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Drone Remote Identification Protocol (DRIP) Architecture

Abstract

This document describes an architecture for protocols and services to support Unmanned Aircraft System (UAS) Remote Identification (RID) and tracking, plus UAS RID-related communications. This architecture adheres to the requirements listed in the DRIP Requirements document (RFC9153).

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Authors' Addresses

1. Introduction

This document describes an architecture for protocols and services to support Unmanned Aircraft System (UAS) Remote Identification (RID) and tracking, plus RID-related communications. The architecture takes into account both current (including proposed) regulations and non-IETF technical standards.

The architecture adheres to the requirements listed in the DRIP Requirements document [RFC9153]. The requirements document provides an extended introduction to the problem space and use cases. Further, this architecture document frames the DRIP Entity Tag (DET) [I-D.ietf-drip-rid] within the architecture.

1.1. Overview of Unmanned Aircraft System (UAS) Remote ID (RID) and Standardization

UAS Remote Identification (RID) is an application that enables a UAS to be identified by Unmanned Aircraft Systems Traffic Management (UTM) and UAS Service Supplier (USS) (Appendix A) or third party entities such as law enforcement. Many considerations (e.g., safety) dictate that a UAS be remotely identifiable.

Civil Aviation Authorities (CAAs) worldwide are mandating UAS RID. CAAs currently promulgate performance-based regulations that do not specify techniques, but rather cite industry consensus technical standards as acceptable means of compliance.

USA Federal Aviation Administration (FAA)

> The FAA published a Notice of Proposed Rule Making [NPRM] in 2019 and thereafter published a "Final Rule" in 2021 [FAA_RID], imposing requirements on UAS manufacturers and operators, both commercial and recreational. The rule states that Automatic Dependent Surveillance Broadcast (ADS-B) Out and transponders cannot be used to satisfy the UAS RID requirements on UAS to which the rule applies (see Appendix B).

European Union Aviation Safety Agency (EASA)

> The EASA published a [Delegated] regulation in 2019 imposing requirements on UAS manufacturers and third-country operators, including but not limited to UAS RID requirements. The same year, EASA also published an [Implementing] regulation laying down detailed rules and procedures for UAS operations and operating personnel which then was updated in 2021 [Implementing_update]. A Notice of Proposed Amendment [NPA] was published in 2021 to provide more information about the development of acceptable

means of compliance and guidance material to support the U-space regulation.

American Society for Testing and Materials (ASTM)

ASTM International, Technical Committee F38 (UAS), Subcommittee F38.02 (Aircraft Operations), Work Item WK65041, developed the ASTM [F3411-19] Standard Specification for Remote ID and Tracking.

ASTM defines one set of UAS RID information and two means, MAC-layer broadcast and IP-layer network, of communicating it. If an UAS uses both communication methods, the same information must be provided via both means. [F3411-19] is cited by the FAA in its UAS RID final rule [FAA_RID] as "a potential means of compliance" to a Remote ID rule.

The 3rd Generation Partnership Project (3GPP)

With release 16, the 3GPP completed the UAS RID requirement study [TS-22.825] and proposed a set of use cases in the mobile network and services that can be offered based on UAS RID. The Release 17 study [TR-23.755] and specification [TS-23.255] focus on enhanced UAS service requirements and provides the protocol and application architecture support that will be applicable for both 4G and 5G networks. The study of Further Architecture Enhancement for Uncrewed Aerial Vehicles (UAV) and Urban Air Mobility (UAM) [FS_AEUA] in release 18 further enhances the communication mechanism between UAS and USS/UTM. The DRIP Entity Tag in Section 3 may be used as the 3GPP CAA-level UAS ID for Remote Identification purposes.

1.2. Overview of Types of UAS Remote ID

This specification introduces two types of UAS Remote ID defined in ASTM [F3411-19].

1.2.1. Broadcast RID

[F3411-19] defines a set of UAS RID messages for direct, one-way, broadcast transmissions from the UA over Bluetooth or Wi-Fi. These are currently defined as MAC-Layer messages. Internet (or other Wide Area Network) connectivity is only needed for UAS registry information lookup by Observers using the directly received UAS ID. Broadcast RID should be functionally usable in situations with no Internet connectivity.

The minimum Broadcast RID data flow is illustrated in Figure 1.

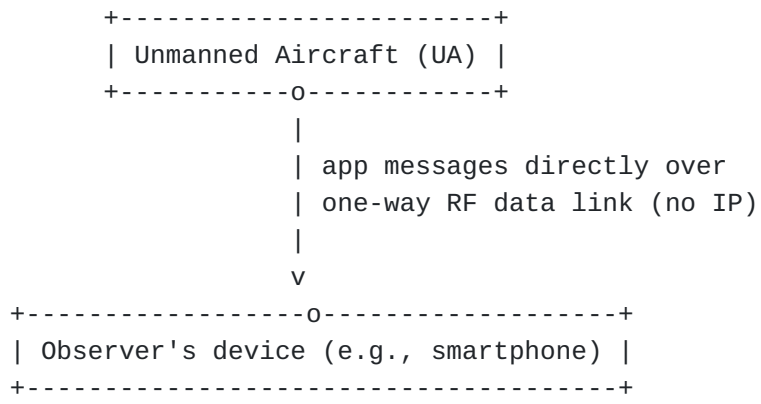


Figure 1

Broadcast RID provides information only about unmanned aircraft (UA) within direct Radio Frequency (RF) Line-Of-Sight (LOS), typically similar to Visual LOS (VLOS), with a range up to approximately 1 km. This information may be 'harvested' from received broadcasts and made available via the Internet, enabling surveillance of areas too large for local direct visual observation or direct RF link-based ID (see Section 6).

