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C. Bormann  
Universitaet Bremen TZI  
B. Carpenter, Ed.  
Univ. of Auckland  
B. Liu, Ed.  
Huawei Technologies Co., Ltd  
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**A Generic Autonomic Signaling Protocol (GRASP)  
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**Abstract**

This document establishes requirements for a signaling protocol that enables autonomic devices and autonomic service agents to dynamically discover peers, to synchronize state with them, and to negotiate parameter settings mutually with them. The document then defines a general protocol for discovery, synchronization and negotiation, while the technical objectives for specific scenarios are to be described in separate documents. An Appendix briefly discusses existing protocols with comparable features.

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## [1.](#) Introduction

The success of the Internet has made IP-based networks bigger and more complicated. Large-scale ISP and enterprise networks have become more and more problematic for human based management. Also, operational costs are growing quickly. Consequently, there are increased requirements for autonomic behavior in the networks. General aspects of autonomic networks are discussed in [[RFC7575](#)] and [[RFC7576](#)].

One approach is to largely decentralize the logic of network management by migrating it into network elements. A reference model for autonomic networking on this basis is given in [[I-D.behringer-anima-reference-model](#)]. In order to fulfil autonomy, devices that embody autonomic service agents have specific signaling requirements. In particular they need to discover each other, to synchronize state with each other, and to negotiate parameters and resources directly with each other. There is no restriction on the type of parameters and resources concerned, which include very basic information needed for addressing and routing, as well as anything else that might be configured in a conventional non-autonomic network. The atomic unit of synchronization or negotiation is referred to as a technical objective, i.e, a configurable parameter or set of parameters (defined more precisely in [Section 3.1](#)).

Following this Introduction, [Section 2](#) describes the requirements for discovery, synchronization and negotiation. Negotiation is an iterative process, requiring multiple message exchanges forming a closed loop between the negotiating devices. State synchronization, when needed, can be regarded as a special case of negotiation, without iteration. [Section 3.2](#) describes a behavior model for a



protocol intended to support discovery, synchronization and negotiation. The design of GeneRic Autonomic Signaling Protocol (GRASP) in [Section 3](#) of this document is mainly based on this behavior model. The relevant capabilities of various existing protocols are reviewed in [Appendix D](#).

The proposed discovery mechanism is oriented towards synchronization and negotiation objectives. It is based on a neighbor discovery process, but also supports diversion to off-link peers. Although many negotiations will occur between horizontally distributed peers, many target scenarios are hierarchical networks, which is the predominant structure of current large-scale managed networks. However, when a device starts up with no pre-configuration, it has no knowledge of the topology. The protocol itself is capable of being used in a small and/or flat network structure such as a small office or home network as well as a professionally managed network. Therefore, the discovery mechanism needs to be able to allow a device to bootstrap itself without making any prior assumptions about network structure.

Because GRASP can be used to perform a decision process among distributed devices or between networks, it must run in a secure and strongly authenticated environment.

It is understood that in realistic deployments, not all devices will support GRASP. It is expected that some autonomic service agents will directly manage a group of non-autonomic nodes, and that other non-autonomic nodes will be managed traditionally. Such mixed scenarios are not discussed in this specification.

## **[2.](#) Requirement Analysis of Discovery, Synchronization and Negotiation**

This section discusses the requirements for discovery, negotiation and synchronization capabilities. The primary user of the protocol is an autonomic service agent (ASA), so the requirements are mainly expressed as the features needed by an ASA. A single physical device might contain several ASAs, and a single ASA might manage several technical objectives.

Note that requirements for ASAs themselves, such as the processing of Intent [[RFC7575](#)] or interfaces for coordination between ASAs are out of scope for the present document.

### **[2.1.](#) Requirements for Discovery**

D1. ASAs may be designed to manage anything, as required in [Section 2.2](#). A basic requirement is therefore that the protocol can



represent and discover any kind of technical objective among arbitrary subsets of participating nodes.

In an autonomic network we must assume that when a device starts up it has no information about any peer devices, the network structure, or what specific role it must play. The ASA(s) inside the device are in the same situation. In some cases, when a new application session starts up within a device, the device or ASA may again lack information about relevant peers. It might be necessary to set up resources on multiple other devices, coordinated and matched to each other so that there is no wasted resource. Security settings might also need updating to allow for the new device or user. The relevant peers may be different for different technical objectives. Therefore discovery needs to be repeated as often as necessary to find peers capable of acting as counterparts for each objective that a discovery initiator needs to handle. From this background we derive the next three requirements:

D2. When an ASA first starts up, it has no knowledge of the specific network to which it is attached. Therefore the discovery process must be able to support any network scenario, assuming only that the device concerned is bootstrapped from factory condition.

D3. When an ASA starts up, it must require no information about any peers in order to discover them.

D4. If an ASA supports multiple technical objectives, relevant peers may be different for different discovery objectives, so discovery needs to be repeated to find counterparts for each objective. Thus, there must be a mechanism by which an ASA can separately discover peer ASAs for each of the technical objectives that it needs to manage, whenever necessary.

D5. Following discovery, an ASA will normally perform negotiation or synchronization for the corresponding objectives. The design should allow for this by associating discovery, negotiation and synchronization objectives. It may provide an optional mechanism to combine discovery and negotiation/synchronization in a single call.

D6. Some objectives may only be significant on the local link, but others may be significant across the routed network and require off-link operations. Thus, the relevant peers might be immediate neighbors on the same layer 2 link, or they might be more distant and only accessible via layer 3. The mechanism must therefore provide both on-link and off-link discovery of ASAs supporting specific technical objectives.





D7. The discovery process should be flexible enough to allow for special cases, such as the following:

- o In some networks, as mentioned above, there will be some hierarchical structure, at least for certain synchronization or negotiation objectives, but this is unknown in advance. The discovery protocol must therefore operate regardless of hierarchical structure, which is an attribute of individual technical objectives and not of the autonomic network as a whole. This is part of the more general requirement to discover off-link peers.
- o During initialisation, a device must be able to establish mutual trust with the rest of the network and join an authentication mechanism. Although this will inevitably start with a discovery action, it is a special case precisely because trust is not yet established. This topic is the subject of [\[I-D.ietf-anima-bootstrapping-keyinfra\]](#). We require that once trust has been established for a device, all ASAs within the device inherit the device's credentials and are also trusted.
- o Depending on the type of network involved, discovery of other central functions might be needed, such as the Network Operations Center (NOC) [\[I-D.eckert-anima-stable-connectivity\]](#). The protocol must be capable of supporting such discovery during initialisation, as well as discovery during ongoing operation.

D8. The discovery process must not generate excessive traffic and must take account of sleeping nodes in the case of a constrained-node network [\[RFC7228\]](#).

D9. There must be a mechanism for handling stale discovery results.

## **[2.2. Requirements for Synchronization and Negotiation Capability](#)**

As background, consider the example of routing protocols, the closest approximation to autonomic networking already in widespread use. Routing protocols use a largely autonomic model based on distributed devices that communicate repeatedly with each other. The focus is reachability, so current routing protocols mainly consider simple link status, i.e., up or down, and an underlying assumption is that all nodes need a consistent view of the network topology in order for the routing algorithm to converge. Thus, routing is mainly based on information synchronization between peers, rather than on bi-directional negotiation. Other information, such as latency, congestion, capacity, and particularly unused capacity, would be helpful to get better path selection and utilization rate, but is not normally used in distributed routing algorithms. Additionally,



autonomic networks need to be able to manage many more dimensions, such as security settings, power saving, load balancing, etc. Status information and traffic metrics need to be shared between nodes for dynamic adjustment of resources and for monitoring purposes. While this might be achieved by existing protocols when they are available, the new protocol needs to be able to support parameter exchange, including mutual synchronization, even when no negotiation as such is required. In general, these parameters do not apply to all participating nodes, but only to a subset.

SN1. A basic requirement for the protocol is therefore the ability to represent, discover, synchronize and negotiate almost any kind of network parameter among arbitrary subsets of participating nodes.

SN2. Negotiation is a request/response process that must be guaranteed to terminate (with success or failure) and if necessary it must contain tie-breaking rules for each technical objective that requires them. While these must be defined specifically for each use case, the protocol should have some general mechanisms in support of loop and deadlock prevention, such as hop count limits or timeouts.

SN3. Synchronization might concern small groups of nodes or very large groups. Different solutions might be needed at different scales.

SN4. To avoid "reinventing the wheel", the protocol should be able to carry the message formats used by existing configuration protocols (such as NETCONF/YANG) in cases where that is convenient.

SN5. Human intervention in complex situations is costly and error-prone. Therefore, synchronization or negotiation of parameters without human intervention is desirable whenever the coordination of multiple devices can improve overall network performance. It therefore follows that the protocol, as part of the Autonomic Networking Infrastructure, must be capable of running in any device that would otherwise need human intervention.

SN6. Human intervention in large networks is often replaced by use of a top-down network management system (NMS). It therefore follows that the protocol, as part of the Autonomic Networking Infrastructure, must be capable of running in any device that would otherwise be managed by an NMS, and that it can co-exist with an NMS, and with protocols such as SNMP and NETCONF.

SN7. Some features are expected to be implemented by individual ASAs, but the protocol must be general enough to allow them:



- o Dependencies and conflicts: In order to decide a configuration on a given device, the device may need information from neighbors. This can be established through the negotiation procedure, or through synchronization if that is sufficient. However, a given item in a neighbor may depend on other information from its own neighbors, which may need another negotiation or synchronization procedure to obtain or decide. Therefore, there are potential dependencies and conflicts among negotiation or synchronization procedures. Resolving dependencies and conflicts is a matter for the individual ASAs involved. To allow this, there need to be clear boundaries and convergence mechanisms for negotiations. Also some mechanisms are needed to avoid loop dependencies. In such a case, the protocol's role is limited to signaling between ASAs.
- o Recovery from faults and identification of faulty devices should be as automatic as possible. The protocol's role is limited to the ability to handle discovery, synchronization and negotiation at any time, in case an ASA detects an anomaly such as a negotiation counterpart failing.
- o Since the goal is to minimize human intervention, it is necessary that the network can in effect "think ahead" before changing its parameters. In other words there must be a possibility of forecasting the effect of a change by a "dry run" mechanism before actually installing the change. This will be an application of the protocol rather than a feature of the protocol itself.
- o Management logging, monitoring, alerts and tools for intervention are required. However, these can only be features of individual ASAs. Another document [[I-D.eckert-anima-stable-connectivity](#)] discusses how such agents may be linked into conventional OAM systems via an Autonomic Control Plane [[I-D.ietf-anima-autonomic-control-plane](#)].

SN8. The protocol will be able to deal with a wide variety of technical objectives, covering any type of network parameter. Therefore the protocol will need either an explicit information model describing its messages, or at least a flexible and easily extensible message format. One design consideration is whether to adopt an existing information model or to design a new one.

### **[2.3. Specific Technical Requirements](#)**

T1. It should be convenient for ASA designers to define new technical objectives and for programmers to express them, without excessive impact on run-time efficiency and footprint. The classes



of device in which the protocol might run is discussed in [\[I-D.behringer-anima-reference-model\]](#).

T2. The protocol should be easily extensible in case the initially defined discovery, synchronization and negotiation mechanisms prove to be insufficient.

T3. To be a generic platform, the protocol payload format should be independent of the transport protocol or IP version. In particular, it should be able to run over IPv6 or IPv4. However, some functions, such as multicasting on a link, might need to be IP version dependent. In case of doubt, IPv6 should be preferred.

