

Draft Recommendation for

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| spacecraft onboard interface systems --  Low data-rate wireless communications for spacecraft  monitoring and control |

AUTHORITY

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    --    The anticipated date of initial operational capability.

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FOREWORD

This document is a CCSDS Recommended Practice, which is the consensus result as of the date of publication of the Best Practices for low data-rate communication systems for spacecraft monitor and control in support of space missions.

Through the process of normal evolution, it is expected that expansion, deletion, or modification to this Report may occur. This Report is therefore subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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PREFACE

This document is a draft CCSDS Recommended Practice. Its ‘Red Book’ status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document’s technical content.

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# Introduction

## Purpose

This document presents the recommended practices for the utilization of low data-rate wireless communication technologies in support of spacecraft ground and flight monitoring and control applications. Relevant technical background information can be found in the CCSDS Wireless Working Group Green Book ref. CCSDS 880.0-G-1.

The recommended practices contained in this report enable member agencies to select the best option(s) available for interoperable wireless communications in the support of spacecraft health monitoring applications. The specification of a recommended practice facilitates interoperable communications and forms the foundation for cross-support of communication systems between separate member space agencies.

This document is a CCSDS Recommended Practice and is therefore not to be taken as a CCSDS Recommended Standard.

## Scope

This recommended practice (Magenta Book) is targeted towards monitoring and control systems, typically low data-rate and low-power wireless-based applications.

## Applicability

This Recommended Practice specifies protocols (including at least the physical (PHY) and medium-access control (MAC) layers of the Open Systems Interconnection (OSI) Model stack) that enable a basic interoperable wireless communication system to support low data-rate spacecraft monitoring and control applications.

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## Rationale

From an engineering standpoint, mission managers, along with engineers and developers, are faced with a plethora of wireless communication choices – both standards-based and proprietary. The provision of a CCSDS recommended practice helps to provide guidance in the selection of systems necessary to achieve interoperable communications in support of wireless, low data-rate monitoring and control.

## Document Structure

Note: This document is composed from a top-down (technology) perspective, first defining the technology as a recommended practice, then providing informative material supporting specific application profiles. For more information on space mission use cases addressed by wireless technologies, see Annex F in the Wireless Working Group Green Book ref. CCSDS 880.0-G-1.

Section 2 provides an informational overview of the rationale and benefits of spacecraft onboard wireless technologies for use in space health monitoring and control operations.

Section 3 provides a normative description for recommended practices and applicable standards relating to low data-rate wireless communication systems.

Section 4 provides an informative description of the recommended practices through an overview of the technologies and a set of application profiles where the recommendations are applicable.

## Conventions

### NOMENCLATURE

The following conventions apply for the normative specifications in this Recommended Practice:

1. the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
2. the word ‘should’ implies an optional, but desirable, specification;
3. the word ‘may’ implies an optional specification;
4. the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

### Informative Text

In the normative section of this document (section 3), informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

* Overview;
* Background;
* Rationale;
* Discussion.

## acronyms

A glossary of terms including common acronyms is provided in Annex C.

## references

The following documents contain provisions that, through reference in this text, constitute provisions of this Recommended Practice. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Practice are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS documents.

[1] *Wireless systems for industrial automation: Process control and related applications*. International Society for Automation, ISA100.11a:2009.

[2] *IEEE standard for information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirement: Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Network (WPANs); IEEE802.15.4-2006,* <http://standards.ieee.org/getieee802/download/802.15.4-2006.pdf>

# 

# OVERVIEW

## rationale and benefits

Monitoring the health of a spacecraft, during testing phases on ground or during nominal operations in orbit, is the key to ensuring the correct functioning of various onboard systems and structures, the responses of these systems in their operational working environments, and the long term reliability of the spacecraft. These data are also highly significant when compiling lessons learned that will be applied to build better space systems and increase the reliability of future space components.

The quantity of acquired spacecraft health data depends on the ability to monitor required parameters at precise locations within a given project time and cost envelope. Hundreds and often thousands of data measurement locations are required, steadily increasing the mass (acquisition systems, cables, and harnesses) and the project costs and time (install and verification of each new sensor).

Wireless technologies are foreseen to reduce the integration effort, cost, and time typically required to instrument a high number of physical measurement points on a space structure. Technicians should need less time to integrate and verify their installations, while the risk of mechanically damaging interfaces during the process should be reduced. Large structures should see health monitoring equipment mass reduce, while last-minute changes in the instrumentation (e.g. addition/removal of sensing nodes at measurement points) should be easier to accept at project level. One of the by-products of using wireless technologies in space systems is the extra flexibility introduced when implementing fault-tolerance and redundancy schemes.

An overriding consideration in this document is the desire to provide recommendations that utilize wireless technology to augment the *overall networking infrastructure* in a spacecraft rather than to provide dedicated data transport to particular end-to-end application-specific sub-systems. That is, although the recommendations specified in this document are related to relatively small-scale *personal area networks* (PANs) rather the more familiar *local area networks* (LANs) such as Ethernet, the desire is for wireless PANs to function as natural extensions of the backbone LAN. This implies in particular that the recommendations specified herein will focus on providing wireless data transport across the lower levels of the *Open Systems Interconnection* model (OSI) with no reference to standards to achieve application-specific behavior.