1.2.2. Network RID

[F3411-19], using the same data dictionary that is the basis of Broadcast RID messages, defines a Network Remote Identification (Net-RID) data flow as follows.

- The information to be reported via UAS RID is generated by the UAS. Typically some of this data is generated by the UA and some by the GCS (Ground Control Station), e.g., their respective Global Navigation Satellite System (GNSS) derived locations.

- The information is sent by the UAS (UA or GCS) via unspecified means to the cognizant Network Remote Identification Service Provider (Net-RID SP), typically the USS under which the UAS is operating if participating in UTM.

- The Net-RID SP publishes via the Discovery and Synchronization Service (DSS) over the Internet that it has operations in various 4-D airspace volumes (Section 2.2 of [RFC9153]), describing the volumes but not the operations.

- An Observer's device, which is expected, but not specified, to be web-based, queries a Network Remote Identification Display Provider (Net-RID DP), typically also a USS, about any operations in a specific 4-D airspace volume.

- Using fully specified web-based methods over the Internet, the Net-RID DP queries all Net-RID SPs that have operations in

volumes intersecting that of the Observer's query for details on all such operations.

*The Net-RID DP aggregates information received from all such Net-RID SPs and responds to the Observer's query.

The minimum Net-RID data flow is illustrated in Figure 2:

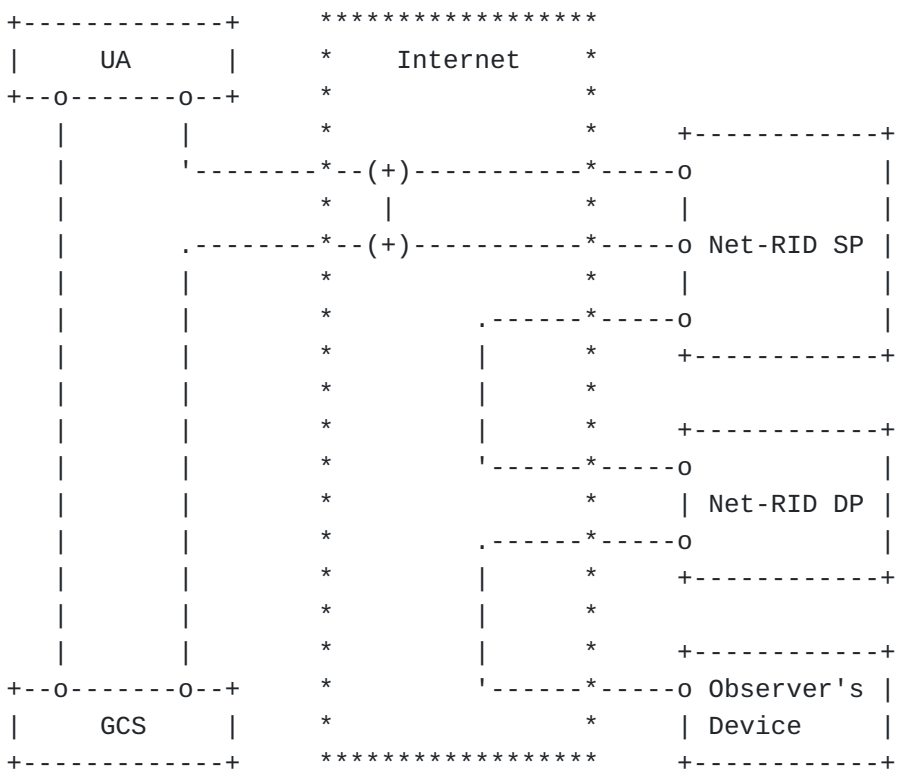


Figure 2

Command and Control (C2) must flow from the GCS to the UA via some path. Currently (in the year 2022) this is typically a direct RF link; however, with increasing Beyond Visual Line of Sight (BVLOS) operations, it is expected often to be a wireless link at either end with the Internet between.

Telemetry (at least the UA's position and heading) flows from the UA to the GCS via some path, typically the reverse of the C2 path. Thus, UAS RID information pertaining to both the GCS and the UA can be sent, by whichever has Internet connectivity, to the Net-RID SP, typically the USS managing the UAS operation.

The Net-RID SP forwards UAS RID information via the Internet to subscribed Net-RID DPs, typically USSs. Subscribed Net-RID DPs then forward RID information via the Internet to subscribed Observer devices. Regulations require and [F3411-19] describes UAS RID data

elements that must be transported end-to-end from the UAS to the subscribed Observer devices.

[F3411-19] prescribes the protocols between the Net-RID SP, Net-RID DP, and the DSS. It also prescribes data elements (in JSON) between the Observer and the Net-RID DP. DRIP could address standardization of secure protocols between the UA and GCS (over direct wireless and Internet connection), between the UAS and the Net-RID SP, and/or between the Net-RID DP and Observer devices.

> Informative note: Neither link layer protocols nor the use of links (e.g., the link often existing between the GCS and the UA) for any purpose other than carriage of UAS RID information is in the scope of [F3411-19] Network RID.

1.3. Overview of USS Interoperability

With Net-RID, there is direct communication between each UAS and its USS. Multiple USS exchange information with the assistance of a DSS so all USS collectively have knowledge about all activities in a 4D airspace. The interactions among an Observer, multiple UAS, and their USS are shown in Figure 3.

