation of certain transmitters under a system of class licencing,
- the auctioning of a right to use certain bands of spectrum time to time and the Australian Communication and Media Authority (ACMA) to auction the right to use spectrum; and
- the issue of apparatus licences that permit the use of specific transmitters in specific frequencies and locations.

Many IoT devices are low powered devices that are permitted to operate in designated spectrum under the *Radiocommunications (Low Potential Interference Devices) Class Licence 2015*. Mobile phone users are permitted to use their mobile phones and devices that use SIM cards by the *Radiocommunications (Cellular Mobile Telecommunications Devices) Class Licence 2014*.

The rules regulating the use of radio transmitters, the radio frequency, power and transmission standards used apply equally to network operators, businesses that use radio enabled sensors, other device owners and users.

The *Telecommunications Act 1997* provides that the owner of a 'network unit' must not use or allow a network unit to be used to provide a carriage service to the public unless the owner holds a carrier licence.

Four types of facilities can be network units:

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38 Taylor Wessing: https://www.taylorwessing.com/download/article_spam_fridge.html

- single line links connecting distinct places in Australia at least 500 metres apart;
- multiple line links connecting distinct places in Australia where the aggregate of the distances between the distinct places is more than 5 kilometres;
- designated radiocommunications facilities (of any range); and
- facilities specified by the Minister in a written determination.

Places are distinct if they are not all in the same property, or a combined area of contiguous properties where the same person or persons is the principal user (essentially the occupier) of the combined area.

A designated radiocommunications facility is a reference to:

- a base station used, or for use, to supply a public mobile telecommunications service; or
- a base station that is part of a terrestrial radiocommunications customer access network; or
- a fixed radiocommunications link; or
- a satellite-based facility.

A ministerial declaration exempts radio networks that supply services to users that are all in the same place. Without this declaration, WiFi routers used by business owners to provide connectivity at cafes, shops and airports would be "a base station that is part of a terrestrial radio communications access network" and require the relevant provider to have a carrier's licence.

If IoT providers want to operate a radio communications network that supplies services to the public some of whom are not in the same place as the transmitter, they must either obtain a carrier's licence or find a carrier that is prepared to act as the nominated carrier for the network under consideration. Nominated carriers are notified to the ACMA and take regulatory responsibility for the operation of unlicensed carriage networks.

A carriage service provider (CSP) supplies or arranges the supply (an intermediary) of a carriage service to the public using:

- a network unit owned by one or more carriers or operated by a nominated carrier;
- a line link connecting a place in Australia and a place outside Australia; or
- a satellite based facility.
- A party is a CSP if it provides a connection into Australia from offshore or resells or arranges the resale of the carriage services of a carrier. An internet service provider (ISP) which does not own any transmission assets will be a CSP, but not a carrier for the purposes of regulation.

CSPs are subject to a range of obligations, but are not required to have a licence.

If part of an IoT business model is to resell customers' access to carriage services on a third-party network, then the IoT provider will be a CSP. On the other hand, if a product or service sends and receives information but using network services arranged by a customer, it is regarded as 'over the top' and does not make the provider of that service a CSP.

9.1.2 Protection of communications

It is important to understand when a provider is a carrier or CSP as carriers and CSPs are subject to various obligations under the *Telecommunications Act 1997*.

A primary security obligation is the duty to protect the confidentiality of information that relates to:

- the contents of communications that have been, or are being, carried; and
- the carriage services supplied; and
- the affairs or personal particulars that come to knowledge or possession by reason of providing the service.

- The disclosure or use of protected information is authorised in limited circumstances, including to employees and contractors acting in accordance with their duties and in connection with the operation of an enforcement agency as required or authorised under a warrant, or otherwise as required under law. Any person to whom such information is disclosed is also prohibited from disclosing it.

Record-keeping requirements are imposed in relation to authorised disclosures or uses of information.

There is also a general obligation to give officers and authorities of the Commonwealth and of the states and territories such help as is reasonably necessary for the purpose of enforcing the criminal law (of Australia or a foreign country) and laws imposing pecuniary penalties, protecting the public revenue and safeguarding national security, which amounts to an obligation to disclose information those authorities require for those purposes (other than the content messages transiting the network), even where they do not have a warrant.

9.1.3 Ability to access and intercept

The Telecommunications (Interception and Access) Act 1979 prohibits the interception of communications passing over a telecommunications system and lays out a number of circumstances in which this prohibition does not apply. These include in the case of emergency requests, where required to do so under various forms of warrant, and where authorised by the Attorney-General for developing and testing interception capabilities.

As an incident of those obligations, *the Telecommunications (Interception and Access) Act 1979* also requires that providers of telecommunications systems such as carriers and CSPs must ensure that their system can:

- enable a communication passing over the system to be intercepted in accordance with an interception warrant; and
- transmit lawfully intercepted information to the delivery points applicable in respect of that kind of service.