## Differentiating Contention-based AND scheduled channel access

There are two predominant types of medium-access schemes currently utilized in wireless sensor networks: *random* or *contention-based* access and *scheduled* access. Contention-based schemes require no centralized control of network access and are thus well-suited for ad-hoc network architectures as well as other situations where it is desirable to minimize network administration overhead and operational complexity. Nodes are allowed to attempt channel access at arbitrary times in an ad-hoc fashion as dictated by local data traffic flow and must therefore contend with one another for access in a fairly random manner. The most common contention-based access technique utilized in sensor networks is *carrier-sense multiple access* (CSMA) with *collision avoidance* (CA), generally abbreviated as CSMA-CA or simply CSMA. In contrast, scheduled access schemes require some type of (generally centralized) control mechanism for coordinating network access for all nodes in the network in a synchronized fashion. Typically, this will be based on predetermined or anticipated traffic flow so that bandwidth is available in a predictable manner that precludes contention among the nodes. This approach increases network administrative overhead and operational complexity but facilitates quality of service (QoS) guarantees and deterministic network behavior. The most common scheduled access technique utilized in sensor networks is time-division multiple access or TDMA.

In terms of application support, CSMA is perhaps best suited for situations where tight bounds on packet latency and packet jitter are not required but nodes may sometimes require relatively large amounts of available channel bandwidth for relatively short periods of time in a relatively unpredictable manner. CSMA does not readily support *deterministic* network behavior but does readily support *bursty* and *aperiodic* traffic flow. In contrast, TDMA is well suited for applications requiring much tighter bounds on packet latency and jitter but for which the traffic flow from the nodes is more uniform and predictable. TDMA readily supports deterministic network behavior but is generally better suited for applications with less bursty and more periodic traffic flow. In addition, interference avoidance schemes such as frequency hopping are far more easily implemented in a scheduled TDMA MAC layer than in a contention-based CSMA MAC layer. The same applies to maintaining connectivity in a mesh network topology that supports multi-hop relay traffic with battery powered nodes on a low duty cycle (long sleep period, short active period), although multi-hop transport is beyond the scope of the current recommendation.

## Scope of Interoperability

The intent of the recommended practices promulgated in this book is to provide a framework for establishing a scalable wireless infrastructure for low-rate data transport that will (1) support traffic generated by diverse sensor types, multiple application-specific devices, and devices supplied by multiple different vendors and (2) facilitate operation of multiple wireless networks in the same bandwidth with minimal interference. As stressed in the previous sections, the recommended practices will ensure interoperability of low data-rate wireless devices on a common network at the PHY and MAC layers so that data packets generated by new devices entering the network will be transported by the existing network devices without regard to the sensor or application that generated the data in the packet payload. In its current form, the book’s recommendations should allow new nodes to enter a star topology network and begin transmitting their data directly to a gateway. Should future revisions augment the current recommendations to allow for transport mechanisms such as multi-hop relaying, new nodes entering the network will not only generate and transmit their own data, but they may also be able to transport data for other network devices.

Adherence to these recommended practices will promote interoperability of the low data-rate wireless networks addressed in this document with other wireless networks using the same bandwidth via the interference mitigation techniques encompassed by the recommendations.

## Evolution of the Book

The current version of this document specifies two recommended practices for low data-rate spacecraft monitoring and control: one for single-hop contention-based access and one for single-hop scheduled access. The evolution of this document is foreseen to propose additional recommended practices for anticipated application profiles, such as recommended practices for multi-hop data transport.

Functionally, the current recommendations specified in this document can be regarded as pertaining only to the behavior of the network at the physical (PHY) and medium-access control (MAC) layers of the OSI network stack. For example, both recommendations provide a mechanism for data packets to be exchanged between a network coordinator or gateway and individual nodes on the wireless network, but they do not address a mechanism for data packets to be exchanged via intermediary nodes in a multi-hop path between an individual node and the network gateway. Nor do they address a mechanism for exchanging data packets between a node on the network and a device outside of the wireless network. It is assumed that the network coordinator or gateway will somehow be able to communicate with the backbone network of the spacecraft, but the mechanisms for that, which are typically implemented at the network (NWK) layer of the stack, are beyond the scope of the current document and are not discussed. Similarly, the recommendations do not discuss or provide mechanisms for end-to-end acknowledgement or re-transmission of data packets sent between user applications. The mechanisms for that behavior are typically implemented at the application (APP) layer of the stack and once again are beyond the scope of the current document.

This level of detail in the recommendations is in line with the philosophy discussed in Section 2.1 above that the recommended behavior of wireless networks should only be specified at the lower layers of the network stack (similar to the behavior specified for the backbone network in the spacecraft), leaving higher-layer behavior at the discretion of system designers. While it is anticipated that future recommendations may address some functionality at the NWK layer, such as routing of internet protocol (IP) packets within the wireless network, it is not anticipated that protocol behavior above the NWK layer (such as any APP-layer functionality) will be addressed by future recommendations.