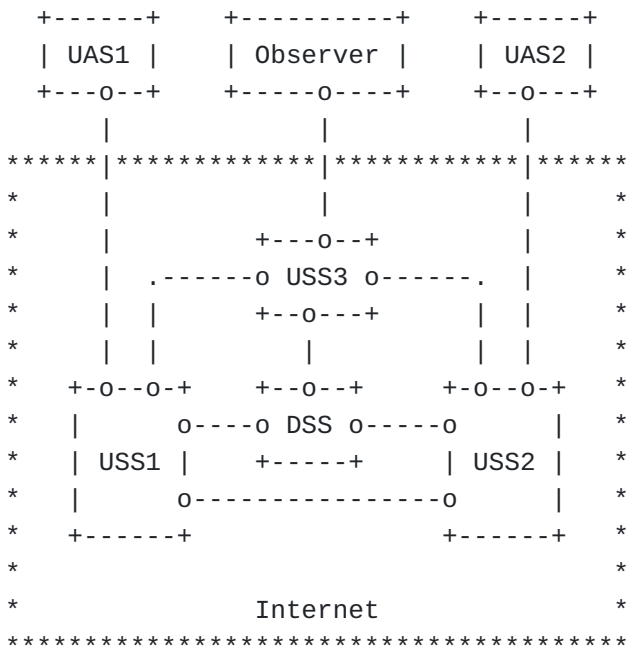
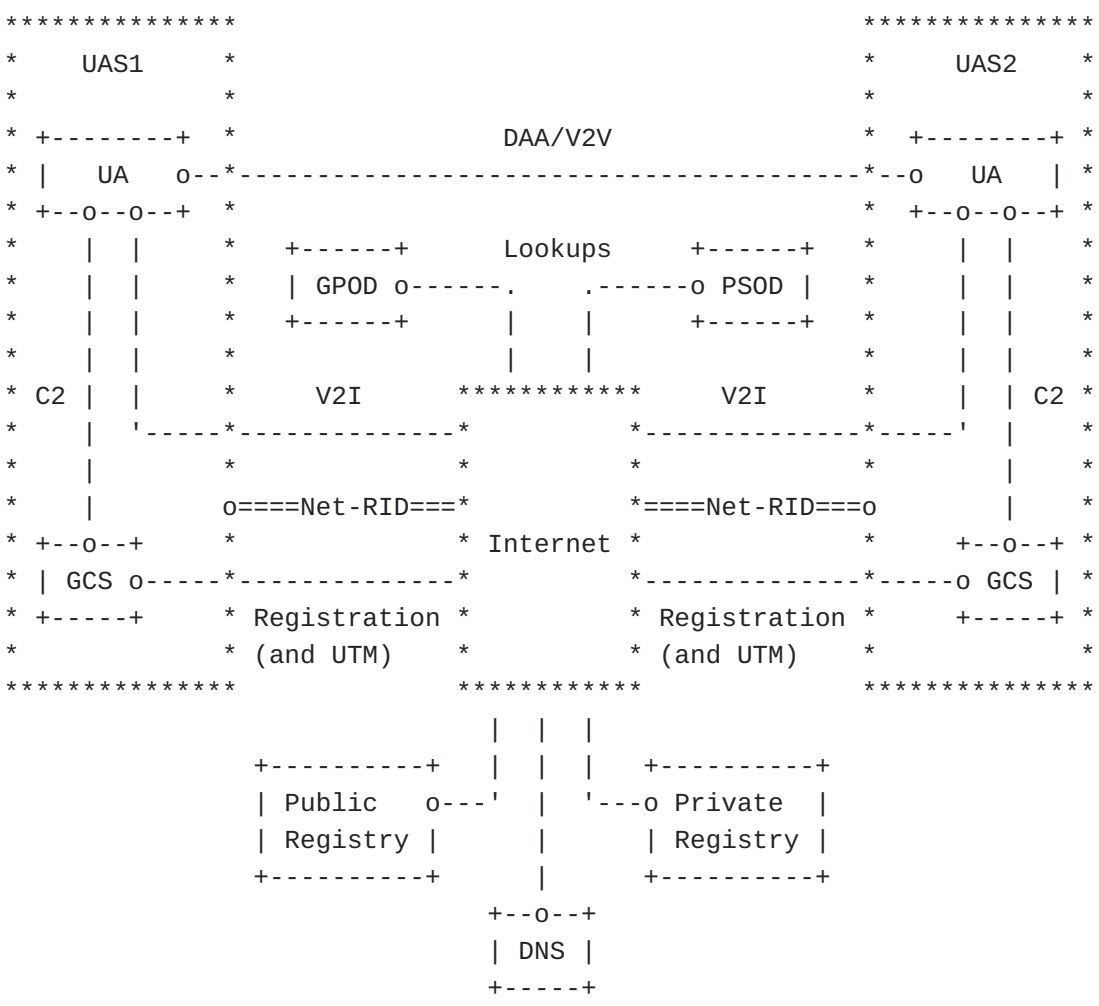


Figure 3

1.4. Overview of DRIP Architecture

Figure 4 illustrates a global UAS RID usage scenario. Broadcast RID links are not shown as they reach from any UA to any listening receiver in range and thus would obscure the intent of the figure.

Figure 4 shows, as context, some entities and interfaces beyond the scope of DRIP (as currently (2022) chartered).



DAA: Detect And Avoid
GPOD: General Public Observer Device
PSOD: Public Safety Observer Device
V2I: Vehicle-to-Infrastructure
V2V: Vehicle-to-Vehicle

Figure 4

Informative note: see [RFC9153] for detailed definitions.

DRIP is meant to leverage existing Internet resources (standard protocols, services, infrastructures, and business models) to meet UAS RID and closely related needs. DRIP will specify how to apply IETF standards, complementing [F3411-19] and other external standards, to satisfy UAS RID requirements.