T4. The protocol must be able to access off-link counterparts via routable addresses, i.e., must not be restricted to link-local operation.

T5. It must also be possible for an external discovery mechanism to be used, if appropriate for a given technical objective. In other words, GRASP discovery must not be a prerequisite for GRASP negotiation or synchronization; the prerequisite is discovering a peer's locator by any method.

T6. ASAs and the signaling protocol need to run asynchronously when wait states occur.

T7. Intent: There must be provision for general Intent rules to be applied by all devices in the network (e.g., security rules, prefix length, resource sharing rules). However, Intent distribution might not use the signaling protocol itself, but its design should not exclude such use.

T8. Management monitoring, alerts and intervention: Devices should be able to report to a monitoring system. Some events must be able to generate operator alerts and some provision for emergency intervention must be possible (e.g. to freeze synchronization or negotiation in a mis-behaving device). These features might not use the signaling protocol itself, but its design should not exclude such use.

T9. The protocol needs to be fully secured against forged messages and man-in-the middle attacks, and secured as much as reasonably possible against denial of service attacks. It needs to be capable of encryption in order to resist unwanted monitoring. However, it is not required that the protocol itself provides these security features; it may depend on an existing secure environment.





### **3. GRASP Protocol Overview**

#### **3.1. Terminology**

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 [\[RFC2119\]](#) when they appear in ALL CAPS. When these words are not in ALL CAPS (such as "should" or "Should"), they have their usual English meanings, and are not to be interpreted as [\[RFC2119\]](#) key words.

This document uses terminology defined in [\[RFC7575\]](#).

The following additional terms are used throughout this document:

- o Autonomic Device: identical to Autonomic Node.
- o Discovery: a process by which an ASA discovers peers according to a specific discovery objective. The discovery results may be different according to the different discovery objectives. The discovered peers may later be used as negotiation counterparts or as sources of synchronization data.
- o Negotiation: a process by which two (or more) ASAs interact iteratively to agree on parameter settings that best satisfy the objectives of one or more ASAs.
- o State Synchronization: a process by which two (or more) ASAs interact to agree on the current state of parameter values stored in each ASA. This is a special case of negotiation in which information is sent but the ASAs do not request their peers to change parameter settings. All other definitions apply to both negotiation and synchronization.
- o Technical Objective (usually abbreviated as Objective): A technical objective is a configurable parameter or set of parameters of some kind, which occurs in three contexts: Discovery, Negotiation and Synchronization. In the protocol, an objective is represented by an identifier and if relevant a value. Normally, a given objective will occur during discovery and negotiation, or during discovery and synchronization, but not in all three contexts.
  - \* One ASA may support multiple independent objectives.
  - \* The parameter described by a given objective is naturally based on a specific service or function or action. It may in



principle be anything that can be set to a specific logical, numerical or string value, or a more complex data structure, by a network node. That node is generally expected to contain an ASA which may itself manage other nodes.

- \* Discovery Objective: if a node needs to synchronize or negotiate a specific objective but does not know a peer that supports this objective, it starts a discovery process. The objective is called a Discovery Objective during this process.
- \* Synchronization Objective: an objective whose specific technical content needs to be synchronized among two or more ASAs.
- \* Negotiation Objective: an objective whose specific technical content needs to be decided in coordination with another ASA.
- o Discovery Initiator: an ASA that spontaneously starts discovery by sending a discovery message referring to a specific discovery objective.
- o Discovery Responder: a peer ASA which responds to the discovery objective initiated by the discovery initiator.
- o Synchronization Initiator: an ASA that spontaneously starts synchronization by sending a request message referring to a specific synchronization objective.
- o Synchronization Responder: a peer ASA which responds with the value of a synchronization objective.
- o Negotiation Initiator: an ASA that spontaneously starts negotiation by sending a request message referring to a specific negotiation objective.
- o Negotiation Counterpart: a peer with which the Negotiation Initiator negotiates a specific negotiation objective.

### **3.2. High-Level Design Choices**

This section describes a behavior model and some considerations for designing a generic signaling protocol initially supporting discovery, synchronization and negotiation, which can act as a platform for different technical objectives.

- o A generic platform



The protocol is designed as a generic platform, which is independent from the synchronization or negotiation contents. It takes care of the general intercommunication between counterparts. The technical contents will vary according to the various technical objectives and the different pairs of counterparts.

- o The protocol is expected to form part of an Autonomic Networking Infrastructure [[I-D.behringer-anima-reference-model](#)]. It will provide services to ASAs via a suitable application programming interface, which will reflect the protocol elements but will not necessarily be in one-to-one correspondence to them. It is expected that a single instance of GRASP will exist in an autonomic node, and that the protocol engine and each ASA will run as independent asynchronous processes.

- o Security infrastructure and trust relationship

Because this negotiation protocol may directly cause changes to device configurations and bring significant impacts to a running network, this protocol is assumed to run within an existing secure environment with strong authentication.

On the other hand, a limited negotiation model might be deployed based on a limited trust relationship. For example, between two administrative domains, ASAs might also exchange limited information and negotiate some particular configurations based on a limited conventional or contractual trust relationship.

- o Discovery, synchronization and negotiation are designed together.

The discovery method and the synchronization and negotiation methods are designed in the same way and can be combined when this is useful. These processes can also be performed independently when appropriate.

- \* GRASP discovery is always available for efficient discovery of GRASP peers and allows a rapid mode of operation described in [Section 3.3.3](#). For some objectives, especially those concerned with application layer services, another discovery mechanism such as the future DNS Service Discovery [[RFC7558](#)] or Service Location Protocol [[RFC2608](#)] MAY be used. The choice is left to the designers of individual ASAs.

- o A uniform pattern for technical contents



The synchronization and negotiation contents are defined according to a uniform pattern. They could be carried either in simple binary format or in payloads described by a flexible language. The basic protocol design uses the Concise Binary Object Representation (CBOR) [[RFC7049](#)]. The format is extensible for unknown future requirements.

- o A flexible model for synchronization

GRASP supports bilateral synchronization, which could be used to perform synchronization among a small number of nodes. It also supports an unsolicited flooding mode when large groups of nodes, possibly including all autonomic nodes, need data for the same technical objective.

- \* There may be some network parameters for which a more traditional flooding mechanism such as DNCP [[I-D.ietf-homenet-dncp](#)] is considered more appropriate. GRASP can coexist with DNCP.

- o A simple initiator/responder model for negotiation

Multi-party negotiations are too complicated to be modeled and there might be too many dependencies among the parties to converge efficiently. A simple initiator/responder model is more feasible and can complete multi-party negotiations by indirect steps.

- o Organizing of synchronization or negotiation content

Naturally, the technical content will be organized according to the relevant function or service. The content from different functions or services is kept independent from each other. They are not combined into a single option or single session because these contents may be negotiated or synchronized with different counterparts or may be different in response time.

- o Self-aware network device

Every autonomic device will be pre-loaded with various functions and ASAs and will be aware of its own capabilities, typically decided by the hardware, firmware or pre-installed software. Its exact role may depend on Intent and on the surrounding network behaviors, which may include forwarding behaviors, aggregation properties, topology location, bandwidth, tunnel or translation





properties, etc. The surrounding topology will depend on the network planning. Following an initial discovery phase, the device properties and those of its neighbors are the foundation of the synchronization or negotiation behavior of a specific device. A device has no pre-configuration for the particular network in which it is installed.

- o Requests and responses in negotiation procedures

The initiator can negotiate with its relevant negotiation counterpart ASAs, which may be different according to the specific negotiation objective. It can request relevant information from the negotiation counterpart so that it can decide its local configuration to give the most coordinated performance. It can request the negotiation counterpart to make a matching configuration in order to set up a successful communication with it. It can request certain simulation or forecast results by sending some dry run conditions.

Beyond the traditional yes/no answer, the responder can reply with a suggested alternative if its answer is 'no'. This would start a bi-directional negotiation ending in a compromise between the two ASAs.

- o Convergence of negotiation procedures

To enable convergence, when a responder makes a suggestion of a changed condition in a negative reply, it should be as close as possible to the original request or previous suggestion. The suggested value of the third or later negotiation steps should be chosen between the suggested values from the last two negotiation steps. In any case there must be a mechanism to guarantee convergence (or failure) in a small number of steps, such as a timeout or maximum number of iterations.

- \* End of negotiation

A limited number of rounds, for example three, or a timeout, is needed on each ASA for each negotiation objective. It may be an implementation choice, a pre-configurable parameter, or network Intent. These choices might vary between different types of ASA. Therefore, the definition of each negotiation objective MUST clearly specify this, so that the negotiation can always be terminated properly.



- \* Failed negotiation

There must be a well-defined procedure for concluding that a negotiation cannot succeed, and if so deciding what happens next (deadlock resolution, tie-breaking, or revert to best-effort service). Again, this MUST be specified for individual negotiation objectives, as an implementation choice, a pre-configurable parameter, or network Intent.

### **3.3. GRASP Protocol Basic Properties and Mechanisms**

#### **3.3.1. Required External Security Mechanism**

The protocol SHOULD run within a secure Autonomic Control Plane (ACP) [[I-D.ietf-anima-autonomic-control-plane](#)]. The ACP is assumed to carry all messages securely, including link-local multicast if possible. A GRASP implementation MUST verify whether the ACP is operational.

If there is no ACP, the protocol MUST use another form of strong authentication and SHOULD use a form of strong encryption. TLS [[RFC5246](#)] is RECOMMENDED for this purpose, based on a local Public Key Infrastructure (PKI) [[RFC5280](#)] managed within the autonomic network itself. The details of such a PKI and how its boundary is established are out of scope for this document. DTLS [[RFC6347](#)] MAY be used but since GRASP operations usually involve several messages this is not expected to be advantageous.

The ACP, or in its absence the local PKI, sets the boundary within which nodes are trusted as GRASP peers. A GRASP implementation MUST refuse to execute any GRASP functions except discovery if there is neither an operational ACP nor an operational TLS environment.

As mentioned in [Section 3.2](#), limited GRASP operations might be performed across an administrative domain boundary by mutual agreement. Such operations MUST be authenticated and SHOULD be encrypted. TLS is RECOMMENDED for this purpose.

Link-local multicast is used for discovery messages. Responses to discovery messages MUST be secured, with one exception.

The exception is that during initialisation, before a node has joined the applicable trust infrastructure, e.g., [[I-D.ietf-anima-bootstrap-keyinfra](#)], or before the ACP is fully established, it might be impossible to secure messages. Indeed, both the security bootstrap process and the ACP creation process might use insecure GRASP discovery and response messages. Such usage MUST be



limited to the strictly necessary minimum. A full analysis of the initialisation process is out of scope for the present document.

### **3.3.2. Transport Layer Usage**

GRASP discovery and flooding messages are designed for use over link-local multicast UDP. They MUST NOT be fragmented, and therefore MUST NOT exceed the link MTU size. Nothing in principle prevents them from working over some other method of sending packets to all on-link neighbors, but this is out of scope for the present specification.

All other GRASP messages are unicast and could in principle run over any transport protocol. An implementation MUST support use of TCP. It MAY support use of another transport protocol. However, GRASP itself does not provide for error detection or retransmission. Use of an unreliable transport protocol is therefore NOT RECOMMENDED.