Pragmatically, it may be necessary in some recommendations, such as Recommendation 2 in this document, to reference standards in which higher-layer behavior is specified as part of the standard. For these recommendations, it is impractical from an implementation point-of-view to separate PHY and MAC layer functionality in the recommended standard from functionality at the higher layers. In some cases, such behavior can simply be ignored in the recommendations, but in other cases, the higher-layer mechanisms of the standard must be referenced in the recommendations in order to guarantee proper behavior of the PHY and MAC layers of the recommendation.

# Recommended practices for Low data-rate wireless communications for spacecraft monitorING and control

## Overview

This chapter presents the recommended practices for *spacecraft monitoring and control applications using low data-rate wireless communication technologies*. First, a quick look table recalls the most relevant typical use-cases where low data-rate wireless communications may be beneficial.

As discussed in chapter 2, in order to ensure the most basic interoperability between low data-rate wireless communication systems, the current recommendations are focused on specification of functionality at the air interface physical layer (PHY) and the medium access sub-layer (MAC) of the open system interconnection reference (OSI) model. Following this guideline, two different compliant systems would thus be able to share the medium and potentially join the same wireless network.

Table 3‑1 presents a set of use-cases which may benefit from using low data-rate wireless communications.

Table 3‑1: Quick look table for scenarios that can utilize low data-rate wireless communications

|  |  |
| --- | --- |
| **Use-case** | **Typical examples** |
| AIT (Assembly, Integration and Testing) / GSE (Ground Support Equipment) / DFI (Development of Flight Instrumentation) activities | *Thermal chamber testing, vibration testing, data bus monitoring…* |
| Spacecraft onboard health monitoring | *Temperature and radiation level monitoring, impact detection…* |
| Scalability / extensibility / retro-fit of instrumentation capabilities | *Instrument replacement, adding capability to existing vehicles…* |
| Habitat environmental monitoring and control | *Temperature, humidity, pressure monitoring…* |
| Crew (physiological) monitoring | *Heartbeat, temperature, location…* |
| Scientific monitoring and control | *Periodic observation of experimental variables…* |
| Intra-spacecraft robotic activities | *Low data-rate positioning telemetry, health data…* |

## RECOMMENDED PRACTICEs

### Applications suited for SINGle-hop CONTENTION-BASED COMMUNICATIONS

For spacecraft monitoring and control activities employing low data-rate contention-based wireless communications in single-hop configurations, both the air interface physical layer (PHY) and the medium access control layer (MAC) shall comply with the IEEE 802.15.4-2006 specification with a preference for the 2.4 GHz frequency band. (See Annex B for rationale pertaining to 2.4 GHz band preferences).

### Applications suited for single-Hop scheduled medium-access COMMUNICATIONS

For spacecraft monitoring and control activities employing low data-rate communications utilizing a scheduled medium-access scheme in a single-hop configuration, both the air interface physical layer (PHY) and the medium-access control sub-layer (MAC) shall comply with the ISA100.11a-2011 PHY and MAC specifications.

### RESTRICTIONS/HAZARDS

#### Explosive Environments

Caution should be exercised with respect to compliance with governing regulations for RF transmissions, particularly in potentially explosive environments.

#### RF Exposure

Due consideration should be given to avoid RF exposure that exceeds limits established by the local governing regulations.

#### RF Scattering

Consideration should be given to scattering environments characterized by small confines with highly conductive perimeters within which resonances can result in increased field levels.

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# informational discussion on Low data-rate wireless communications for spacecraft monitorING and control

## Overview

The following sections contain engineering discussions applicable to the above recommended practices.

### Discussion - contention-based channel-access mechanism

As discussed in Section 2.2, the operation of a contention-based channel-access mechanism cannot readily support packet delivery with reliably low and predictable latency in many situations, particularly when the number of active nodes in the network grows to even moderate levels. As such, it is generally not appropriate for use in situations requiring deterministic or “real-time” behavior, such as spacecraft control loops or life-critical applications.

Although this recommendation will support the implementation of both secure and multi-hop communications, additional functionality necessary to implement both of these services must be provided by higher layers of the network protocol stack. While the 802.15.4 MAC sub-layer specification will support secure communication by providing encryption and decryption services based on symmetric-key cryptographic techniques, the procedures for establishing and maintaining the necessary keys are beyond the scope of the standard and must be provided by higher layers. Further discussion of 802.15.4 security mechanisms is provided in ANNEX A. Similarly, while peer-to-peer communication within an arbitrary mesh topology is supported by the 802.15.4 MAC sub-layer, no routing or synchronization mechanisms are specified within the standard to support multi-hop relaying strategies that utilize such peer-to-peer communication. Such synchronization and routing mechanisms must be implemented in higher layers of the protocol stack.