This document outlines the DRIP architecture in the context of the UAS RID architecture. This includes closing the gaps between the

CAAs' Concepts of Operations and [F3411-19] as it relates to the use of Internet technologies and UA direct RF communications. Issues include, but are not limited to:

- Design of trustworthy remote identifiers required by GEN-1 (Section 3).

- Mechanisms to leverage the Domain Name System (DNS [RFC1034]), for registering and publishing public and private information (see Section 4.1 and Section 4.2) as required by REG-1 and REG-2.

- Specific authentication methods and message payload formats to enable verification that Broadcast RID messages were sent by the claimed sender (Section 5) and that the sender is in the claimed DIME (Section 4 and Section 5) as required by GEN-2.

- Harvesting Broadcast RID messages for UTM inclusion, with the optional DRIP extension of Crowd Sourced Remote ID (CS-RID, Section 6), using the DRIP support for gateways required by GEN-5 [RFC9153].

- Methods for instantly establishing secure communications between an Observer and the pilot of an observed UAS (Section 7), using the DRIP support for dynamic contact required by GEN-4 [RFC9153].

- Privacy in UAS RID messages (PII protection) (Section 9).

2. Terms and Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

To encourage comprehension necessary for adoption of DRIP by the intended user community, the UAS community's norms are respected herein.

This document uses terms defined in [RFC9153].

2.1. Additional Abbreviations

DET: DRIP Entity Tag

EdDSA: Edwards-Curve Digital Signature Algorithm

HHIT: Hierarchical HIT

HI: Host Identity

HIP: Host Identity Protocol

HIT: Host Identity Tag

2.2. Additional Definitions

This section introduces the terms "Claim", "Evidence", "Endorsement", and "Certificate" as used in DRIP. A DRIP certificate has a different context compared with security certificates and Public Key Infrastructure used in X.509.

Claim:

> A claim shares the same definition as a claim in RATS [I-D.ietf-rats-architecture]; it is a piece of asserted information, sometimes in the form of a name/value pair. It could also been seen as a predicate (e.g., "X is Y", "X has property Y", and most importantly "X owns Y" or "X is owned by Y").

Evidence:

> Evidence in DRIP borrows the same definition as in RATS [I-D.ietf-rats-architecture]; that is a set of claims.

Endorsement:

> An Endorsement is inspired from RATS [I-D.ietf-rats-architecture]; it is a secure (i.e. signed) statement vouching the integrity and veracity of evidence.

Certificate:

> A certificate in DRIP is an endorsement, strictly over identity information, signed by a third party. This third party should be one with no stake in the endorsement over which it is signing.

DRIP Identity Management Entity (DIME):

> An entity that performs functions similar to a domain registrar/registry. A DIME vets Claims and/or Evidence from a registrant and delivers back Endorsements and/or Certificates in response. It is a high-level entity in the DRIP registration/provisioning process that can hold the role of RAA or HDA.

3. HHIT as the DRIP Entity Identifier

This section describes the DRIP architectural approach to meeting the basic requirements of a DRIP entity identifier within external

technical standard ASTM [F3411-19] and regulatory constraints. It justifies and explains the use of Hierarchical Host Identity Tags (HHITs) [I-D.ietf-drip-rid] as self-asserting IPv6 addresses suitable as a UAS ID type and, more generally, as trustworthy multipurpose remote identifiers.

Self-asserting in this usage means that given the Host Identity (HI), the HHIT ORCHID construction (see section 3.5 of [I-D.ietf-drip-rid]) and a signature of the DIME on the HHIT and HI; the HHIT can be verified by the receiver as a trusted UAS ID. The explicit registration hierarchy within the HHIT provides registration discovery (managed by a DRIP Identity Management Entity (DIME)) to either yield the HI for a 3rd-party (seeking UAS ID endorsement) validation or prove that the HHIT and HI have been registered uniquely.

3.1. UAS Remote Identifiers Problem Space

A DRIP entity identifier needs to be "Trustworthy" (see DRIP Requirement GEN-1, ID-4 and ID-5 in [RFC9153]). This means that given a sufficient collection of UAS RID messages, an Observer can establish that the identifier claimed therein uniquely belongs to the claimant. To satisfy DRIP requirements and maintain important security properties, the DRIP identifier should be self-generated by the entity it names (e.g., a UAS) and registered (e.g., with a USS, see Requirements GEN-3 and ID-2).

However the Broadcast RID, especially its support for Bluetooth 4.x, imposes severe constraints. The ASTM UAS RID [F3411-19] allows a UAS ID of types 1, 2 and 3 of 20 bytes. [F3411-22a] add an additional type 4 (Specific Session ID). Type 4 uses one byte to index the Specific Session ID (leaving 19 bytes, see ID-1 of DRIP Requirement [RFC9153]); Specific Session ID of value 1 is allocated to IETF DRIP by ASTM. This new Specific Session ID will be standardized by IETF and other standards development organizations (SDOs) as extensions to ASTM UAS RID.

Likewise, the maximum ASTM UAS RID [F3411-19] Authentication Message payload is 201 bytes for most authentication types. A type 5 is also added in this revision for IETF and other SDOs to develop Specific Authentication Methods as extensions to ASTM UAS RID. One byte out of 201 bytes is consumed to index the sub-type which leaves only 200 for DRIP authentication payloads, including one or more DRIP entity identifiers and associated authentication data.

3.2. HHIT as a Cryptographic Identifier

The only (known to the authors at the time of this writing) existing types of IP address compatible identifiers cryptographically derived

from the public keys of the identified entities are Cryptographically Generated Addresses (CGAs) [RFC3972] and Host Identity Tags (HITs) [RFC7401]. CGAs and HITs lack registration/ retrieval capability. To provide this, each HHIT embeds plaintext information designating the hierarchy within which it is registered and a cryptographic hash of that information concatenated with the entity's public key, etc. Although hash collisions may occur, the DIME can detect them and reject registration requests rather than issue credentials, e.g., by enforcing a first-claimed, first-attested policy. Pre-image hash attacks are also mitigated through this registration process, locking the HHIT to a specific HI.