When running within a secure ACP on reliable infrastructure, UDP MAY be used for unicast messages not exceeding the minimum IPv6 path MTU; however, TCP MUST be used for longer messages. In other words, IPv6 fragmentation is avoided. If a node receives a UDP message but the reply is too long, it MUST open a TCP connection to the peer for the reply. Note that when the network is under heavy load or in a fault condition, UDP might become unreliable. Since this is when autonomic functions are most necessary, automatic fallback to TCP MUST be implemented. The simplest implementation is therefore to use only TCP.

When running without an ACP, TLS MUST be supported and used by default, except for link-local multicast messages. DTLS MAY be supported as an alternative but the details are out of scope for this document.

For all transport protocols, the GRASP protocol listens to the GRASP Listen Port ([Section 3.5](#)).

### **3.3.3. Discovery Mechanism and Procedures**

- o Separated discovery and negotiation mechanisms

Although discovery and negotiation or synchronization are defined together in the GRASP, they are separated mechanisms. The discovery process could run independently from the negotiation or synchronization process. Upon receiving a Discovery ([Section 3.7.3](#)) message, the recipient ASA should return a response message in which it either indicates itself as a discovery responder or diverts the initiator towards another more suitable ASA.



The discovery action will normally be followed by a negotiation or synchronization action. The discovery results could be utilized by the negotiation protocol to decide which ASA the initiator will negotiate with.

It is entirely possible to use GRASP discovery without a subsequent negotiation or synchronization action. In this case, the discovered objective is simply used as a name during the discovery process and any subsequent operations between the peers are outside the scope of GRASP.

#### o Discovery Procedures

Discovery starts as an on-link operation. The Divert option can tell the discovery initiator to contact an off-link ASA for that discovery objective. Every Discovery message is sent by a discovery initiator via UDP to the ALL\_GRASP\_NEIGHBOR multicast address ([Section 3.5](#)). Every network device that supports the GRASP always listens to a well-known UDP port to capture the discovery messages.

If an ASA in the neighbor device supports the requested discovery objective, it MAY respond with a Discovery Response message ([Section 3.7.4](#)) with locator option(s). Otherwise, if the neighbor has cached information about an ASA that supports the requested discovery objective (usually because it discovered the same objective before), it SHOULD respond with a Discovery Response message with a Divert option pointing to the appropriate Discovery Responder.

If no discovery response is received within a reasonable timeout (default GRASP\_DEF\_TIMEOUT milliseconds, [Section 3.5](#)), the Discovery message MAY be repeated, with a newly generated Session ID ([Section 3.6](#)). An exponential backoff SHOULD be used for subsequent repetitions, in order to mitigate possible denial of service attacks.

After a GRASP device successfully discovers a Discovery Responder supporting a specific objective, it MUST cache this information. This cache record MAY be used for future negotiation or synchronization, and SHOULD be passed on when appropriate as a Divert option to another Discovery Initiator. The cache lifetime is an implementation choice that MAY be modified by network Intent.

If multiple Discovery Responders are found for the same objective, they SHOULD all be cached, unless this creates a resource shortage. The method of choosing between multiple





responders is an implementation choice. This choice MUST be available to each ASA but the GRASP implementation SHOULD provide a default choice.

Because Discovery Responders will be cached in a finite cache, they might be deleted at any time. In this case, discovery will need to be repeated. If an ASA exits for any reason, its locator might still be cached for some time, and attempts to connect to it will fail. ASAs need to be robust in these circumstances.

A GRASP device with multiple link-layer interfaces (typically a router) MUST support discovery on all interfaces. If it receives a Discovery message on a given interface for a specific objective that it does not support and for which it has not previously cached a Discovery Responder, it MUST relay the query by re-issuing a Discovery message on its other interfaces. The relayed message MUST have a new Session ID. Before this, it MUST decrement the loop count within the objective, and MUST NOT relay the Discovery message if the result is zero. Also, it MUST limit the total rate at which it relays discovery messages to a reasonable value, in order to mitigate possible denial of service attacks. It MUST cache the Session ID value of each relayed discovery message and, to prevent loops, MUST NOT relay a Discovery message which carries such a cached Session ID. These precautions avoid discovery loops and mitigate potential overload.

This relayed discovery mechanism, with caching of the results, should be sufficient to support most network bootstrapping scenarios.

- o A complete discovery process will start with a multicast on the local link. On-link neighbors supporting the discovery objective will respond directly. A neighbor with multiple interfaces will respond with a cached discovery response if any. If not, it will relay the discovery on its other interfaces, for example reaching a higher-level gateway in a hierarchical network. If a node receiving the relayed discovery supports the discovery objective, it will respond to the relayed discovery. If it has a cached response, it will respond with that. If not, it will repeat the discovery process, which thereby becomes recursive. The loop count and timeout will ensure that the process ends.
- o Rapid Mode (Discovery/Negotiation binding)

A Discovery message MAY include a Negotiation Objective option. This allows a rapid mode of negotiation described in



[Section 3.3.4](#). A similar mechanism is defined for synchronization in [Section 3.3.5](#).

#### **[3.3.4](#). Negotiation Procedures**

A negotiation initiator sends a negotiation request to a counterpart ASA, including a specific negotiation objective. It may request the negotiation counterpart to make a specific configuration. Alternatively, it may request a certain simulation or forecast result by sending a dry run configuration. The details, including the distinction between dry run and an actual configuration change, will be defined separately for each type of negotiation objective.

If no reply message of any kind is received within a reasonable timeout (default GRASP\_DEF\_TIMEOUT milliseconds, [Section 3.5](#)), the negotiation request MAY be repeated, with a newly generated Session ID ([Section 3.6](#)). An exponential backoff SHOULD be used for subsequent repetitions.

If the counterpart can immediately apply the requested configuration, it will give an immediate positive (accept) answer. This will end the negotiation phase immediately. Otherwise, it will negotiate. It will reply with a proposed alternative configuration that it can apply (typically, a configuration that uses fewer resources than requested by the negotiation initiator). This will start a bi-directional negotiation to reach a compromise between the two ASAs.

The negotiation procedure is ended when one of the negotiation peers sends a Negotiation Ending message, which contains an accept or decline option and does not need a response from the negotiation peer. Negotiation may also end in failure (equivalent to a decline) if a timeout is exceeded or a loop count is exceeded.

A negotiation procedure concerns one objective and one counterpart. Both the initiator and the counterpart may take part in simultaneous negotiations with various other ASAs, or in simultaneous negotiations about different objectives. Thus, GRASP is expected to be used in a multi-threaded mode. Certain negotiation objectives may have restrictions on multi-threading, for example to avoid over-allocating resources.

Some configuration actions, for example wavelength switching in optical networks, might take considerable time to execute. The ASA concerned needs to allow for this by design, but GRASP does allow for a peer to insert latency in a negotiation process if necessary ([Section 3.7.8](#)).



#### **3.3.4.1. Rapid Mode (Discovery/Negotiation Linkage)**

A Discovery message MAY include a Negotiation Objective option. In this case the Discovery message also acts as a Request Negotiation message to indicate to the Discovery Responder that it could directly reply to the Discovery Initiator with a Negotiation message for rapid processing, if it could act as the corresponding negotiation counterpart. However, the indication is only advisory not prescriptive.

This rapid mode could reduce the interactions between nodes so that a higher efficiency could be achieved. This rapid negotiation function SHOULD be configured off by default and MAY be configured on or off by Intent.

#### **3.3.5. Synchronization and Flooding Procedure**

A synchronization initiator sends a synchronization request to a counterpart, including a specific synchronization objective. The counterpart responds with a Synchronization message ([Section 3.7.9](#)) containing the current value of the requested synchronization objective. No further messages are needed.

If no reply message of any kind is received within a reasonable timeout (default GRASP\_DEF\_TIMEOUT milliseconds, [Section 3.5](#)), the synchronization request MAY be repeated, with a newly generated Session ID ([Section 3.6](#)). An exponential backoff SHOULD be used for subsequent repetitions.

##### **3.3.5.1. Flooding**

In the case just described, the message exchange is unicast and concerns only one synchronization objective. For large groups of nodes requiring the same data, synchronization flooding is available. For this, a flooding initiator MAY send an unsolicited Flood Synchronization message containing one or more Synchronization Objective option(s), if and only if the specification of those objectives permits it. This is sent as a multicast message to the ALL\_GRASP\_NEIGHBOR multicast address ([Section 3.5](#)). To ensure that flooding does not result in a loop, the originator of the Flood Synchronization message MUST set the loop count in the objectives to a suitable value (the default is GRASP\_DEF\_LOOPCT). In this case a suitable mechanism is needed to avoid excessive multicast traffic. This mechanism MUST be defined as part of the specification of the synchronization objective(s) concerned. It might be a simple rate limit or a more complex mechanism such as the Trickle algorithm [[RFC6206](#)].



A GRASP device with multiple link-layer interfaces (typically a router) MUST support synchronization flooding on all interfaces. If it receives a multicast Flood Synchronization message on a given interface, it MUST relay it by re-issuing a Flood Synchronization message on its other interfaces. The relayed message MUST have a new Session ID. Before this, it MUST decrement the loop count within the objective, and MUST NOT relay the Flood Synchronization message if the result is zero. Also, it MUST limit the total rate at which it relays Flood Synchronization messages to a reasonable value, in order to mitigate possible denial of service attacks. It MUST cache the Session ID value of each relayed Flood Synchronization message and, to prevent loops, MUST NOT relay a Flood Synchronization message which carries such a cached Session ID. These precautions avoid synchronization loops and mitigate potential overload.

Note that this mechanism is unreliable in the case of sleeping nodes. Sleeping nodes that require an objective subject to flooding SHOULD periodically request unicast synchronization for that objective.

The multicast messages for synchronization flooding are subject to the security rules in [Section 3.3.1](#). In practice this means that they MUST NOT be transmitted and MUST be ignored on receipt unless there is an operational ACP. However, because of the security weakness of link-local multicast ([Section 4](#)), synchronization objectives that are flooded SHOULD NOT contain unencrypted sensitive information and SHOULD be validated by the recipient ASA.

#### **[3.3.5.2](#). Rapid Mode (Discovery/Synchronization Linkage)**

A Discovery message MAY include a Synchronization Objective option. In this case the Discovery message also acts as a Request Synchronization message to indicate to the Discovery Responder that it could directly reply to the Discovery Initiator with a Synchronization message [Section 3.7.9](#) with synchronization data for rapid processing, if the discovery target supports the corresponding synchronization objective. However, the indication is only advisory not prescriptive.

This rapid mode could reduce the interactions between nodes so that a higher efficiency could be achieved. This rapid synchronization function SHOULD be configured off by default and MAY be configured on or off by Intent.

### **[3.4](#). High Level Deployment Model**

It is expected that a GRASP implementation will reside in an autonomic node that also contains both the appropriate security environment (preferably the ACP) and one or more Autonomic Service





Agents (ASAs). In the minimal case of a single-purpose device, these three components might be fully integrated. A more common model is expected to be a multi-purpose device capable of containing several ASAs. In this case it is expected that the ACP, GRASP and the ASAs will be implemented as separate processes, which are probably multi-threaded to support asynchronous operation. It is expected that GRASP will access the ACP by using a typical socket interface. Well defined Application Programming Interfaces (APIs) will be needed between GRASP and the ASAs. For further details of possible deployment models, see [[I-D.behringer-anima-reference-model](#)].

### 3.5. GRASP Constants

#### o ALL\_GRASP\_NEIGHBOR

A link-local scope multicast address used by a GRASP-enabled device to discover GRASP-enabled neighbor (i.e., on-link) devices. All devices that support GRASP are members of this multicast group.