Finally, the 802.15.4 MAC sub-layer specified in this recommendation provides no specific mechanisms for adaptive channel selection or interference avoidance. The recommendation as stated presumes operation on a single, predetermined sub-channel of the 2.4 GHz ISM band and persistent interference on the selected channel will lead to substantial performance degradation. Mechanisms for detecting and avoiding such interference, if necessary, must be implemented at higher layers of the protocol stack. As such, the current recommendation may not be well suited for operation in a very cluttered spectral environment with many different wireless systems contending for the same bandwidth. Additionally, the environment may induce interference effects such as multi-path fading. When these effects are time-varying and not well characterized a priori, the current recommendation may not be well suited. Conversely, the current recommendation can be expected to work very well in environment for which the available spectrum is well understood over time and carefully managed.

### Discussion - scheduled channel-access mechanism

A scheduled channel-access mechanism requires a method for synchronizing transmissions/receptions among the nodes in the network. Furthermore, the ISA100.11a recommendation allows nodes to switch among the 16 available channels in the 802.15.4 2.4 GHz PHY with each subsequent transmission attempt, coordinating transmitters and receivers so that they both use the same channel at the same time. As discussed in Section 2.2, a centralized Network Manager entity is required to establish this “channel hopping” mechanism for each node in the network and mediate bandwidth usage through granting communication “contracts” to nodes.

The Network Manager is the key to an ISA100.11a network’s operation and is its most complicated component. A Network Manager is constantly optimizing the channel hopping scheme in response both to nodes’ requests for communication bandwidth and nodes’ reports of the channel qualities in their individual locations. Implementing this functionality from scratch, while possible, may prove time-consuming and it may be more feasible to employ a pre-certified ISA100.11a Network Manager. This, however, comes with a caveat: ISA100.11a is designed as a complete networking solution for high-reliability industrial process monitoring and control. As a result, an ISA100.11a-compliant Network Manager functions on all levels (PHY through APP) of the OSI model. To achieve the PHY and MAC layer behavior specified in this recommendation, we advise the use of a complete ISA100.11a stack configured so that behavior at layers above the MAC layer is either disabled or transparent to the user. Specifically, we recommend the following configuration:

1. All nodes, except for the network gateway, should be configured as non-routing devices.
2. Application layer tunneling should be used to bypass the object-oriented APP layer scheme recommended by ISA100.11a.

Configuration (1) results in a star network topology, giving the single-hop behavior mandated in this recommendation. It reduces functionality at each of the upper data link layer and network layer to a pass-through, since the upper data link layer is responsible for multi-hop routing within an ISA100.11a mesh network and the network layer is responsible for routing outside of the gateway on the backbone network (a recommendation for which is not covered in this document). Configuration (2) reduces functionality at each of the transport and APP layers to a pass-through as well.

It is worth noting that over-the-air transmissions must be secured in an ISA100.11a network. While security is optional in the 802.15.4 PHY/MAC recommendation, security is required in the ISA100.11a PHY/MAC recommendation implicitly through the use of an ISA100.11a stack configured as directed above. A Security Manager entity joins the Network Manager in a proper ISA100.11a implementation, and its inclusion is non-optional. Messages are encrypted on both a hop-by-hop and end-to-end basis, and distribution and maintenance of encryption keys is handled automatically by the Security Manager.

As such, this recommendation covers secure, single-hop communications. Should a user wish to extend this functionality to multi-hop communication, configuration (1) can of course be ignored, but such functionality is outside the scope of the current recommendation.

It is also worth cautioning the user that ISA100.11a is a relatively resource-heavy protocol with regards to computational complexity at the Network Manager. Network formation will generally take longer compared to the 802.15.4 PHY/MAC recommendation, and support for node mobility will be more limited. The same caveat applies to administrative messages to the nodes from the Network Manager (and vice versa). A greater percentage of available bandwidth will be used to maintain the ISA100.11a network to achieve more efficient use of the remaining bandwidth in contention-based environments. Thus, the current recommendation can be expected to work quite well in an environment in which contention for bandwidth from other systems and interference effects are significantly present but not well modeled. Conversely, when the available spectrum is well understood over time and carefully managed, the current recommendation may not be well suited.

## Application profiles

An application profile is an explicit listing of the configuration settings of a typical implementation that may be suitable for multiple use cases or applications.   Table 4‑1 is a quick-look table which lists the most common application profiles targeted by the two recommendations specified in this document. Notice that all of these application profiles are based on a star network topology in which the individual nodes in the network all communicate directly with a central gateway node that aggregates data, disseminates commands, or both. Both the 802.15.4 standard, which is specified in Section 3.2.1 and the ISA100.11a standard, which is specified in Section 3.2.2, are well suited for applications based on such a topology and can be expected to work well for both periodic, fixed-length, block data transfer as well as a-periodic, variable-length, bursty data transfer.