3.3. HHIT as A Trustworthy DRIP Entity Identifier

A Remote UAS ID that can be trustworthy for use in Broadcast RID can be built from an asymmetric keypair. In this method, the UAS ID is cryptographically derived directly from the public key. The proof of UAS ID ownership (verifiable endorsement, versus mere claim) is guaranteed by signing this cryptographic UAS ID with the associated private key. The association between the UAS ID and the private key is ensured by cryptographically binding the public key with the UAS ID; more specifically, the UAS ID results from the hash of the public key. The public key is designated as the HI while the UAS ID is designated as the HIT.

By construction, the HIT is statistically unique through the mandatory use of cryptographic hash functions with second-preimage resistance. The cryptographically-bound addition of the Hierarchy and an HHIT registration process provide complete, global HHIT uniqueness. This registration forces the attacker to generate the same public key rather than a public key that generates the same HHIT. This is in contrast to general IDs (e.g., a UUID or device serial number) as the subject in an X.509 certificate.

A UA equipped for Broadcast RID MUST be provisioned not only with its HHIT but also with the HI public key from which the HHIT was derived and the corresponding private key, to enable message signature.

A UAS equipped for DRIP enhanced Network RID MUST be provisioned likewise; the private key resides only in the ultimate source of Network RID messages. If the GCS is the source of the Network RID messages; the GCS MUST hold the private key. If the UA is the source of the Network RID messages and they are being relayed by the GCS; the UA MUST hold the private key, just as a UA that directly connects to the network rather than through its GCS.

Each Observer device functioning with Internet connectivity MAY be provisioned either with public keys of the DRIP identifier root

registries or certificates for subordinate registries; each Observer devices that needs to operate without Internet connectivity at any time MUST be so provisioned.

HHITs can also be used throughout the USS/UTM system. Operators and Private Information Registries, as well as other UTM entities, can use HHITs for their IDs. Such HHITs can facilitate DRIP security functions such as used with HIP to strongly mutually authenticate and encrypt communications.

A self-endorsement of a HHIT used as a UAS ID can be done in as little as 88-bytes when Ed25519 [RFC8032] is used by only including the 16-byte HHIT, two 4-byte timestamps, and the 64-byte Ed25519 signature.

Ed25519 [RFC8032] is used as the HHIT Mandatory to Implement signing algorithm as [RFC9153] GEN-1 and ID-5 can best be met by restricting the HI to 32 bytes. A larger public key would rule out the offline endorsement feature that fits within the 200-byte Authentication Message maximum length. Other algorithms that meet this 32 byte constraint can be added as deemed needed.

A DRIP identifier can be assigned to a UAS as a static HHIT by its manufacturer, such as a single HI and derived HHIT encoded as a hardware serial number per [CTA2063A]. Such a static HHIT SHOULD only be used to bind one-time use DRIP identifiers to the unique UA. Depending upon implementation, this may leave a HI private key in the possession of the manufacturer (see also Section 8).

In general, Internet access may be needed to validate Endorsements or Certificates. This may be obviated in the most common cases (e.g., endorsement of the UAS ID), even in disconnected environments, by prepopulating small caches on Observer devices with DIME public keys and a chain of Endorsements or Certificates (tracing a path through the DIME tree). This is assuming all parties on the trust path also use HHITs for their identities.

3.4. HHIT for DRIP Identifier Registration and Lookup

UAS RID needs a deterministic lookup mechanism that rapidly provides actionable information about the identified UA. Given the size constraints imposed by the Bluetooth 4 broadcast media, the UAS ID itself needs to be a non-spoofable inquiry input into the lookup.

A DRIP registration process based on the explicit hierarchy within a HHIT provides manageable uniqueness of the HI for the HHIT. The hierarchy is defined in [I-D.ietf-drip-rid] and consists of 2-levels, a Registered Assigning Authority (RAA) and then a Hierarchical HIT Domain Authority (HDA). The registration within this hierarchy is the defense against a cryptographic hash second

pre-image attack on the HHIT (e.g., multiple HIs yielding the same HHIT, see Requirement ID-3 in [RFC9153]). Registration first-come-first served is adequate.

A lookup of the HHIT into the DIME provides the registered HI for HHIT proof of ownership and deterministic access to any other needed actionable information based on inquiry access authority (more details in Section 4.2).

4. DRIP Identifier Registration and Registries

DRIP registries hold both public and private UAS information (see PRIV-1 in [RFC9153]) resulting from the DRIP identifier registration process. Given these different uses, and to improve scalability, security, and simplicity of administration, the public and private information can be stored in different registries. This section introduces the public and private information registries for DRIP identifiers. This DRIP Identifier registration process satisfies the following DRIP requirements defined in [RFC9153]: GEN-3, GEN-4, ID-2, ID-4, ID-6, PRIV-3, PRIV-4, REG-1, REG-2, REG-3 and REG-4.

4.1. Public Information Registry

4.1.1. Background

The public information registry provides trustable information such as endorsements of UAS RID ownership and registration with the HDA (Hierarchical HIT Domain Authority). Optionally, pointers to the registries for the HDA and RAA (Registered Assigning Authority) implicit in the UAS RID can be included (e.g., for HDA and RAA HHIT| HI used in endorsement signing operations). This public information will be principally used by Observers of Broadcast RID messages. Data on UASs that only use Network RID, is available via an Observer's Net-RID DP that would directly provide all public registry information. The Net-RID DP is the only source of information for a query on an airspace volume.