It is possible to apply for an exemption from these requirements. Carriers and nominated CSPs are also required to file an 'Interception Capability Plan' with the Department of Communications and the Arts, which sets out how precisely it intends and is able to comply with its obligation to provide interception capabilities.

9.1.4 Mandatory data retention

There is also a mandatory data retention obligation in the *Telecommunications (Interception and Access) Act 1979*. This obligation requires carriers and CSPs to retain for a period of two years certain information relating to accounts and communications, including, broadly, identifying information associated with an account, the source, destination, date, time, type and duration of communications, and the location of equipment used to transmit the communication. This information must be made available to law enforcement and national security agencies on request. If the information is used for any purpose other than to meet these statutory obligations of the data retention regime, any such information must also be provided in response to any civil subpoena seeking disclosure of it.

There is an ability to apply to the Attorney-General for exemption from all or part of the data retention requirements. If the data collected by an IoT solution is unlikely to have any value to law enforcement or national security, an IoT provider may wish to apply for an exemption.

9.1.5 New developments

As of August 2017 the Telecommunications Sector Security Reforms Act has been passed by the Australian Senate and has been referred to the House of Representatives. It introduces a broad obligation on carriers and CSPs to protect the security of their telecommunications services and facilities and for carriers and certain CSPs to report any changes to their network or services that may have an impact on security.

9.2 Other Areas Impacted by IoT

9.2.1 Network access

IoT devices rely on either internal network connectivity or internet access, or both. Any network access disruption can result in failure of the IoT system. Such disruption may be caused by a breakdown of net neutrality, inadequate bandwidth provision by an internet provider or the result of a denial of service attack. The legal consequences of such failures should be considered when designing the IoT system.

9.2.2 Liability

An IoT system will generally consist of many components interacting in a complex fashion. The attack surface of an IoT will expand in proportion to the multiple sensors and actuators it contains, as well as by the cloud services it consumes. These components are likely to be manufactured, contracted, or leased from multiple sources. The liability as a result of accidental failure or deliberate cyber breach of any point is not currently clear.

9.2.3 Data Ownership

The deployment of IoT will result in significant data being generated. As IoT evolves, it is likely that an increasing amount of its data will be shared. Data ownership will become more complex, and the consequences of corrupted data (either accidentally or deliberately) may reach beyond its source organisation.

9.2.4 Nation State Activities

IoT will substantially expand the infrastructure surface for nation state attacks from the current critical infrastructure. Such attacks may result from designed backdoors in equipment and/or remote penetration, and will be well-resourced. Both government and utility companies will need to ensure the integrity of devices and systems, and that adequate protection is in place.

APPENDIX I

OWASP Principles of Security

#	Name	Description
1	Assume a Hostile Edge	Edge components are likely to fall into adversarial hands. Assume attackers will have physical access to edge components and can manipulate them, move them to hostile networks, and control resources such as DNS, DHCP, and internet routing.
2	Test for Scale	The volume of IoT means that every design and security consideration must also take into account scale. Simple bootstrapping into an ecosystem can create a self-denial of service condition at IoT scale. Security counter measures must perform at volume.
3	Internet of Lies	Automated systems are extremely capable of presenting misinformation in convincing formats. IoT systems should always verify data from the edge in order to prevent autonomous misinformation from tainting a system.
4	Exploit Autonomy	Automated systems are capable of complex, monotonous, and tedious operations that human users would never tolerate. IoT systems should seek to exploit this advantage for security.
5	Expect Isolation	The advantage of autonomy should also extend to situations where a component is isolated. Security countermeasures must never degrade in the absence of connectivity.
6	Protect Uniformly	Data encryption only protects encrypted pathways. Data that is transmitted over an encrypted link is still exposed at any point it is unencrypted, such as prior to encryption, after decryption, and along any communications pathways that do not enforce encryption. Careful consideration must be given to full data lifecycle to ensure that encryption is applied uniformly and appropriately to guarantee protections. Encryption is not total – be aware that metadata about encrypted data might also provide valuable information to attackers.
7	Encryption is Tricky	It is very easy for developers to make mistakes when applying encryption. Using encryption but failing to validate certificates, failing to validate intermediate certificates, failing to encrypt traffic with a strong key, using a uniform seed, or exposing private key material are all common pitfalls when deploying encryption. Ensure a thorough review of any encryption capability to avoid these mistakes.
8	System Hardening	Be sure that IoT components are stripped down to the minimum viable feature set to reduce attack surface. Unused ports and protocols should be disabled, and unnecessary supporting software should be uninstalled or turned off. Be sure to track third party components and update them where possible.
9	Limit What You Can	To the extent possible limit access based on acceptable use criteria. There's no advantage in exposing a sensor interface to the entire internet if there's no good case for a remote user in a hostile country. Limit access to white lists of rules that make sense.
10	Lifecycle Support	IoT systems should be able to quickly on-board new components, but should also be capable of re-credentialing existing components, and de-provisioning components for a full device lifecycle. This capability should include all components in the ecosystem from devices to users.
11	Data in Aggregate is Unpredictable	IoT systems are capable of collecting vast quantities of data that may seem innocuous at first, but complex data analysis may reveal very sensitive patterns or information hidden in data. IoT systems must prepare for the data stewardship responsibilities of unexpected information sensitivity that may only be revealed after an ecosystem is deployed.