\* IPv6 multicast address: TBD1

\* IPv4 multicast address: TBD2

#### o GRASP\_LISTEN\_PORT (TBD3)

A UDP and TCP port that every GRASP-enabled network device always listens to.

#### o GRASP\_DEF\_TIMEOUT (60000 milliseconds)

The default timeout used to determine that a discovery etc. has failed to complete.

#### o GRASP\_DEF\_LOOPCT (6)

The default loop count used to determine that a negotiation has failed to complete, and to avoid looping messages.

### 3.6. Session Identifier (Session ID)

This is an up to 24-bit opaque value used to distinguish multiple sessions between the same two devices. A new Session ID MUST be generated by the initiator for every new Discovery, Flood Synchronization or Request message. All responses and follow-up messages in the same discovery, synchronization or negotiation procedure MUST carry the same Session ID.



The Session ID SHOULD have a very low collision rate locally. It MUST be generated by a pseudo-random algorithm using a locally generated seed which is unlikely to be used by any other device in the same network [[RFC4086](#)].

However, there is a finite probability that two nodes might generate the same Session ID value. For that reason, when a Session ID is communicated via GRASP, the receiving node MUST tag it with the initiator's IP address to allow disambiguation. Multicast GRASP messages, which may be relayed between links, therefore require a new Session ID each time they are relayed.

### **[3.7.](#) GRASP Messages**

#### **[3.7.1.](#) Message Overview**

This section defines the GRASP message format and message types. Message types not listed here are reserved for future use.

The messages currently defined are:

Discovery and Discovery Response.

Request Negotiation, Negotiation, Confirm Waiting and Negotiation End.

Request Synchronization, Synchronization, and Flood Synchronization.

No Operation.

#### **[3.7.2.](#) GRASP Message Format**

GRASP messages share an identical header format and a variable format area for options. GRASP message headers and options are transmitted in Concise Binary Object Representation (CBOR) [[RFC7049](#)]. In this specification, they are described using CBOR data definition language (CDDL) [[I-D.greevenbosch-appsawg-cbor-cddl](#)]. Fragmentary CDDL is used to describe each item in this section. A complete and normative CDDL specification of GRASP is given in [Section 5](#), including constants such as message types.

Every GRASP message, except the No Operation message, carries a Session ID ([Section 3.6](#)). Options are then presented serially in the options field.

In fragmentary CDDL, every GRASP message follows the pattern:



```
grasp-message = (message .within message-structure) / noop-message
```

```
message-structure = [MESSAGE_TYPE, session-id, +grasp-option]
```

```
MESSAGE_TYPE = 1..255
```

```
session-id = 0..16777215 ;up to 24 bits
```

```
grasp-option = any
```

The MESSAGE\_TYPE indicates the type of the message and thus defines the expected options. Any options received that are not consistent with the MESSAGE\_TYPE SHOULD be silently discarded.

The No Operation (noop) message is described in [Section 3.7.11](#).

The various MESSAGE\_TYPE values are defined in [Section 5](#).

All other message elements are described below and formally defined in [Section 5](#).

### **[3.7.3](#). Discovery Message**

In fragmentary CDDL, a Discovery message follows the pattern:

```
discovery-message = [M_DISCOVERY, session-id, objective]
```

A discovery initiator sends a Discovery message to initiate a discovery process for a particular objective option.

The discovery initiator sends the Discovery messages to the link-local ALL\_GRASP\_NEIGHBOR multicast address for discovery, and stores the discovery results (including responding discovery objectives and corresponding unicast addresses, FQDNs or URIs).

A Discovery message MUST include exactly one of the following:

- o a discovery objective option ([Section 3.9.1](#)). Its loop count MUST be set to a suitable value to prevent discovery loops (default value is GRASP\_DEF\_LOOPCT).
- o a negotiation objective option ([Section 3.9.1](#)). This is used both for the purpose of discovery and to indicate to the discovery target that it MAY directly reply to the discovery initiator with a Negotiation message for rapid processing, if it could act as the corresponding negotiation counterpart. The sender of such a Discovery message MUST initialize a negotiation timer and loop count in the same way as a Request Negotiation message ([Section 3.7.5](#)).



- o a synchronization objective option ([Section 3.9.1](#)). This is used both for the purpose of discovery and to indicate to the discovery target that it MAY directly reply to the discovery initiator with a Synchronization message for rapid processing, if it could act as the corresponding synchronization counterpart. Its loop count MUST be set to a suitable value to prevent discovery loops (default value is GRASP\_DEF\_LOOPCT).

#### **[3.7.4.](#) Discovery Response Message**

In fragmentary CDDL, a Discovery Response message follows the pattern:

```
response-message = [M_RESPONSE, session-id,  
                    (+locator-option // divert-option), ?objective)]
```

A node which receives a Discovery message SHOULD send a Discovery Response message if and only if it can respond to the discovery. It MAY include a copy of the discovery objective from the Discovery message.

If the responding node supports the discovery objective of the discovery, it MUST include at least one kind of locator option ([Section 3.8.5](#)) to indicate its own location. A sequence of multiple kinds of locator options (e.g. IP address option and FQDN option) is also valid.

If the responding node itself does not support the discovery objective, but it knows the locator of the discovery objective, then it SHOULD respond to the discovery message with a divert option ([Section 3.8.2](#)) embedding a locator option or a combination of multiple kinds of locator options which indicate the locator(s) of the discovery objective.

#### **[3.7.5.](#) Request Messages**

In fragmentary CDDL, Request Negotiation and Request Synchronization messages follow the patterns:

```
request-negotiation-message = [M_REQ_NEG, session-id, objective]
```

```
request-synchronization-message = [M_REQ_SYN, session-id, objective]
```

A negotiation or synchronization requesting node sends the appropriate Request message to the unicast address (directly stored





or resolved from an FQDN) of the negotiation or synchronization counterpart (selected from the discovery results).

A Request message MUST include the relevant objective option. In the case of Request Negotiation, the objective option MUST include the requested value.

When an initiator sends a Request Negotiation message, it MUST initialize a negotiation timer for the new negotiation thread with the value GRASP\_DEF\_TIMEOUT milliseconds. Unless this timeout is modified by a Confirm Waiting message ([Section 3.7.8](#)), the initiator will consider that the negotiation has failed when the timer expires.

When an initiator sends a Request message, it MUST initialize the loop count of the objective option with a value defined in the specification of the option or, if no such value is specified, with GRASP\_DEF\_LOOPCT.

If a node receives a Request message for an objective for which no ASA is currently listening, it MUST immediately close the relevant socket to indicate this to the initiator.

#### **3.7.6. Negotiation Message**

In fragmentary CDDL, a Negotiation message follows the pattern:

```
discovery-message = [M_NEGOTIATE, session-id, objective]
```

A negotiation counterpart sends a Negotiation message in response to a Request Negotiation message, a Negotiation message, or a Discovery message in Rapid Mode. A negotiation process MAY include multiple steps.

The Negotiation message MUST include the relevant Negotiation Objective option, with its value updated according to progress in the negotiation. The sender MUST decrement the loop count by 1. If the loop count becomes zero the message MUST NOT be sent. In this case the negotiation session has failed and will time out.

#### **3.7.7. Negotiation End Message**

In fragmentary CDDL, a Negotiation End message follows the pattern:

```
end-message = [M_END, session-id, accept-option / decline-option]
```

A negotiation counterpart sends an Negotiation End message to close the negotiation. It MUST contain either an accept or a decline



option, defined in [Section 3.8.3](#) and [Section 3.8.4](#). It could be sent either by the requesting node or the responding node.

#### **[3.7.8](#). Confirm Waiting Message**

In fragmentary CDDL, a Confirm Waiting message follows the pattern:

```
wait-message = [M_WAIT, session-id, waiting-time]
waiting-time = 0..4294967295 ; in milliseconds
```

A responding node sends a Confirm Waiting message to ask the requesting node to wait for a further negotiation response. It might be that the local process needs more time or that the negotiation depends on another triggered negotiation. This message **MUST NOT** include any other options. When received, the waiting time value overwrites and restarts the current negotiation timer ([Section 3.7.5](#)).

The responding node **SHOULD** send a Negotiation, Negotiation End or another Confirm Waiting message before the negotiation timer expires. If not, the initiator **MUST** abandon or restart the negotiation procedure, to avoid an indefinite wait.

#### **[3.7.9](#). Synchronization Message**

In fragmentary CDDL, a Synchronization message follows the pattern:

```
synch-message = [M_SYNCH, session-id, objective]
```

A node which receives a Request Synchronization, or a Discovery message in Rapid Mode, sends back a unicast Synchronization message with the synchronization data, in the form of a GRASP Option for the specific synchronization objective present in the Request Synchronization.

#### **[3.7.10](#). Flood Synchronization Message**

In fragmentary CDDL, a Flood Synchronization message follows the pattern:

```
flood-message = [M_FLOOD, session-id, +objective]
```

A node **MAY** initiate flooding by sending an unsolicited Flood Synchronization Message with synchronization data. This **MAY** be sent to the link-local ALL\_GRASP\_NEIGHBOR multicast address, in accordance with the rules in [Section 3.3.5](#). The synchronization data will be in the form of GRASP Option(s) for specific synchronization



objective(s). The loop count(s) **MUST** be set to a suitable value to prevent flood loops (default value is GRASP\_DEF\_LOOPCT).

A node that receives a Flood Synchronization message **SHOULD** cache the received objectives for use by local ASAs.

#### **3.7.11. No Operation Message**

In fragmentary CDDL, a No Operation message follows the pattern:

```
noop-message = [M_NOOP]
```

This message **MAY** be sent by an implementation that for practical reasons needs to activate a socket. It **MUST** be silently ignored by a recipient.

### **3.8. GRASP Options**

This section defines the GRASP options for the negotiation and synchronization protocol signaling. Additional options may be defined in the future.

#### **3.8.1. Format of GRASP Options**

GRASP options are CBOR objects that **MUST** start with an unsigned integer identifying the specific option type carried in this option. These option types are formally defined in [Section 5](#). Apart from that the only format requirement is that each option **MUST** be a well-formed CBOR object. In general a CBOR array format is **RECOMMENDED** to limit overhead.

GRASP options are usually scoped by using encapsulation. However, this is not a requirement

#### **3.8.2. Divert Option**

The Divert option is used to redirect a GRASP request to another node, which may be more appropriate for the intended negotiation or synchronization. It may redirect to an entity that is known as a specific negotiation or synchronization counterpart (on-link or off-link) or a default gateway. The divert option **MUST** only be encapsulated in Discovery Response messages. If found elsewhere, it **SHOULD** be silently ignored.

In fragmentary CDDL, the Divert option follows the pattern:

```
divert-option = [O_DIVERT, +locator-option]
```



The embedded Locator Option(s) ([Section 3.8.5](#)) point to diverted destination target(s) in response to a Discovery message.

### **3.8.3. Accept Option**

The accept option is used to indicate to the negotiation counterpart that the proposed negotiation content is accepted.

The accept option MUST only be encapsulated in Negotiation End messages. If found elsewhere, it SHOULD be silently ignored.

In fragmentary CDDL, the Accept option follows the pattern:

```
accept-option = [0_ACCEPT]
```

### **3.8.4. Decline Option**

The decline option is used to indicate to the negotiation counterpart the proposed negotiation content is declined and end the negotiation process.

The decline option MUST only be encapsulated in Negotiation End messages. If found elsewhere, it SHOULD be silently ignored.