Table 4‑1: Application profile quick-look table

|  |
| --- |
| **List of application profiles falling under the recommended practice** |
| 1. Single-hop periodic data aggregation |
| 2. Single-hop triggered (event-driven) data aggregation |
| 3. Single-hop, latency tolerant command and control or command-driven data aggregation (polling) |

### Single-hop periodic data aggregation

This profile covers the most common implementation of a wireless sensor network; One which consists of a central data sink (i.e., a gateway or network coordinator) and a number of child nodes that perform periodic data acquisition. The network is configured in a star topology, with each child node having a direct link to the coordinator. Typically, a child node wakes up from a very low-power (sleep) mode on a predetermined periodic schedule, executes a data acquisition task, formats the acquired data, transmits a data packet to the network coordinator, and then goes back into sleep mode. Alternatively, the acquisition node may sample data during each wake cycle but only transmit data to the coordinator when a full packet’s worth of data has been accumulated. The coordinator node, which either never sleeps or sleeps only infrequently, aggregates the data from all of the child nodes and relays it over a backbone network to user applications that consume the data. Generally, the duty cycle of the child nodes is quite low, with data acquired at rates from one observation per second down to one observation every several minutes and children often spending 99% or more of their lifetimes in sleep mode. For this profile, the data payload transmitted in each packet is generally small and fixed in size.

Vehicle ground test applications require flexibility in the implementation of the tests and the location and orientation of the nodes and antennas. Hence, it is often the case that all nodes will have omni-directional antennas rather than directional higher-gain antennas.

The RF transmit power is a very application-specific parameter and heavily depends on the operational environment and on Electromagnetic Interference (EMI) / Electromagnetic Compatibility (EMC) constraints. Some spacecraft will not allow transmission powers higher than perhaps -15 dBm, while others may permit powers up to 10 dBm. In contrast, for other applications such as structural testing of small components in a laboratory thermal-vacuum chamber, relaxed transmit power constraints are often seen. The permissible transmit power is thus one of the first parameters/constraints to be identified before setting up a wireless sensor network.

The number of acquisition nodes in the wireless network is also very application-dependent. In a typical laboratory testing activity, a few nodes, each with several sensors, may well prove to be enough for the task at hand. Spacecraft testing and monitoring on the other hand may require the utilization of hundreds of wireless nodes.

Table 4‑2 summarizes the high-level implementation parameters and operational configurations for the periodic data aggregation application profile.

Table 4‑2: Typical operating parameters for the single-hop,  
periodic data aggregation application profile.

|  |  |
| --- | --- |
| **Implementation parameter / operational configuration** | **Typical value** |
| **Topology** | Star |
| **Antenna type** | Typically omni-directional |
| **Transmit power** | Typically -15 dBm to +10 dBm |
| **Typical number of nodes** | 10 – 100 |
| **Antenna Polarization (master/slave)** | Linear/linear; circular/linear |
| **Spectrum/Channel utilization** | Per IEEE 802.15.4 specifications; spectrum and channel management |
| **Typical communication range** | 0 – 10 m |
| **Typical transmit periodicity** | Seconds to minutes |
| **Expected battery life** | Months to years |
| **Typical receiver periodicity** | Low |
| **Latency constraints** | Typically relaxed |
| **Routing** | None |
| **Data payload characteristics** | Periodic, fixed-length, uniform rate |

### Single-hop triggered, event-driven data acquisition

This profile covers an implementation of a wireless sensor network that consists of a central data sink and a number of child nodes that perform non-periodic data acquisition. The network is configured in a star topology, with each child node having a direct link to the coordinator. For this profile, however, a child node wakes up to acquire data only when triggered by the occurrence of some local event rather than on a predetermined periodic schedule. The triggering event is sensed by the child node using a low-power circuit that remains active even in sleep mode. When data collection is triggered, the acquisition node collects some amount of data, which may be either predetermined or based on the length or intensity of the triggering event. The collected data may be transmitted back to the sink in raw form or may be processed locally to reduce the data in some fashion. In either case, the resulting data payload is formatted and transmitted back to the sink via a single packet or subdivided into several sequential packets, as necessary. The coordinator node, which either never sleeps or sleeps only infrequently, aggregates the data from all of the child nodes and relays it over a backbone network to user applications that consume the data. For this profile, the duty cycle of the child nodes is obviously determined by the frequency of triggering events, but is generally extremely low.

Please see the discussion given in Profile 4.2.1 for general considerations regarding antenna configuration, power level, and network size, which are identical in this case. Table 4‑3 summarizes the high-level implementation parameters and operational configurations for the event-driven data aggregation application profile.

Table 4‑3: Typical operating parameters for the single-hop   
triggered, event-driven data acquisition application profile

|  |  |
| --- | --- |
| **Implementation parameter / operational configuration** | **Typical value** |
| **Topology** | Star |
| **Antenna type** | Typically omni-directional |
| **Transmit power** | Typically -15 dBm to +10 dBm |
| **Typical number of nodes** | 10 – 100 |
| **Antenna Polarization (master/slave)** | Linear/linear; circular/linear |
| **Spectrum/Channel utilization** | Per IEEE 802.15.4 specifications; spectrum and channel management |
| **Typical communication range** | 0 – 10 m |
| **Typical transmit periodicity** | Event driven |
| **Expected battery life** | Months to years |
| **Typical receiver periodicity** | Low, depends on beacon and acknowledgement mode |
| **Latency constraints** | Typically relaxed |
| **Routing** | None |
| **Data payload characteristics** | Non-periodic, variable-length, bursty |

### Single-hop command and control or command-driven data aggregation

This profile again covers an implementation of a wireless sensor network that consists of a central coordinator and a number of child nodes. In this case, however, the child nodes may acquire data from a sensor, control an actuator, or both. Further, in this profile, data may flow not only from the child node to the coordinator in the form of telemetry or command status but also from the coordinator to the child node in the form of commands. The network is configured in a star topology, with each child node having a direct, bi-directional link to the coordinator.