12	Plan for the Worst	IoT systems should have capabilities to respond to compromises, hostile participants, malware, or other adverse events. There should be features in place to re-issue credentials, exclude participants, distribute security patches and updates, and so on, before they are ever necessary.
13	The Long Haul	IoT system designers must recognise the extended lifespan of devices will require forward compatible security features. IoT ecosystems must be capable of aging in place and still addressing evolving security concerns. New encryption, advances in protocols, new attack methods and techniques, and changing topology all necessitate that IoT systems be capable of addressing emerging security concerns for years after they are deployed.
14	Attackers Target Weakness	Ensure that security controls are equivalent across interfaces in an ecosystem. Attackers will identify the weakest component and attempt to exploit it. Mobile interfaces, hidden API's, or resource constrained environments must enforce security in the same way as more robust or feature rich interfaces. Using multi-factor authentication for a web interface is useless if a mobile application allows access to the same API's with a four digit PIN.
15	Transitive Ownership	IoT components are often sold or transferred during their lifespan. Plan for this eventuality and be sure IoT systems can protect and isolate data to enable safe transfer of ownership, even if a component is sold or transferred to a competitor or attacker.
16	N:N Authentication	Realise that IoT does not follow a traditional 1:1 model of users to applications. Each component may have more than one user and a user may interact with multiple components. Several users might access different data or capabilities on a single device, and one user might have varying rights to multiple devices. Multiple devices may need to broker permissions on behalf of a single user account, and so on. Be sure the IoT system can handle these complex trust and authentication schemes.

Source and further details on OWASP security principles:
www.owasp.org/index.php/Principles_of_IoT_Security

APPENDIX II

OWASP Security Testing Guide

#	Name	Description
1	Insecure Web Interface	Assess any web interface to determine if weak passwords are allowed Assess the account lockout mechanism Assess the web interface for XSS, SQLi and CSRF vulnerabilities and other web application vulnerabilities Assess the use of HTTPS to protect transmitted information Assess the ability to change the username and password Determine if web application firewalls are used to protect web interfaces
2	Insufficient Authentication/Authorisation	Assess the solution for the use of strong passwords where authentication is needed Assess the solution for multi-user environments and ensure it includes functionality for role separation Assess the solution for Implementation two-factor authentication where possible Assess password recovery mechanisms Assess the solution for the option to require strong passwords Assess the solution for the option to force password expiration after a specific period Assess the solution for the option to change the default username and password
3	Insecure Network Services	Assess the solution to ensure network services don't respond poorly to buffer overflow, fuzzing or denial of service attacks Assess the solution to ensure test ports are not present
4	Lack of Transport Encryption	Assess the solution to determine the use of encrypted communication between devices and between devices and the internet Assess the solution to determine if accepted encryption practices are used and if proprietary protocols are avoided Assess the solution to determine if a firewall option available is available
5	Privacy Concerns	Assess the solution to determine the amount of personal information collected Assess the solution to determine if collected personal data is properly protected using encryption at rest and in transit Assess the solution to determine if Ensuring data is de-identified or anonymised Assess the solution to ensure end-users are given a choice for data collected beyond what is needed for proper operation of the device
6	Insecure Cloud Interface	Assess the cloud interfaces for security vulnerabilities (e.g. API interfaces and cloud-based web interfaces) Assess the cloud-based web interface to ensure it disallows weak passwords Assess the cloud-based web interface to ensure it includes an account lockout mechanism Assess the cloud-based web interface to determine if two-factor authentication is used