In fragmentary CDDL, the Decline option follows the pattern:

```
decline-option = [0_DECLINE, ?reason]  
reason = text ;optional error message
```

Note: there are scenarios where a negotiation counterpart wants to decline the proposed negotiation content and continue the negotiation process. For these scenarios, the negotiation counterpart SHOULD use a Negotiate message, with either an objective option that contains a data field set to indicate a meaningless initial value, or a specific objective option that provides further conditions for convergence.

### **3.8.5. Locator Options**

These locator options are used to present reachability information for an ASA, a device or an interface. They are Locator IPv4 Address Option, Locator IPv6 Address Option, Locator FQDN (Fully Qualified Domain Name) Option and Uniform Resource Identifier Option.

Note: It is assumed that all locators are in scope throughout the GRASP domain. GRASP is not intended to work across disjoint addressing or naming realms.





#### **3.8.5.1. Locator IPv4 address option**

In fragmentary CDDL, the IPv4 address option follows the pattern:

```
ipv4-locator-option = bytes .size 4
```

The content of this option is a binary IPv4 address.

Note: If an operator has internal network address translation for IPv4, this option MUST NOT be used within the Divert option.

#### **3.8.5.2. Locator IPv6 address option**

In fragmentary CDDL, the IPv6 address option follows the pattern:

```
ipv6-locator-option = bytes .size 16
```

The content of this option is a binary IPv6 address.

Note 1: The IPv6 address MUST normally have global scope. Exceptionally, during node bootstrap, a link-local address MAY be used for specific objectives only.

Note 2: A link-local IPv6 address MUST NOT be used when this option is included in a Divert option.

#### **3.8.5.3. Locator FQDN option**

In fragmentary CDDL, the FQDN option follows the pattern:

```
fqdn-locator-option = [0_FQDN_LOCATOR, text]
```

The content of this option is the Fully Qualified Domain Name of the target.

Note 1: Any FQDN which might not be valid throughout the network in question, such as a Multicast DNS name [[RFC6762](#)], MUST NOT be used when this option is used within the Divert option.

Note 2: Normal GRASP operations are not expected to use this option. It is intended for special purposes such as discovering external services.

#### **3.8.5.4. Locator URI option**

In fragmentary CDDL, the URI option follows the pattern:

```
uri-locator-option = [0_URI_LOCATOR, text]
```



The content of this option is the Uniform Resource Identifier of the target [[RFC3986](#)].

Note 1: Any URI which might not be valid throughout the network in question, such as one based on a Multicast DNS name [[RFC6762](#)], MUST NOT be used when this option is used within the Divert option.

Note 2: Normal GRASP operations are not expected to use this option. It is intended for special purposes such as discovering external services.

### **[3.9.](#) Objective Options**

#### **[3.9.1.](#) Format of Objective Options**

An objective option is used to identify objectives for the purposes of discovery, negotiation or synchronization. All objectives MUST be in the following format, described in fragmentary CDDL:

```
objective = [objective-name, objective-flags, loop-count, ?any]
```

```
objective-name = text
```

```
loop-count = 0..255
```

All objectives are identified by a unique name which is a case-sensitive UTF-8 string.

The names of generic objectives MUST NOT include a colon (":") and MUST be registered with IANA ([Section 6](#)).

The names of privately defined objectives MUST include at least one colon (":"). The string preceding the last colon in the name MUST be globally unique and in some way identify the entity or person defining the objective. The following three methods MAY be used to create such a globally unique string:

1. The unique string is a decimal number representing a registered 32 bit Private Enterprise Number (PEN) [[I-D.liang-iana-pen](#)] that uniquely identifies the enterprise defining the objective.
2. The unique string is a fully qualified domain name that uniquely identifies the entity or person defining the objective.
3. The unique string is an email address that uniquely identifies the entity or person defining the objective.



The GRASP protocol treats the objective name as an opaque string. For example, "EX1", "411:EX1", "example.com:EX1", "example.org:EX1" and "user@example.org:EX1" would be five different objectives.

The 'objective-flags' field is described below.

The 'loop-count' field is used for terminating negotiation as described in [Section 3.7.6](#). It is also used for terminating discovery as described in [Section 3.3.3](#), and for terminating flooding as described in [Section 3.3.5.1](#).

The 'any' field is to express the actual value of a negotiation or synchronization objective. Its format is defined in the specification of the objective and may be a single value or a data structure of any kind. It is optional because it is optional in a Discovery or Discovery Response message.

### [3.9.2.](#) Objective flags

An objective may be relevant for discovery only, for discovery and negotiation, or for discovery and synchronization. This is expressed in the objective by logical flags:

```
objective-flags = uint .bits objective-flag
objective-flag = &(
  F_DISC: 0    ; valid for discovery only
  F_NEG: 1    ; valid for discovery and negotiation
  F_SYNCH: 2   ; valid for discovery and synchronization
)
```

### [3.9.3.](#) General Considerations for Objective Options

As mentioned above, Objective Options MUST be assigned a unique name. As long as privately defined Objective Options obey the rules above, this document does not restrict their choice of name, but the entity or person concerned SHOULD publish the names in use.

All Objective Options MUST respect the CBOR patterns defined above as "objective" and MUST replace the "any" field with a valid CBOR data definition for the relevant use case and application.

An Objective Option that contains no additional fields beyond its "loop-count" can only be a discovery objective and MUST only be used in Discovery and Discovery Response messages.

The Negotiation Objective Options contain negotiation objectives, which vary according to different functions/services. They MUST be carried by Discovery, Request Negotiation or Negotiation messages



only. The negotiation initiator **MUST** set the initial "loop-count" to a value specified in the specification of the objective or, if no such value is specified, to GRASP\_DEF\_LOOPCT.

For most scenarios, there should be initial values in the negotiation requests. Consequently, the Negotiation Objective options **MUST** always be completely presented in a Request Negotiation message, or in a Discovery message in rapid mode. If there is no initial value, the bits in the value field **SHOULD** all be set to indicate a meaningless value, unless this is inappropriate for the specific negotiation objective.

Synchronization Objective Options are similar, but **MUST** be carried by Discovery, Discovery Response, Request Synchronization, or Flood Synchronization messages only. They include value fields only in Synchronization or Flood Synchronization messages.

#### **3.9.4. Organizing of Objective Options**

Generic objective options **MUST** be specified in documents available to the public and **SHOULD** be designed to use either the negotiation or the synchronization mechanism described above.

As noted earlier, one negotiation objective is handled by each GRASP negotiation thread. Therefore, a negotiation objective, which is based on a specific function or action, **SHOULD** be organized as a single GRASP option. It is **NOT RECOMMENDED** to organize multiple negotiation objectives into a single option, nor to split a single function or action into multiple negotiation objectives.

It is important to understand that GRASP negotiation does not support transactional integrity. If transactional integrity is needed for a specific objective, this must be ensured by the ASA. For example, an ASA might need to ensure that it only participates in one negotiation thread at the same time. Such an ASA would need to stop listening for incoming negotiation requests before generating an outgoing negotiation request.

A synchronization objective **SHOULD** be organized as a single GRASP option.

Some objectives will support more than one operational mode. An example is a negotiation objective with both a "dry run" mode (where the negotiation is to find out whether the other end can in fact make the requested change without problems) and a "live" mode. Such modes will be defined in the specification of such an objective. These objectives **SHOULD** include flags indicating the applicable mode(s).





An objective may have multiple parameters. Parameters can be categorized into two classes: the obligatory ones presented as fixed fields; and the optional ones presented in CBOR sub-options or some other form of data structure embedded in CBOR. The format might be inherited from an existing management or configuration protocol, the objective option acting as a carrier for that format. The data structure might be defined in a formal language, but that is a matter for the specifications of individual objectives. There are many candidates, according to the context, such as ABNF, RBNF, XML Schema, possibly YANG, etc. The GRASP protocol itself is agnostic on these questions.

It is NOT RECOMMENDED to split parameters in a single objective into multiple options, unless they have different response periods. An exception scenario may also be described by split objectives.

All objectives MUST support GRASP discovery. However, as mentioned in [Section 3.2](#), it is acceptable for an ASA to use an alternative method of discovery.

Normally, a GRASP objective will refer to specific technical parameters as explained in [Section 3.1](#). However, it is acceptable to define an abstract objective for the purpose of managing or coordinating ASAs. It is also acceptable to define a special-purpose objective for purposes such as trust bootstrapping or formation of the ACP.

#### **[3.9.5](#). Experimental and Example Objective Options**

The names "EX0" through "EX9" have been reserved for experimental options. Multiple names have been assigned because a single experiment may use multiple options simultaneously. These experimental options are highly likely to have different meanings when used for different experiments. Therefore, they SHOULD NOT be used without an explicit human decision and SHOULD NOT be used in unmanaged networks such as home networks.

These names are also RECOMMENDED for use in documentation examples.

## **[4](#). Security Considerations**

It is obvious that a successful attack on negotiation-enabled nodes would be extremely harmful, as such nodes might end up with a completely undesirable configuration that would also adversely affect their peers. GRASP nodes and messages therefore require full protection.

- Authentication



A cryptographically authenticated identity for each device is needed in an autonomic network. It is not safe to assume that a large network is physically secured against interference or that all personnel are trustworthy. Each autonomic node **MUST** be capable of proving its identity and authenticating its messages. GRASP relies on a separate external certificate-based security mechanism to support authentication, data integrity protection, and anti-replay protection.

Since GRASP is intended to be deployed in a single administrative domain operating its own trust anchor and CA, there is no need for a trusted public third party. In a network requiring "air gap" security, such a dependency would be unacceptable.

If GRASP is used temporarily without an external security mechanism, for example during system bootstrap ([Section 3.3.1](#)), the Session ID ([Section 3.6](#)) will act as a nonce to provide limited protection against third parties injecting responses. A full analysis of the secure bootstrap process is out of scope for the present document.

#### - Authorization and Roles

The GRASP protocol is agnostic about the role of individual ASAs and about which objectives a particular ASA is authorized to support. It **SHOULD** apply obvious precautions such as allowing only one ASA in a given node to modify a given objective, but otherwise authorization is out of scope.

#### - Privacy and confidentiality

Generally speaking, no personal information is expected to be involved in the signaling protocol, so there should be no direct impact on personal privacy. Nevertheless, traffic flow paths, VPNs, etc. could be negotiated, which could be of interest for traffic analysis. Also, operators generally want to conceal details of their network topology and traffic density from outsiders. Therefore, since insider attacks cannot be excluded in a large network, the security mechanism for the protocol **MUST** provide message confidentiality. This is why [Section 3.3.1](#) requires either an ACP or the use of TLS.

#### - Link-local multicast security

GRASP has no reasonable alternative to using link-local multicast for Discovery or Flood Synchronization messages and these messages are sent in clear and with no authentication. They are therefore available to on-link eavesdroppers, and could be forged by on-link



attackers. In the case of Discovery, the Discovery Responses are unicast and will therefore be protected ([Section 3.3.1](#)), and an untrusted forger will not be able to receive responses. In the case of Flood Synchronization, an on-link eavesdropper will be able to receive the flooded objectives but there is no response message to consider. Some precautions for Flood Synchronization messages are suggested in [Section 3.3.5.1](#).

- DoS Attack Protection

GRASP discovery partly relies on insecure link-local multicast. Since routers participating in GRASP sometimes relay discovery messages from one link to another, this could be a vector for denial of service attacks. Relevant mitigations are specified in [Section 3.3.3](#). Additionally, it is of great importance that firewalls prevent any GRASP messages from entering the domain from an untrusted source.