For the command-driven data aggregation application, a child node wakes up on a periodic schedule and communicates with the coordinator for a possible command to acquire data. If there is no command waiting, the node goes back into sleep mode. If there is a data acquisition command waiting, the node decodes the command, acquires and formats the requested amount of data, transmits the data back to the coordinator in as many packets as necessary, and goes back into sleep mode. For the command and control application, the child node wakes up on a periodic schedule and polls the coordinator for a possible command to change an actuator setting. If there is no command waiting, the node goes back into sleep mode. If there is an actuation command waiting, the node retrieves the command, decodes it, activates an appropriate control signal for the actuator, optionally transmits a command status to the coordinator (e.g., success/failure), and goes back into sleep mode. One could again envision such an operation being conducted in conjunction with the periodic or event-triggered transmissions in Sections 4.2.1 and 4.2.2. Should a control algorithm interfacing with the gateway decide a local actuation (e.g., turning on a heater or a fan), is necessary based on measured data (e.g., a temperature reading), a command for that actuation would be sent to the node which measured the data and is capable of actuating the control device.

For either application, the coordinator aggregates the data from all of the child nodes (either telemetry or command status data) and relays it over a backbone network to user applications that consume the data. The coordinator once again sleeps only infrequently. The duty cycle of the child nodes is command-driven, but is generally extremely low.

General considerations regarding antenna configuration, power level, and network size are again identical to those discussed in Section 4.2.1. Table 4‑4 summarizes the high-level implementation parameters and operational configurations for both the command and control and command-driven data aggregation application profiles.

Table 4‑4: Typical operating parameters for the single-hop   
command and control application profile

|  |  |
| --- | --- |
| **Implementation parameter / operational configuration** | **Typical value** |
| **Topology** | Star |
| **Antenna type** | Typically omni-directional |
| **Transmit power** | Typically -15 dBm to +10 dBm |
| **Typical number of nodes** | 10 – 100 |
| **Antenna Polarization (master/slave)** | Linear/linear; circular/linear |
| **Spectrum/Channel utilization** | Per IEEE 802.15.4 specifications; spectrum and channel management |
| **Typical communication range** | 0 – 10 m |
| **Typical transmit periodicity** | Command-driven |
| **Expected battery life** | Months to years |
| **Typical receiver periodicity** | Low, depends on beacon and acknowledgement mode |
| **Latency constraints** | Typically relaxed |
| **Routing** | None |
| **Data payload characteristics** | A-periodic, variable-length, bursty |
|  |  |

1. : SECURITY concerns for Wireless Systems (Informative)

A1 Introduction

A2 General Risks

A3 Security provisioning within the recommended standards

1. : Justifications for the 2.4 GHz band preference

**(INFORMATIONAL)**

Standard 802.15.4 allows for operation at one frequency in the 868 MHz band (license-free in Europe), ten frequencies in the 900-915 MHz band (license-free in the United States) and sixteen frequencies in the 2.4-2.485 GHz band (license-free world-wide). Of these, the 2.4 GHz band was chosen for the following reasons.

Outside the United States, operation between 900 and 915MHz requires a license, and in Europe systems operating in this band must compete with a radar band, so the license is generally only available on an “at risk” basis. This implies that the operator cannot restrict the operation of an (unlicensed?) interfering system but can be shut down if he interferes with anyone else who is licensed in that band. This incurs a risk to guaranteed operation.

Antennas for lower frequency radiation must be larger than antennas for higher-frequency radiation in order to achieve the same efficiency and gain. Hence, antennas for communication nodes operating in the UHF bands (868 MHz and 900-915 MHz) will generally be much larger than antennas for nodes operating in the 2.4 GHz band.

The UHF wavelength is approximately 0.3 meters, which is of the same order as the size of many spacecraft cavities. In such environments, UHF propagation is likely to be influenced by resonant mechanisms. The 2.4 GHz wavelength is approximately 12.5 cm, so multiple-antenna techniques can be readily utilized, even by small devices, to provide spatial diversity and/or multiplexing gain in reverberant environments.

Due to the international acceptance of other 2.4GHz systems such as 802.11b/g/n, radios and antennas for this band are readily available commercially. Radios for 868-915MHz are less common. Additionally, with more frequencies available in the 2.4GHz band, there is more opportunity for selection to avoid co-channel or adjacent channel interference.

***Regional Constraints***

Unlicensed operation of wireless networks is in bands designated by the International Telecommunications Union, but governed by national and international standards. At the top level, band availability is by ITU Region:

Region 1: Europe, Africa, the former Soviet Union, Mongolia, and the Middle East west of the Arabian Gulf including Iraq.

Region 2: The Americas, Greenland and some of the Eastern Pacific Islands

Region 3: Most of Oceania, and Asia outside the former Soviet Union, with the exception of those areas of the Middle East designated in Region 1.