4.1.2. Public DRIP Identifier Registry

A DRIP identifier MUST be registered as an Internet domain name (at an arbitrary level in the hierarchy, e.g., in .ip6.arpa). Thus DNS can provide all the needed public DRIP information. A standardized HHIT FQDN (Fully Qualified Domain Name) can deliver the HI via a HIP RR (Resource Record) [RFC8005] and other public information (e.g., RAA and HDA PTRs, and HIP RVS (Rendezvous Servers) [RFC8004]). These public information registries can use DNSSEC to deliver public information that is not inherently trustable (e.g., everything other than endorsements).

This DNS entry for the HHIT can also provide a revocation service. For example, instead of returning the HI RR it may return some record showing that the HI (and thus HHIT) has been revoked.

4.2. Private Information Registry

4.2.1. Background

The private information required for DRIP identifiers is similar to that required for Internet domain name registration. A DRIP identifier solution can leverage existing Internet resources: registration protocols, infrastructure, and business models, by fitting into a UAS ID structure compatible with DNS names. The HHIT hierarchy can provide the needed scalability and management structure. It is expected that the private information registry function will be provided by the same organizations that run a USS, and likely integrated with a USS. The lookup function may be implemented by the Net-RID DPs.

4.2.2. Private DRIP Identifier Registry Methods

A DRIP private information registry supports essential registry operations (e.g., add, delete, update, query) using interoperable open standard protocols. It can accomplish this by leveraging aspects of Extensible Provisioning Protocol (EPP [RFC5730]) and the Registry Data Access Protocol (RDAP [RFC7480] [RFC9082] [RFC9083]). The DRIP private information registry in which a given UAS is registered needs to be findable, starting from the UAS ID, using the methods specified in [RFC9224].

4.2.3. Alternative Private DRIP Registry Methods

A DRIP private information registry might be an access-controlled DNS (e.g., via DNS over TLS) or a blockchain. Additionally, WebFinger [RFC7033] can be supported. These alternative methods may be used by Net-RID DP with specific customers.

5. DRIP Identifier Trust

While the DRIP entity identifier is self-asserting, it alone does not provide the trustworthiness (non-repudiability, protection vs. spoofing, message integrity protection, scalability, etc.) essential to UAS RID, as justified in [RFC9153]. For that it MUST be registered (under DRIP Registries) and be actively used by the party (in most cases the UA). A sender's identity can not be proved by only possessing a DRIP Entity Tag (DET) and broadcasting it as a claim that it belongs to that sender. Even the sender using that HI's private key to sign static data proves nothing as well, as it is subject to trivial replay attacks. Only sending the DET and a signature on frequently changing data (which is unpredicatable) that

can be externally validated by the Observer (such as a Location/ Vector message matching actually seeing the UA at that location) proves that the observed UA possesses the claimed UAS ID.

The severe constraints of Broadcast RID make it challenging to satisfy UAS RID requirements. From received Broadcast RID messages and information that can be looked up using the received UAS ID in online registries or local caches, it is possible to establish levels of trust in the asserted information and the Operator.

Optimization of different DRIP Authentication Messages allows an Observer, without Internet connection (offline) or with (online), to be able to validate a UAS DRIP ID in real-time. First is the sending of messages containing the relevant registration of the UA's DRIP ID in the claimed DIME. Next is sending messages that sign over both static (e.g., above registration) and dynamically changing data (such as UA location data). Combining these two sets of information, an Observer can piece together a chain of trust and real-time evidence to make their determination of the UA's claims.

This process (combining the DRIP entity identifier, Registries and Authentication Formats for Broadcast RID) can satisfy the following DRIP requirement defined in [RFC9153]: GEN-1, GEN-2, GEN-3, ID-2, ID-3, ID-4 and ID-5.

6. Harvesting Broadcast Remote ID messages for UTM Inclusion

ASTM anticipated that regulators would require both Broadcast RID and Network RID for large UASs, but allow UAS RID requirements for small UAS to be satisfied with the operator's choice of either Broadcast RID or Network RID. The EASA initially specified Broadcast RID for essentially all UAS, and is now also considering Network RID. The FAA UAS RID Final Rules [FAA_RID] permit only Broadcast RID for rule compliance, but still encourage Network RID for complementary functionality, especially in support of UTM.

One opportunity is to enhance the architecture with gateways from Broadcast RID to Network RID. This provides the best of both and gives regulators and operators flexibility. It offers advantages over either form of UAS RID alone: greater fidelity than Network RID reporting of planned area operations; surveillance of areas too large for local direct visual observation and direct RF-LOS link based Broadcast RID (e.g., a city or a national forest).

These gateways could be pre-positioned (e.g., around airports, public gatherings, and other sensitive areas) and/or crowd-sourced (as nothing more than a smartphone with a suitable app is needed). As Broadcast RID media have limited range, gateways receiving messages claiming locations far from the gateway can alert

authorities or a SDSP to the failed sanity check possibly indicating intent to deceive. Surveillance SDSPs can use messages with precise date/time/position stamps from the gateways to multilaterate UA location, independent of the locations claimed in the messages, which are entirely operator self-reported in UAS RID and UTM, and thus are subject not only to natural time lag and error but also operator misconfiguration or intentional deception.

Multilateration technologies use physical layer information, such as precise Time Of Arrival (TOA) of transmissions from mobile transmitters at receivers with a priori precisely known locations, to estimate the locations of the mobile transmitters.

Further, gateways with additional sensors (e.g., smartphones with cameras) can provide independent information on the UA type and size, confirming or refuting those claims made in the UAS RID messages.