- Security during bootstrap and discovery

A node cannot authenticate GRASP traffic from other nodes until it has identified the trust anchor and can validate certificates for other nodes. Also, until it has successfully enrolled [[I-D.ietf-anima-bootstrapping-keyinfra](#)] it cannot assume that other nodes are able to authenticate its own traffic. Therefore, GRASP discovery during the bootstrap phase for a new device will inevitably be insecure and GRASP synchronization and negotiation will be impossible until enrollment is complete.

- Security of discovered locators

When GRASP discovery returns an IP address, it MUST be that of a node within the secure environment ([Section 3.3.1](#)). If it returns an FQDN or a URI, the ASA that receives it MUST NOT assume that the target of the locator is within the secure environment.

## 5. CDDL Specification of GRASP

<CODE BEGINS>

grasp-message = (message .within message-structure) / noop-message

message-structure = [MESSAGE\_TYPE, session-id, \*grasp-option]

MESSAGE\_TYPE = 0..255

session-id = 0..16777215 ;up to 24 bits

grasp-option = any

message /= discovery-message



```
discovery-message = [M_DISCOVERY, session-id, objective]

message /= response-message ;response to Discovery
response-message = [M_RESPONSE, session-id,
                    (+locator-option // divert-option), ?objective]

message /= synch-message ;response to Synchronization request
synch-message = [M_SYNCH, session-id, objective]

message /= flood-message
flood-message = [M_FLOOD, session-id, +objective]

message /= request-negotiation-message
request-negotiation-message = [M_REQ_NEG, session-id, objective]

message /= request-synchronization-message
request-synchronization-message = [M_REQ_SYN, session-id, objective]

message /= negotiation-message
negotiation-message = [M_NEGOTIATE, session-id, objective]

message /= end-message
end-message = [M_END, session-id, accept-option / decline-option ]

message /= wait-message
wait-message = [M_WAIT, session-id, waiting-time]

noop-message = [M_NOOP]

divert-option = [O_DIVERT, +locator-option]

accept-option = [O_ACCEPT]

decline-option = [O_DECLINE, ?reason]
reason = text ;optional error message

waiting-time = 0..4294967295 ; in milliseconds

locator-option /= ipv4-locator-option
ipv4-locator-option = bytes .size 4
; this is simpler than [O_IPv4_LOCATOR, bytes .size 4]

locator-option /= ipv6-locator-option
ipv6-locator-option = bytes .size 16

locator-option /= fqdn-locator-option
fqdn-locator-option = [O_FQDN_LOCATOR, text]
```





```
locator-option /= uri-locator-option
uri-locator-option = [O_URI_LOCATOR, text]

objective-flags = uint .bits objective-flag

objective-flag = &(
  F_DISC: 0 ; valid for discovery only
  F_NEG: 1 ; valid for discovery and negotiation
  F_SYNCH: 2) ; valid for discovery and synchronization

objective = [objective-name, objective-flags, loop-count, ?any]

objective-name = text ;see specification for uniqueness rules

loop-count = 0..255

; Constants for message types and option types

M_NOOP = 0
M_DISCOVERY = 1
M_RESPONSE = 2
M_REQ_NEG = 3
M_REQ_SYN = 4
M_NEGOTIATE = 5
M_END = 6
M_WAIT = 7
M_SYNCH = 8
M_FLOOD = 9

O_DIVERT = 100
O_ACCEPT = 101
O_DECLINE = 102
O_FQDN_LOCATOR = 103
O_URI_LOCATOR = 104
<CODE ENDS>
```

## 6. IANA Considerations

This document defines the General Discovery and Negotiation Protocol (GRASP).

[Section 3.5](#) explains the following link-local multicast addresses, which IANA is requested to assign for use by GRASP:

ALL\_GRASP\_NEIGHBOR multicast address (IPv6): (TBD1). Assigned in the IPv6 Link-Local Scope Multicast Addresses registry.



ALL\_GRASP\_NEIGHBOR multicast address (IPv4): (TBD2). Assigned in the IPv4 Multicast Local Network Control Block.

[Section 3.5](#) explains the following UDP and TCP port, which IANA is requested to assign for use by GRASP:

GRASP\_LISTEN\_PORT: (TBD3)

The IANA is requested to create a GRASP Parameter Registry including two registry tables. These are the GRASP Messages and Options Table and the GRASP Objective Names Table.

GRASP Messages and Options Table. The values in this table are names paired with decimal integers. Future values MUST be assigned using the Standards Action policy defined by [\[RFC5226\]](#). The following initial values are assigned by this document:

M\_NOOP = 0  
M\_DISCOVERY = 1  
M\_RESPONSE = 2  
M\_REQUEST = 3  
M\_NEGOTIATE = 4  
M\_END = 5  
M\_WAIT = 6

O\_DIVERT = 100  
O\_ACCEPT = 101  
O\_DECLINE = 102  
O\_FQDN\_LOCATOR = 103  
O\_URI\_LOCATOR = 104  
O\_DEVICE\_ID = 105

GRASP Objective Names Table. The values in this table are UTF-8 strings. Future values MUST be assigned using the Specification Required policy defined by [\[RFC5226\]](#). The following initial values are assigned by this document:

EX0  
EX1  
EX2  
EX3  
EX4  
EX5  
EX6  
EX7  
EX8  
EX9



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This document was produced using the xml2rfc tool [[RFC2629](#)].

## **8. References**

### **8.1. Normative References**

- [I-D.greevenbosch-appsawg-cbor-cddl]  
Vigano, C. and H. Birkholz, "CBOR data definition language (CDDL): a notational convention to express CBOR data structures", [draft-greevenbosch-appsawg-cbor-cddl-07](#) (work in progress), October 2015.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC3986] Berners-Lee, T., Fielding, R., and L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax", STD 66, [RFC 3986](#), DOI 10.17487/RFC3986, January 2005, <<http://www.rfc-editor.org/info/rfc3986>>.
- [RFC4086] Eastlake 3rd, D., Schiller, J., and S. Crocker, "Randomness Requirements for Security", [BCP 106](#), [RFC 4086](#), DOI 10.17487/RFC4086, June 2005, <<http://www.rfc-editor.org/info/rfc4086>>.
- [RFC5246] Dierks, T. and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.2", [RFC 5246](#), DOI 10.17487/RFC5246, August 2008, <<http://www.rfc-editor.org/info/rfc5246>>.



- [RFC5280] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 5280](#), DOI 10.17487/RFC5280, May 2008, <<http://www.rfc-editor.org/info/rfc5280>>.
- [RFC6347] Rescorla, E. and N. Modadugu, "Datagram Transport Layer Security Version 1.2", [RFC 6347](#), DOI 10.17487/RFC6347, January 2012, <<http://www.rfc-editor.org/info/rfc6347>>.
- [RFC7049] Bormann, C. and P. Hoffman, "Concise Binary Object Representation (CBOR)", [RFC 7049](#), DOI 10.17487/RFC7049, October 2013, <<http://www.rfc-editor.org/info/rfc7049>>.
- [RFC7217] Gont, F., "A Method for Generating Semantically Opaque Interface Identifiers with IPv6 Stateless Address Autoconfiguration (SLAAC)", [RFC 7217](#), DOI 10.17487/RFC7217, April 2014, <<http://www.rfc-editor.org/info/rfc7217>>.

## **8.2. Informative References**

- [I-D.behringer-anima-reference-model]  
Behringer, M., Carpenter, B., Eckert, T., Ciavaglia, L., Liu, B., Jeff, J., and J. Strassner, "A Reference Model for Autonomic Networking", [draft-behringer-anima-reference-model-04](#) (work in progress), October 2015.
- [I-D.chaparadza-intarea-igcp]  
Behringer, M., Chaparadza, R., Petre, R., Li, X., and H. Mahkonen, "IP based Generic Control Protocol (IGCP)", [draft-chaparadza-intarea-igcp-00](#) (work in progress), July 2011.
- [I-D.eckert-anima-stable-connectivity]  
Eckert, T. and M. Behringer, "Using Autonomic Control Plane for Stable Connectivity of Network OAM", [draft-eckert-anima-stable-connectivity-02](#) (work in progress), October 2015.
- [I-D.ietf-anima-autonomic-control-plane]  
Behringer, M., Bjarnason, S., BL, B., and T. Eckert, "An Autonomic Control Plane", [draft-ietf-anima-autonomic-control-plane-01](#) (work in progress), October 2015.





[I-D.ietf-anima-bootstrapping-keyinfra]

Pritikin, M., Richardson, M., Behringer, M., and S. Bjarnason, "Bootstrapping Key Infrastructures", [draft-ietf-anima-bootstrapping-keyinfra-01](#) (work in progress), October 2015.

[I-D.ietf-homenet-dncp]

Stenberg, M. and S. Barth, "Distributed Node Consensus Protocol", [draft-ietf-homenet-dncp-12](#) (work in progress), November 2015.

[I-D.ietf-homenet-hncp]

Stenberg, M., Barth, S., and P. Pfister, "Home Networking Control Protocol", [draft-ietf-homenet-hncp-10](#) (work in progress), November 2015.

[I-D.ietf-netconf-restconf]

Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", [draft-ietf-netconf-restconf-09](#) (work in progress), December 2015.

[I-D.liang-iana-pen]

Liang, P., Melnikov, A., and D. Conrad, "Private Enterprise Number (PEN) practices and Internet Assigned Numbers Authority (IANA) registration considerations", [draft-liang-iana-pen-06](#) (work in progress), July 2015.

[I-D.stenberg-anima-adncp]

Stenberg, M., "Autonomic Distributed Node Consensus Protocol", [draft-stenberg-anima-adncp-00](#) (work in progress), March 2015.

[RFC2205] Braden, R., Ed., Zhang, L., Berson, S., Herzog, S., and S. Jamin, "Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification", [RFC 2205](#), DOI 10.17487/RFC2205, September 1997, <<http://www.rfc-editor.org/info/rfc2205>>.

[RFC2608] Guttman, E., Perkins, C., Veizades, J., and M. Day, "Service Location Protocol, Version 2", [RFC 2608](#), DOI 10.17487/RFC2608, June 1999, <<http://www.rfc-editor.org/info/rfc2608>>.

[RFC2629] Rose, M., "Writing I-Ds and RFCs using XML", [RFC 2629](#), DOI 10.17487/RFC2629, June 1999, <<http://www.rfc-editor.org/info/rfc2629>>.