Under ITU regulations, the 900-928MHz band is not to be used outside Region 2, especially in areas that use the GSM 900 band, with the exception of Australia and Israel.

In the United States, the ISM bands are described by CFR (Code of Federal Regulations) Title 47 Part 18, and wireless LAN and PAN are governed by Part 15 Sub-part 247. Canadian regulation is by RSS-210, which tends to follow the US standard with a slight temporal lag.

In Europe the over-arching definition is by the European Telecommunications Standards Institute (ETSI) but this is subject to acceptance and ratification by local regulatory authorities. This is normally a matter of formality only. The applicable standard is EN 300 328.

Japanese regulation is governed by standard ARIB-STD-T66. The official version is in Japanese but the Association of Radio Industries and Businesses (ARIB) provide an English overview on their site [www.arib.or.jp](http://www.arib.or.jp/) . This second generation standard governs only the use of the 2400-2483.5MHz band. The first generation allowed use only in the 2471-2497MHz band.

This section summarizes the national regulations for unlicensed operation of low-power low-rate data networks. These are the salient points, there is much more regulation of ancillary issues such as out of band emissions, and should the system designer seek to source or design a radio, rather than using one which is commercially available and states compliance to the regulations, then the source regulations will have to be consulted. Although not all authorities have been consulted, the European regulations have been largely adopted in ITU Region 1, the FCC/RSS Regulations in ITU Region 2, and the Japanese regulation in ITU Region 3.

Table B‑1: Power regulations

|  |  |  |  |
| --- | --- | --- | --- |
| Band | US/Canada | Europe | Japan |
| 2400 – 2483.5 MHz | Freely available. 1W maximum | Freely available, 100mW maximum | Freely available, 10mW / MHz maximum |
| 868MHz | No. | Available, 1 channel of operation in 802.15.4, 868-868.6MHz, 25mW maximum, duty cycle less than 1% in any one hour time period. | No |
| 902-928 MHz | Freely available, unlicensed, 1W maximum | Not available except with a license and on a non-interfering basis. Clashes with GSM900. | No |

As can be seen from the foregoing, the 2400-2483.5MHz band is the only one applicable to 802.15.4 that is universally adopted.

1. :   
   Acronyms

**(INFORMATIONAL)**

AIT Assembly, Integration and Testing

APP Application (layer)

CCSDS Consultative Committee for Space Data Systems

CSMA Carrier-Sense Multiple Access

CTB Cargo Transfer Bag

DFI Developmental Flight Instrumentation

EMC Electromagnetic Compatibility

EMI Electromagnetic Interference

ETSI European Telecommunications Standards Institute

FCC Federal Communications Commission

FHSS Frequency Hopping Spread Spectrum

GSE Ground Support Equipment

IC Integrated Circuit

IEEE Institute of Electrical and Electronics Engineers

IP Internet Protocol

ISM Industrial, Scientific, and Medical

ISO International Organization for Standardization

LAN Local Area Network

MAC Media Access Control

NWK Network (layer)

OSI Open System Interconnection

PHY Physical (layer)

RF Radio Frequency

TDMA Time-Division Multiple Access

1. : ITU INDUSTRIAL, SCIENTIFIC, AND MEDICAL BANDS

**(INFORMATIONAL)**

Table D-1: ITU Industrial, Scientific, and Medical RF Bands.

|  |  |
| --- | --- |
| **Frequency Range\*** | **Center Frequency** |
| 6.765 - 6.795 MHz | 6.780 MHz |
| 13.553 - 13.567 MHz | 13.560 MHz |
| 26.957 - 27.283 MHz | 27.120 MHz |
| 40.66 - 40.70 MHz | 40.68 MHz |
| 433.05 - 434.79 MHz | 433.92 MHz |
| 902 - 928 MHz | 915 MHz |
| 2.400 - 2.500 GHz | 2.450 GHz |
| 5.725 - 5.875 GHz | 5.800 GHz |
| 24 - 24.25 GHz | 24.125 GHz |
| 61 - 61.5 GHz | 61.25 GHz |
| 122 - 123 GHz | 122.5 GHz |
| 244 - 246 GHz | 245 GHz |

\* Wireless networking communications equipment use of ISM bands is on a non-interference basis (NIB)

1. : RADIO BAND DESIGNATIONS

**(INFORMATIONAL)**

Table E-1: NATO or Electronic Warfare (EW) RF Band Designations

|  |  |  |  |
| --- | --- | --- | --- |
| **Radar Designation** | **ITU Designation** | **IEEE Designation** | **Wireless Bands** |
| HF  3-30MHz | HF  3-30MHz | A  0-250MHz |  |
| Not designated | VHF  30-300MHz |
| P  216-450MHz | B  250-500MHz |  |
| UHF  300-3000MHz |
| Not designated | C  500 – 1000MHz | 802.15.4 |
| L  1-2GHz | D  1-2GHz |  |
| S  3-4GHz | E  3-3GHz | 802.11b, 802.11g, 802.11n  802.15.1, Bluetooth, 802.15.4 |
| SHF  3-30GHz | F  3-4GHz |  |
| C  3-8GHz | G  3-6GHz | 802.11a, 802.11k |
| H  6-8GHz |  |
| X  8-12.4GHz | I  8-10GHz |
| J  10-20GHz |
| J / Ku  12.4 –18GHz |
| K  18-26.5GHz |
| K  20-40GHz |
| Q / Ka  26.5 - 40GHz |
| EHF  30-300GHz |