Section 6.1 and Section 6.2 define two additional entities that are required to provide this Crowd Sourced Remote ID (CS-RID).

This approach satisfies the following DRIP requirements defined in [RFC9153]: GEN-5, GEN-11, and REG-1. As Broadcast messages are inherently multicast, GEN-10 is met for local-link multicast to multiple Finders (how multilateration is possible).

6.1. The CS-RID Finder

A CS-RID Finder is the gateway for Broadcast Remote ID Messages into UTM. It performs this gateway function via a CS-RID SDSP. A CS-RID Finder could implement, integrate, or accept outputs from a Broadcast RID receiver. However, it should not depend upon a direct interface with a GCS, Net-RID SP, Net-RID DP or Network RID client. It would present a new interface to a CS-RID SDSP, similar to but readily distinguishable from that between a GCS and a Net-RID SP.

6.2. The CS-RID SDSP

A CS-RID SDSP aggregates and processes (e.g., estimates UA location using multilateration when possible) information collected by CS-RID Finders. A CS-RID SDSP should appear (i.e., present the same interface) to a Net-RID SP as a Net-RID DP and to a Net-RID DP like a Net-RID SP but be readily distinguishable with its data source.

7. DRIP Contact

One of the ways in which DRIP can enhance [F3411-19] with immediately actionable information is by enabling an Observer to instantly initiate secure communications with the UAS remote pilot, Pilot In Command, operator, USS under which the operation is being

flown, or other entity potentially able to furnish further information regarding the operation and its intent and/or to immediately influence further conduct or termination of the operation (e.g., land or otherwise exit an airspace volume). Such potentially distracting communications demand strong "AAA" (Authentication, Attestation, Authorization, Access Control, Accounting, Attribution, Audit) per applicable policies (e.g., of the cognizant CAA).

A DRIP entity identifier based on a HHIT as outlined in Section 3 embeds an identifier of the DIME in which it can be found (expected typically to be the USS under which the UAS is flying) and the procedures outlined in Section 5 enable Observer verification of that relationship. A DRIP entity identifier with suitable records in public and private registries as outlined in Section 5 can enable lookup not only of information regarding the UAS, but also identities of and pointers to information regarding the various associated entities (e.g., the USS under which the UAS is flying an operation), including means of contacting those associated entities (i.e., locators, typically IP addresses).

A suitably equipped Observer could initiate a secure communication channel, using the DET HI, to a similarly equipped and identified entity: the UA itself, if operating autonomously; the GCS, if the UA is remotely piloted and the necessary records have been populated in DNS; the USS, etc. Assuming secure communication setup (e.g. via IPsec or HIP), arbitrary standard higher layer protocols can then be used for Observer to Pilot (O2P) communications (e.g., SIP [RFC3261] et seq), V2X communications (e.g., [MAVLink]), etc. Certain preconditions are necessary: each party needs a currently usable means (typically DNS) of resolving the other party's DRIP entity identifier to a currently usable locator (IP address); and there must be currently usable bidirectional IP (not necessarily Internet) connectivity between the parties. One method directly supported by the use of HHITs as DRIP entity identifiers is initiation of a HIP Base Exchange (BEX) and Bound End-to-End Tunnel (BEET).

This approach satisfies DRIP requirement GEN-6 Contact, supports satisfaction of requirements [RFC9153] GEN-8, GEN-9, PRIV-2, PRIV-5 and REG-3, and is compatible with all other DRIP requirements.

8. Security Considerations

The size of the public key hash in the HHIT is vulnerable to a second preimage attack. It is well within current server array technology to compute another key pair that hashes to the same HHIT. Thus, if a receiver were to check HHIT validity only by verifying that the received HI and associated information, when hashed in the ORCHID construction, reproduce the received HHIT, an adversary could

impersonate a validly registered UA. To defend against this, on-line receivers should verify the received HHIT and received HI with the USS with which the HHIT purports to be registered. On-line and off-line receivers can use a chain of received DRIP link endorsements from a root of trust through the RAA and the HDA to the UA, as described, in [I-D.ietf-drip-auth] and [I-D.ietf-drip-registries].

Compromise of a DIME private key could do widespread harm [I-D.ietf-drip-registries]. In particular, it would allow bad actors to impersonate trusted members of said DIME. These risks are in addition to those involving key management practices and will be addressed as part of the DIME process. All DRIP public keys can be found in DNS thus they can be revoked in DNS and users SHOULD check DNS when available. Specific key revocation procedures are as yet to be determined.

8.1. Private Key Physical Security

The security provided by asymmetric cryptographic techniques depends upon protection of the private keys. It may be necessary for the GCS to have the key pair to register the HHIT to the USS. Thus it may be the GCS that generates the key pair and delivers it to the UA, making the GCS a part of the key security boundary. Leakage of the private key either from the UA or GCS to the component manufacturer is a valid concern and steps need to be in place to ensure safe keeping of the private key.

Since it is possible for the UAS RID sender of a small harmless UA (or the entire UA) to be carried by a larger dangerous UA as a "false flag", it is out of scope to deal with secure store for the private key.

8.2. Quantum Resistant Cryptography

There has been no effort, at this time, to address post quantum computing cryptography. UAs and Broadcast Remote ID communications are so constrained that current post quantum computing cryptography is not applicable. Plus since a UA may use a unique HHIT for each operation, the attack window could be limited to the duration of the operation.

One potential use for post quantum cryptography is its use in keypairs that have long usage lives, but rarely if ever need to be transmitted over bandwidth constrained links; such as for Serial Numbers or Operators. Finally, as the HHIT contains the ID for the cryptographic suite used in its creation, a future post quantum computing safe algorithm that fits the Remote ID constraints may readily be added.