- [RFC2865] Rigney, C., Willens, S., Rubens, A., and W. Simpson, "Remote Authentication Dial In User Service (RADIUS)", [RFC 2865](#), DOI 10.17487/RFC2865, June 2000, <<http://www.rfc-editor.org/info/rfc2865>>.
- [RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", [RFC 3209](#), DOI 10.17487/RFC3209, December 2001, <<http://www.rfc-editor.org/info/rfc3209>>.
- [RFC3315] Droms, R., Ed., Bound, J., Volz, B., Lemon, T., Perkins, C., and M. Carney, "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)", [RFC 3315](#), DOI 10.17487/RFC3315, July 2003, <<http://www.rfc-editor.org/info/rfc3315>>.
- [RFC3416] Presuhn, R., Ed., "Version 2 of the Protocol Operations for the Simple Network Management Protocol (SNMP)", STD 62, [RFC 3416](#), DOI 10.17487/RFC3416, December 2002, <<http://www.rfc-editor.org/info/rfc3416>>.
- [RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", [RFC 4861](#), DOI 10.17487/RFC4861, September 2007, <<http://www.rfc-editor.org/info/rfc4861>>.
- [RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an IANA Considerations Section in RFCs", [BCP 26](#), [RFC 5226](#), DOI 10.17487/RFC5226, May 2008, <<http://www.rfc-editor.org/info/rfc5226>>.
- [RFC5971] Schulzrinne, H. and R. Hancock, "GIST: General Internet Signalling Transport", [RFC 5971](#), DOI 10.17487/RFC5971, October 2010, <<http://www.rfc-editor.org/info/rfc5971>>.
- [RFC6206] Levis, P., Clausen, T., Hui, J., Gnawali, O., and J. Ko, "The Trickle Algorithm", [RFC 6206](#), DOI 10.17487/RFC6206, March 2011, <<http://www.rfc-editor.org/info/rfc6206>>.
- [RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", [RFC 6241](#), DOI 10.17487/RFC6241, June 2011, <<http://www.rfc-editor.org/info/rfc6241>>.
- [RFC6733] Fajardo, V., Ed., Arkko, J., Loughney, J., and G. Zorn, Ed., "Diameter Base Protocol", [RFC 6733](#), DOI 10.17487/RFC6733, October 2012, <<http://www.rfc-editor.org/info/rfc6733>>.



- [RFC6762] Cheshire, S. and M. Krochmal, "Multicast DNS", [RFC 6762](#), DOI 10.17487/RFC6762, February 2013, <<http://www.rfc-editor.org/info/rfc6762>>.
- [RFC6763] Cheshire, S. and M. Krochmal, "DNS-Based Service Discovery", [RFC 6763](#), DOI 10.17487/RFC6763, February 2013, <<http://www.rfc-editor.org/info/rfc6763>>.
- [RFC6887] Wing, D., Ed., Cheshire, S., Boucadair, M., Penno, R., and P. Selkirk, "Port Control Protocol (PCP)", [RFC 6887](#), DOI 10.17487/RFC6887, April 2013, <<http://www.rfc-editor.org/info/rfc6887>>.
- [RFC7228] Bormann, C., Ersue, M., and A. Keranen, "Terminology for Constrained-Node Networks", [RFC 7228](#), DOI 10.17487/RFC7228, May 2014, <<http://www.rfc-editor.org/info/rfc7228>>.
- [RFC7558] Lynn, K., Cheshire, S., Blanchet, M., and D. Migault, "Requirements for Scalable DNS-Based Service Discovery (DNS-SD) / Multicast DNS (mDNS) Extensions", [RFC 7558](#), DOI 10.17487/RFC7558, July 2015, <<http://www.rfc-editor.org/info/rfc7558>>.
- [RFC7575] Behringer, M., Pritikin, M., Bjarnason, S., Clemm, A., Carpenter, B., Jiang, S., and L. Ciavaglia, "Autonomic Networking: Definitions and Design Goals", [RFC 7575](#), DOI 10.17487/RFC7575, June 2015, <<http://www.rfc-editor.org/info/rfc7575>>.
- [RFC7576] Jiang, S., Carpenter, B., and M. Behringer, "General Gap Analysis for Autonomic Networking", [RFC 7576](#), DOI 10.17487/RFC7576, June 2015, <<http://www.rfc-editor.org/info/rfc7576>>.

## **Appendix A. Open Issues**

- o 7. Cross-check against other ANIMA WG documents for consistency and gaps.
- o 43. Rapid mode synchronization and negotiation is currently limited to a single objective for simplicity of design and implementation. A future consideration is to allow multiple objectives in rapid mode for greater efficiency.
- o 48. Should the Appendix "Capability Analysis of Current Protocols" be deleted before RFC publication?



**Appendix B. Closed Issues [RFC Editor: Please remove]**

- o 1. UDP vs TCP: For now, this specification suggests UDP and TCP as message transport mechanisms. This is not clarified yet. UDP is good for short conversations, is necessary for multicast discovery, and generally fits the discovery and divert scenarios well. However, it will cause problems with large messages. TCP is good for stable and long sessions, with a little bit of time consumption during the session establishment stage. If messages exceed a reasonable MTU, a TCP mode will be required in any case. This question may be affected by the security discussion.

RESOLVED by specifying UDP for short message and TCP for longer one.

- o 2. DTLS or TLS vs built-in security mechanism. For now, this specification has chosen a PKI based built-in security mechanism based on asymmetric cryptography. However, (D)TLS might be chosen as security solution to avoid duplication of effort. It also allows essentially similar security for short messages over UDP and longer ones over TCP. The implementation trade-offs are different. The current approach requires expensive asymmetric cryptographic calculations for every message. (D)TLS has startup overheads but cheaper crypto per message. DTLS is less mature than TLS.

RESOLVED by specifying external security (ACP or (D)TLS).

- o The following open issues applied only if the original security model was retained:
  - \* 2.1. For replay protection, GRASP currently requires every participant to have an NTP-synchronized clock. Is this OK for low-end devices, and how does it work during device bootstrapping? We could take the Timestamp out of signature option, to become an independent and OPTIONAL (or RECOMMENDED) option.
  - \* 2.2. The Signature Option states that this option could be any place in a message. Wouldn't it be better to specify a position (such as the end)? That would be much simpler to implement.

RESOLVED by changing security model.

- o 3. DoS Attack Protection needs work.

RESOLVED by adding text.





- o 4. Should we consider preferring a text-based approach to discovery (after the initial discovery needed for bootstrapping)? This could be a complementary mechanism for multicast based discovery, especially for a very large autonomic network. Centralized registration could be automatically deployed incrementally. At the very first stage, the repository could be empty; then it could be filled in by the objectives discovered by different devices (for example using Dynamic DNS Update). The more records are stored in the repository, the less the multicast-based discovery is needed. However, if we adopt such a mechanism, there would be challenges: stateful solution, and security.

RESOLVED for now by adding optional use of DNS-SD by ASAs.  
Subsequently removed by editors as irrelevant to GRASP itself.

- o 5. Need to expand description of the minimum requirements for the specification of an individual discovery, synchronization or negotiation objective.

RESOLVED for now by extra wording.

- o 6. Use case and protocol walkthrough. A description of how a node starts up, performs discovery, and conducts negotiation and synchronisation for a sample use case would help readers to understand the applicability of this specification. Maybe it should be an artificial use case or maybe a simple real one, based on a conceptual API. However, the authors have not yet decided whether to have a separate document or have it in the protocol document.

RESOLVED: recommend a separate document.

- o 8. Consideration of ADNCP proposal.

RESOLVED by adding optional use of DNCP for flooding-type synchronization.

- o 9. Clarify how a GDNP instance knows whether it is running inside the ACP. (Sheng)

RESOLVED by improved text.

- o 10. Clarify how a non-ACP GDNP instance initiates (D)TLS. (Sheng)

RESOLVED by improved text and declaring DTLS out of scope for this draft.



- o 11. Clarify how UDP/TCP choice is made. (Sheng) [Like DNS? - Brian]

RESOLVED by improved text.

- o 12. Justify that IP address within ACP or (D)TLS environment is sufficient to prove AN identity; or explain how Device Identity Option is used. (Sheng)

RESOLVED for now: we assume that all ASAs in a device are trusted as soon as the device is trusted, so they share credentials. In that case the Device Identity Option is useless. This needs to be reviewed later.

- o 13. Emphasise that negotiation/synchronization are independent from discovery, although the rapid discovery mode includes the first step of a negotiation/synchronization. (Sheng)

RESOLVED by improved text.

- o 14. Do we need an unsolicited flooding mechanism for discovery (for discovery results that everyone needs), to reduce scaling impact of flooding discovery messages? (Toerless)

RESOLVED: Yes, added to requirements and solution.

- o 15. Do we need flag bits in Objective Options to distinguish distinguish Synchronization and Negotiation "Request" or rapid mode "Discovery" messages? (Bing)

RESOLVED: yes, work on the API showed that these flags are essential.

- o 16. (Related to issue 14). Should we revive the "unsolicited Response" for flooding synchronisation data? This has to be done carefully due to the well-known issues with flooding, but it could be useful, e.g. for Intent distribution, where DNCP doesn't seem applicable.

RESOLVED: Yes, see #14.

- o 17. Ensure that the discovery mechanism is completely proof against loops and protected against duplicate responses.

RESOLVED: Added loop count mechanism.

- o 18. Discuss the handling of multiple valid discovery responses.



RESOLVED: Stated that the choice must be available to the ASA but GRASP implementation should pick a default.

- o 19. Should we use a text-oriented format such as JSON/CBOR instead of native binary TLV format?

RESOLVED: Yes, changed to CBOR.

- o 20. Is the Divert option needed? If a discovery response provides a valid IP address or FQDN, the recipient doesn't gain any extra knowledge from the Divert. On the other hand, the presence of Divert informs the receiver that the target is off-link, which might be useful sometimes.

RESOLVED: Decided to keep Divert option.

- o 21. Rename the protocol as GRASP (GeneRic Autonomic Signaling Protocol)?

RESOLVED: Yes, name changed.

- o 22. Does discovery mechanism scale robustly as needed? Need hop limit on relaying?

RESOLVED: Added hop limit.

- o 23. Need more details on TTL for caching discovery responses.

RESOLVED: Done.

- o 24. Do we need "fast withdrawal" of discovery responses?

RESOLVED: This doesn't seem necessary. If an ASA exits or stops supporting a given objective, peers will fail to start future sessions and will simply repeat discovery.

- o 25. Does GDNP discovery meet the needs of multi-hop DNS-SD?

RESOLVED: Decided not to consider this further as a GRASP protocol issue. GRASP objectives could embed DNS-SD formats if needed.

- o 26. Add a URL type to the locator options (for security bootstrap etc.)

RESOLVED: Done, later renamed as URI.

- o 27. Security of Flood multicasts ([Section 3.3.5.1](#)).



RESOLVED: added text.

- o 28. Does ACP support secure link-local multicast?

RESOLVED by new text in the Security Considerations.

- o 29. PEN is used to distinguish vendor options. Would it be better to use a domain name? Anything unique will do.

RESOLVED: Simplified this by removing PEN field and changing naming rules for objectives.

- o 30. Does response to discovery require randomized delays to mitigate amplification attacks?

RESOLVED: WG feedback is that it's unnecessary.

- o 31. We have specified repeats for failed discovery etc. Is that sufficient to deal with sleeping nodes?

RESOLVED: WG feedback is that it's unnecessary to say more.

- o 32. We have one-to-one synchronization and flooding synchronization. Do we also need selective flooding to a subset of nodes?

RESOLVED: This will be discussed as a protocol extension in a separate draft ([draft-liu-anima-grasp-distribution](#)).

- o 33. Clarify if/when discovery needs to be repeated.

RESOLVED: Done.

- o 34. Clarify what is mandatory for running in ACP, expand discussion of security boundary when running with no ACP - might rely on the local PKI infrastructure.

RESOLVED: Done.

- o 35. State that role-based authorization of ASAs is out of scope for GRASP. GRASP doesn't recognize/handle any "roles".

RESOLVED: Done.

- o 36. Reconsider CBOR definition for PEN syntax. ( objective-name = text / [pen, text] ; pen = uint )

RESOLVED: See issue 29.





- o 37. Are URI locators really needed?

RESOLVED: Yes, e.g. for security bootstrap discovery, but added note that addresses are the normal case (same for FQDN locators).