		Assess any cloud interfaces for XSS, SQLi and CSRF vulnerabilities and other vulnerabilities Assess all cloud interfaces to ensure transport encryption is used Assess the cloud interfaces to determine if the option to require strong passwords is available Assess the cloud interfaces to determine if the option to force password expiration after a specific period is available Assess the cloud interfaces to determine if the option to change the default username and password is available
7	Insecure Mobile Interface	Assess the mobile interface to ensure it disallows weak passwords Assess the mobile interface to ensure it includes an account lockout mechanism Assess the mobile interface to determine if it Implements two-factor authentication (e.g. Apple's Touch ID) Assess the mobile interface to determine if it uses transport encryption Assess the mobile interface to determine if the option to require strong passwords is available Assess the mobile interface to determine if the option to force password expiration after a specific period is available Assess the mobile interface to determine if the option to change the default username and password is available Assess the mobile interface to determine the amount of personal information collected
8	Insufficient Security Configurability	Assess the solution to determine if password security options (e.g. Enabling 20 character passwords or enabling two-factor authentication) are available Assess the solution to determine if encryption options (e.g. Enabling AES-256 where AES-128 is the default setting) are available Assess the solution to determine if logging for security events is available Assess the solution to determine if alerts and notifications to the user for security events are available
9	Insecure Software/Firmware	Assess the device to ensure it includes update capability and can be updated quickly when vulnerabilities are discovered Assess the device to ensure it uses encrypted update files and that the files are transmitted using encryption Assess the device to ensure is uses signed files and then validates that file before installation
10	Poor Physical Security	Assess the device to ensure it utilises a minimal number of physical external ports (e.g. USB ports) on the device Assess the device to determine if it can be accessed via unintended methods such as through an unnecessary USB port Assess the device to determine if it allows for disabling of unused physical ports such as USB Assess the device to determine if it includes the ability to limit administrative capabilities to a local interface only

Source and further details on IoT testing guidelines:
https://www.owasp.org/index.php/IoT_Testing_Guides

APPENDIX III

GSMA Security Recommendations[39]

Endpoint	Eco-System
Critical	
Implement an endpoint trusted computing base	Implement a service trusted computing base
Utilise a trust anchor	Define an organisational root of trust
Use a tamper resistant trust anchor	Define a bootstrap method
Define an API for using the TCB	Define a security front-end for public systems
Define an organisational root of trust	Define a persistent storage model
Personalise each endpoint device prior to fulfilment	Define an administration model
Minimum viable execution platform	Define a systems logging and monitoring model
Uniquely provision each endpoint	Define an incident response model
Endpoint password management	Define a recovery model
Use a proven random number generator	Define a sun-setting model
Cryptographically sign application images	Define a set of security classifications
Remote endpoint administration	Define classifications for sets of data types
Logging and diagnostics	
Enforce memory protection	
Boot loading outside of internal ROM	
Locking critical sections of memory	
Insecure bootloaders	
Perfect forward secrecy	
Endpoint communications security	
Authenticating an endpoint	
High Priority	
Use internal memory for secrets	Define a clear authorisation model
Anomaly detection	Manage the cryptographic architecture
Use tamper resistant product casing	Define a communications model
Enforce confidentiality/integrity to/from the trust anchor	Use network authentication services
Over the air application updates	Provisioning servers where possible
Improperly engineered or Unimplemented mutual authentication	Define an update model
Privacy management	Define a breach policy for abused data
Privacy and unique endpoint identities	Force authentication through the service ecosystem
Run applications with appropriate privilege levels	Implement input validation
Enforce a separation of duties in the application architecture	Implement output filtering
Enforce language security	Enforce strong password policy
	Define application layer authentication and authorisation
	Default-open of fail-open firewall rules
	Evaluate the communications privacy model

39 http://www.gsma.com/connectedliving/wp-content/uploads/2016/02/CLP.13-v1.0.pdf

Medium	
Enforce operating system level security enhancements	Define an application execution environment
Disable debugging and testing technologies	Use partner-enhanced monitoring services
Tainted memory via peripheral based attacks	Use a private access point name for cellular connectivity
User interface security	Define a third party data distribution policy
Third party code auditing	Build a third party data filter
Utilise a private access point name	
Implement environmental lock-out thresholds	
Enforce power warning thresholds	
Environment without backend connectivity	
Device decommissioning and sun-setting	
Unauthorised metadata harvesting	
Low	
Intentional and unintentional denial of service	Rowhammer and similar attacks
Safety critical analysis	Virtual machine compromises
Defeating shadowed components and untrusted bridges	Build an API for users to control privacy attributes
Defeating a cold boot attack	Define a false positive/negative assessment model
Non-obvious security risks	
Combating focused ion beams and x-rays	
Consider supply chain security	
Lawful interception	

ABOUT IOT Alliance Australia, (IoTAA)

The vision of IoTAA is to empower industry to grow Australia's competitive advantage through IoT.

IoTAA has 650 members from approximately 330 organisations across its seven workstreams. The workstreams are focused on:

- Collaboration
- Smart industries and cities
- Data use, access and privacy
- Spectrum availability and licensing
- Cyber security and network resilience
- IoT start-up Innovation and;
- Platforms and Interoperability.

IoTAA was incorporated as a not-for-profit entity in July 2016, emerging from the Communications Alliance IoT Think Tank, established in 2015.

IoTAA is hosted and supported by the University of Technology, Sydney (UTS) at its Broadway Campus in Sydney.

http://www.iot.org.au/