Table E-2: IEEE Std (521-2002) Letter Designations for Radar Frequency Bands

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **International table** | | | | |
| **Band designation** | **Nominal frequency range** | **Specific frequency range for radar based on ITU assignments (see Notes 1, 2)** | | |
| **Region 1** | **Region 2** | **Region 3** |
| HF | 3-30 MHz | (Note 3) | | |
| VHF | 30-300 MHz | None | 138-144 MHz 216-225 MHz (See Note 4) | 223-230 MHz |
| UHF | 300-1000 MHz (Note 5) | 420-450 MHz (Note 4) 890-942 MHz (Note 6) | | |
| L | 1-2 GHz | 1215-1400 MHz | | |
| S | 2-4 GHz | 2300-2500 MHz | | |
| 2700-3600 MHz | 2700-3700 MHz | |
| C | 4-8 GHz | 4200-4400 MHz (Note 7) | | |
| 5250-5850 MHz | 5250-5925 MHz | |
| X | 8-12 GHz | 8.5-10.68 GHz | | |
| Ku | 12-18 GHz | 13.4-14 GHz | | |
| 15.7-17.7 GHz | | |
| K | 18-27 GHz | 24.05-24.25 GHz | 24.05-24.25 GHz 24.65-24.75 GHz (Note 8) | 24.05-24.25 GHz |
| Ka | 27-40 GHz | 33.4-36 GHz | | |
| V | 40-75 GHz | 59-64 GHz | | |
| W | 75-110 GHz | 76-81 GHz | | |
| 92-100 GHz | | |
| mm (Note 9) | 110-300 GHz | 126-142 GHz | | |
| 144-149 GHz | | |
| 231-235 GHz 238-248 GHz (Note 10) | | |
|  |  |  |  |  |
|  | NOTES |  |  |  |
|  | 1 - These international ITU frequency allocations are from the table contained in Article S5 of the *ITU Radio Regulations*, 1998 Edition. The ITU defines no specific service for radar, and the frequency assignments listed are derived from those radio services that use radiolocation. The frequency allocations listed include those for both *primary* and *secondary* service. The listing of frequency assignments are included for reference only and are subject to change. | | |  |
|  | 2 - The specific frequency rages for radiolocation are listed in the NTIA Manual of Regulations & Procedures for Federal Radio Frequency Management, Chapter 4. The NTIA manual (known as the Redbook) can be downloaded from the website: http://www.ntia.doc.gov/osmhome/redbook/redbook.html. | | |  |
|  | 3 - There are no official ITU radiolocation bands at HF. So-called HF radars might operate anywhere from just above the broadcast band (1.605 MHz) to 40 MHz or higher. | | |  |
|  | 4 - Frequencies from 216 – 450 MHz were sometimes called *P-band*. | | |  |
|  | 5 - The official ITU designation for the ultra high frequency band extends to 3000 MHz. In radar practice, however, the upper limit is usually taken as 1000 MHz. L- and S-bands being used to describe the higher UHF region. | | |  |
|  | 6 -  Sometimes included in L-band. | | |  |
|  | 7 -  Designated for aeronautical navigation, this band is reserved (with few exceptions) exclusively for airborne radar altimeters. | | |  |
|  | 8 -  The frequency range of 24.65 – 24.76 GHz includes satellite radiolocation (earth to space only). | | |  |
|  | 9 -  The designation mm is derived from *millimeter* wave radar, and is also used to refer to V- and W-bands, and part of Ka-band, when general information relating to the region above 30 GHz is to be conveyed. | | |  |
|  | 10 - No ITU allocations are listed for frequencies above 275 GHz. | | |  |

Table E-3: Comparison of Radar-Frequency Letter Band Nomenclature

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Radar letter designation** | **Frequency range** | **Frequency range** | **Band No.** | **Adjectival band designation** | **Corresponding metric designation** |
| HF | 3-30 MHz | 3-30MHz | 7 | High frequency (HF) | Dekametric waves |
| VHF | 30-300 MHz | 30-300 MHz | 8 | Very high frequency (VHF) | Metric waves |
| UHF | 300-1000 MHz | 0.3-3 GHz | 9 | Ultra high frequency (UHF) | Decimetric waves |
| L | 1-2 GHz |
| S | 2-4 GHz |
| 3-30 GHz | 10 | Super high frequency (SHF) | Centimetric waves |
| C | 4-8 GHz |
| X | 8-12 GHz |
| Ku | 12-18 GHz |
| K | 18-27 GHz |
| Ka | 27-40 GHz | 30-300 GHz | 11 | Extremely high frequency (EHF) | Millimetric waves |
| V | 40-75 GHz |
| W | 75-110 GHz |
| mm | 110-300 GHz |

1. : INFORMATIVE REFERENCES

[TO BE FILLED BY RB/RW]