8.3. Denial Of Service (DOS) Protection

Remote ID services from the UA use a wireless link in a public space. As such, they are open to many forms of RF jamming. It is trivial for an attacker to stop any UA messages from reaching a wireless receiver. Thus it is pointless to attempt to provide relief from DOS attacks as there is always the ultimate RF jamming attack. Also the DRIP architecture make spoofing/replay attacks, that might be used to attempt DOS, very hard.

9. Privacy & Transparency Considerations

Broadcast RID messages can contain Personally Identifiable Information (PII). A viable architecture for PII protection would be symmetric encryption of the PII using a session key known to the UAS and its USS. Authorized Observers could obtain plaintext in either of two ways. An Observer can send the UAS ID and the cyphertext to a server that offers decryption as a service. An Observer can send the UAS ID only to a server that returns the session key, so that Observer can directly locally decrypt all cyphertext sent by that UA during that session (UAS operation). In either case, the server can be: a Public Safety USS, the Observer's own USS, or the UA's USS if the latter can be determined (which under DRIP it can be, from the UAS ID itself). PII can be protected unless the UAS is informed otherwise. This could come as part of UTM operation authorization. It can be special instructions at the start or during an operation. PII protection MUST NOT be used if the UAS loses connectivity to the USS, as if the UAS loses connectivity chances are Observers also won't have connectivity in the vicinity to enabled decryption of the PII. The UAS always has the option to abort the operation if PII protection is disallowed.

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Appendix A. Overview of Unmanned Aircraft Systems (UAS) Traffic Management (UTM)

A.1. Operation Concept

The National Aeronautics and Space Administration (NASA) and FAA's effort to integrate UAS operations into the national airspace system (NAS) led to the development of the concept of UTM and the ecosystem around it. The UTM concept was initially presented in 2013 and version 2.0 was published in 2020 [FAA_UAS_Concept_Of_Ops].

The eventual concept refinement, initial prototype implementation, and testing were conducted by the joint FAA and NASA UTM research transition team. World efforts took place afterward. The Single European Sky ATM Research (SESAR) started the CORUS project to research its UTM counterpart concept, namely [U-Space]. This effort is led by the European Organization for the Safety of Air Navigation (Eurocontrol).

Both NASA and SESAR have published their UTM concepts of operations to guide the development of their future air traffic management (ATM) system and ensure safe and efficient integration of manned and unmanned aircraft into the national airspace.

UTM comprises UAS operations infrastructure, procedures and local regulation compliance policies to guarantee safe UAS integration and

operation. The main functionality of UTM includes, but is not limited to, providing means of communication between UAS operators and service providers and a platform to facilitate communication among UAS service providers.

A.2. UAS Service Supplier (USS)

A USS plays an important role to fulfill the key performance indicators (KPIs) that UTM has to offer. Such an Entity acts as a proxy between UAS operators and UTM service providers. It provides services like real-time UAS traffic monitoring and planning, aeronautical data archiving, airspace and violation control, interacting with other third-party control entities, etc. A USS can coexist with other USS to build a large service coverage map that can load-balance, relay, and share UAS traffic information.

The FAA works with UAS industry shareholders and promotes the Low Altitude Authorization and Notification Capability [LAANC] program, which is the first system to realize some of the envisioned functionality of UTM. The LAANC program can automate UAS operational intent (flight plan) submission and application for airspace authorization in real-time by checking against multiple aeronautical databases such as airspace classification and operating rules associated with it, FAA UAS facility map, special use airspace, Notice to Airmen (NOTAM), and Temporary Flight Restriction (TFR).

A.3. UTM Use Cases for UAS Operations

This section illustrates a couple of use case scenarios where UAS participation in UTM has significant safety improvement.

1. For a UAS participating in UTM and taking off or landing in controlled airspace (e.g., Class Bravo, Charlie, Delta, and Echo in the United States), the USS under which the UAS is operating is responsible for verifying UA registration, authenticating the UAS operational intent (flight plan) by checking against a designated UAS facility map database, obtaining the air traffic control (ATC) authorization, and monitoring the UAS flight path in order to maintain safe margins and follow the pre-authorized sequence of authorized 4-D volumes (route).

2. For a UAS participating in UTM and taking off or landing in uncontrolled airspace (e.g., Class Golf in the United States), pre-flight authorization must be obtained from a USS when operating Beyond-Visual-Line-of-Sight (BVLOS). The USS either accepts or rejects the received operational intent (flight plan) from the UAS. Approved UAS operation may share its current flight data such as GPS position and altitude to the

USS. The USS may keep the UAS operation status near real-time and may keep it as a record for overall airspace air traffic monitoring.

Appendix B. Automatic Dependent Surveillance Broadcast (ADS-B)

The ADS-B is the de jure technology used in manned aviation for sharing location information, from the aircraft to ground and satellite-based systems, designed in the early 2000s. Broadcast RID is conceptually similar to ADS-B, but with the receiver target being the general public on generally available devices (e.g., smartphones).

For numerous technical reasons, ADS-B itself is not suitable for low-flying small UAS. Technical reasons include but are not limited to the following:

1. Lack of support for the 1090 MHz ADS-B channel on any consumer handheld devices

2. Weight and cost of ADS-B transponders on CSWaP (Cost, Size, Weight, and Power) constrained UA

3. Limited bandwidth of both uplink and downlink, which would likely be saturated by large numbers of UASs, endangering manned aviation

Understanding these technical shortcomings, regulators worldwide have ruled out the use of ADS-B for the small UAS for which UAS RID and DRIP are intended.

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