- o 38. Is Session ID sufficient to identify relayed responses? Isn't the originator's address needed too?

RESOLVED: Yes, this is needed for multicast messages and their responses.

- o 39. Clarify that a node will contain one GRASP instance supporting multiple ASAs.

RESOLVED: Done.

- o 40. Add a "reason" code to the DECLINE option?

RESOLVED: Done.

- o 41. What happens if an ASA cannot conveniently use one of the GRASP mechanisms? Do we (a) add a message type to GRASP, or (b) simply pass the discovery results to the ASA so that it can open its own socket?

RESOLVED: Both would be possible, but (b) is preferred.

- o 42. Do we need a feature whereby an ASA can bypass the ACP and use the data plane for efficiency/throughput? This would require discovery to return non-ACP addresses and would evade ACP security.

RESOLVED: This is considered out of scope for GRASP, but a comment has been added in security considerations.

- o 44. In requirement T9, the words that encryption "may not be required in all deployments" were removed. Is that OK?.

RESOLVED: No objections.

- o 45. Device Identity Option is unused. Can we remove it completely?.

RESOLVED: No objections. Done.

- o 46. The 'initiator' field in DISCOVER, RESPONSE and FLOOD messages is intended to assist in loop prevention. However, we also have the loop count for that. Also, if we create a new



Session ID each time a DISCOVER or FLOOD is relayed, that ID can be disambiguated by recipients. It would be simpler to remove the initiator from the messages, making parsing more uniform. Is that OK?

RESOLVED: Yes. Done.

- o 47. REQUEST is a dual purpose message (request negotiation or request synchronization). Would it be better to split this into two different messages (and adjust various message names accordingly)?

RESOLVED: Yes. Done.

### **Appendix C. Change log [RFC Editor: Please remove]**

[draft-ietf-anima-grasp-03](#), 2016-02-24:

Protocol change: Removed initiator field from certain messages and adjusted relaying requirement to simplify loop detection. Also clarified narrative explanation of discovery relaying.

Protocol change: Split Request message into two (Request Negotiation and Request Synchronization) and updated other message names for clarity.

Protocol change: Dropped unused Device ID option.

Further clarified text on transport layer usage.

New text about multicast insecurity in Security Considerations.

Various other clarifications and editorial fixes, including moving some material to Appendix.

[draft-ietf-anima-grasp-02](#), 2016-01-13:

Resolved numerous issues according to WG discussions.

Renumbered requirements, added D9.

Protocol change: only allow one objective in rapid mode.

Protocol change: added optional error string to DECLINE option.

Protocol change: removed statement that seemed to say that a Request not preceded by a Discovery should cause a Discovery response. That



made no sense, because there is no way the initiator would know where to send the Request.

Protocol change: Removed PEN option from vendor objectives, changed naming rule accordingly.

Protocol change: Added FLOOD message to simplify coding.

Protocol change: Added SYNCH message to simplify coding.

Protocol change: Added initiator id to DISCOVER, RESPONSE and FLOOD messages. But also allowed the relay process for DISCOVER and FLOOD to regenerate a Session ID.

Protocol change: Require that discovered addresses must be global (except during bootstrap).

Protocol change: Receiver of REQUEST message must close socket if no ASA is listening for the objective.

Protocol change: Simplified Waiting message.

Protocol change: Added No Operation message.

Renamed URL locator type as URI locator type.

Updated CDDL definition.

Various other clarifications and editorial fixes.

[draft-ietf-anima-grasp-01](#), 2015-10-09:

Updated requirements after list discussion.

Changed from TLV to CBOR format - many detailed changes, added co-author.

Tightened up loop count and timeouts for various cases.

Noted that GRASP does not provide transactional integrity.

Various other clarifications and editorial fixes.

[draft-ietf-anima-grasp-00](#), 2015-08-14:

File name and protocol name changed following WG adoption.

Added URL locator type.



[draft-carpenter-anima-gdn-protocol-04](#), 2015-06-21:

Tuned wording around hierarchical structure.

Changed "device" to "ASA" in many places.

Reformulated requirements to be clear that the ASA is the main customer for signaling.

Added requirement for flooding unsolicited synch, and added it to protocol spec. Recognized DNCP as alternative for flooding synch data.

Requirements clarified, expanded and rearranged following design team discussion.

Clarified that GDNP discovery must not be a prerequisite for GDNP negotiation or synchronization (resolved issue 13).

Specified flag bits for objective options (resolved issue 15).

Clarified usage of ACP vs TLS/DTLS and TCP vs UDP (resolved issues 9,10,11).

Updated DNCP description from latest DNCP draft.

Editorial improvements.

[draft-carpenter-anima-gdn-protocol-03](#), 2015-04-20:

Removed intrinsic security, required external security

Format changes to allow DNCP co-existence

Recognized DNS-SD as alternative discovery method.

Editorial improvements

[draft-carpenter-anima-gdn-protocol-02](#), 2015-02-19:

Tuned requirements to clarify scope,

Clarified relationship between types of objective,

Clarified that objectives may be simple values or complex data structures,

Improved description of objective options,





Added loop-avoidance mechanisms (loop count and default timeout, limitations on discovery relaying and on unsolicited responses),

Allow multiple discovery objectives in one response,

Provided for missing or multiple discovery responses,

Indicated how modes such as "dry run" should be supported,

Minor editorial and technical corrections and clarifications,

Reorganized future work list.

[draft-carpenter-anima-gdn-protocol-01](#), restructured the logical flow of the document, updated to describe synchronization completely, add unsolicited responses, numerous corrections and clarifications, expanded future work list, 2015-01-06.

[draft-carpenter-anima-gdn-protocol-00](#), combination of [draft-jiang-config-negotiation-ps-03](#) and [draft-jiang-config-negotiation-protocol-02](#), 2014-10-08.

#### **[Appendix D](#). Capability Analysis of Current Protocols**

This appendix discusses various existing protocols with properties related to the above negotiation and synchronisation requirements. The purpose is to evaluate whether any existing protocol, or a simple combination of existing protocols, can meet those requirements.

Numerous protocols include some form of discovery, but these all appear to be very specific in their applicability. Service Location Protocol (SLP) [[RFC2608](#)] provides service discovery for managed networks, but requires configuration of its own servers. DNS-SD [[RFC6763](#)] combined with mDNS [[RFC6762](#)] provides service discovery for small networks with a single link layer. [[RFC7558](#)] aims to extend this to larger autonomous networks but this is not yet standardized. However, both SLP and DNS-SD appear to target primarily application layer services, not the layer 2 and 3 objectives relevant to basic network configuration. Both SLP and DNS-SD are text-based protocols.

Routing protocols are mainly one-way information announcements. The receiver makes independent decisions based on the received information and there is no direct feedback information to the announcing peer. This remains true even though the protocol is used in both directions between peer routers; there is state synchronization, but no negotiation, and each peer runs its route calculations independently.



Simple Network Management Protocol (SNMP) [[RFC3416](#)] uses a command/response model not well suited for peer negotiation. Network Configuration Protocol (NETCONF) [[RFC6241](#)] uses an RPC model that does allow positive or negative responses from the target system, but this is still not adequate for negotiation.

There are various existing protocols that have elementary negotiation abilities, such as Dynamic Host Configuration Protocol for IPv6 (DHCPv6) [[RFC3315](#)], Neighbor Discovery (ND) [[RFC4861](#)], Port Control Protocol (PCP) [[RFC6887](#)], Remote Authentication Dial In User Service (RADIUS) [[RFC2865](#)], Diameter [[RFC6733](#)], etc. Most of them are configuration or management protocols. However, they either provide only a simple request/response model in a master/slave context or very limited negotiation abilities.

There are some signaling protocols with an element of negotiation. For example Resource ReSerVation Protocol (RSVP) [[RFC2205](#)] was designed for negotiating quality of service parameters along the path of a unicast or multicast flow. RSVP is a very specialised protocol aimed at end-to-end flows. However, it has some flexibility, having been extended for MPLS label distribution [[RFC3209](#)]. A more generic design is General Internet Signalling Transport (GIST) [[RFC5971](#)], but it is complex, tries to solve many problems, and is also aimed at per-flow signaling across many hops rather than at device-to-device signaling. However, we cannot completely exclude extended RSVP or GIST as a synchronization and negotiation protocol. They do not appear to be directly useable for peer discovery.

We now consider two protocols that are works in progress at the time of this writing. Firstly, RESTCONF [[I-D.ietf-netconf-restconf](#)] is a protocol intended to convey NETCONF information expressed in the YANG language via HTTP, including the ability to transit HTML intermediaries. While this is a powerful approach in the context of centralised configuration of a complex network, it is not well adapted to efficient interactive negotiation between peer devices, especially simple ones that are unlikely to include YANG processing already.

Secondly, we consider Distributed Node Consensus Protocol (DNCP) [[I-D.ietf-homenet-dncp](#)]. This is defined as a generic form of state synchronization protocol, with a proposed usage profile being the Home Networking Control Protocol (HNCP) [[I-D.ietf-homenet-hncp](#)] for configuring Homenet routers. A specific application of DNCP for autonomic networking was proposed in [[I-D.stenberg-anima-adncp](#)].

DNCP "is designed to provide a way for each participating node to publish a set of TLV (Type-Length-Value) tuples, and to provide a shared and common view about the data published... DNCP is most



suitable for data that changes only infrequently... If constant rapid state changes are needed, the preferable choice is to use an additional point-to-point channel..."

Specific features of DNCP include:

- o Every participating node has a unique node identifier.
- o DNCP messages are encoded as a sequence of TLV objects, sent over unicast UDP or TCP, with or without (D)TLS security.
- o Multicast is used only for discovery of DNCP neighbors when lower security is acceptable.
- o Synchronization of state is maintained by a flooding process using the Trickle algorithm. There is no bilateral synchronization or negotiation capability.
- o The HNCP profile of DNCP is designed to operate between directly connected neighbors on a shared link using UDP and link-local IPv6 addresses.

DNCP does not meet the needs of a general negotiation protocol, because it is designed specifically for flooding synchronization. Also, in its HNCP profile it is limited to link-local messages and to IPv6. However, at the minimum it is a very interesting test case for this style of interaction between devices without needing a central authority, and it is a proven method of network-wide state synchronization by flooding.

A proposal was made some years ago for an IP based Generic Control Protocol (IGCP) [[I-D.chaparadza-intarea-igcp](#)]. This was aimed at information exchange and negotiation but not directly at peer discovery. However, it has many points in common with the present work.

None of the above solutions appears to completely meet the needs of generic discovery, state synchronization and negotiation in a single solution. Many of the protocols assume that they are working in a traditional top-down or north-south scenario, rather than a fluid peer-to-peer scenario. Most of them are specialized in one way or another. As a result, we have not identified a combination of existing protocols that meets the requirements in [Section 2](#). Also, we have not identified a path by which one of the existing protocols could be extended to meet the requirements.



Authors' Addresses

Carsten Bormann  
Universitaet Bremen TZI  
Postfach 330440  
D-28359 Bremen  
Germany

Email: cabo@tzi.org

Brian Carpenter (editor)  
Department of Computer Science  
University of Auckland  
PB 92019  
Auckland 1142  
New Zealand

Email: brian.e.carpenter@gmail.com

Bing Liu (editor)  
Huawei Technologies Co., Ltd  
Q14, Huawei Campus  
No.156 Beiqing Road  
Hai-Dian District, Beijing 100095  
P.R. China

Email: leo.liubing@huawei.com



