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Information Distribution over GRASP  
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Abstract

This document proposes a solution for information distribution in autonomic networks. Information distribution is categorized into two different modes: 1) instantaneous distribution; 2) publication for retrieval. In the former case, the information is sent, propagates and is disposed of after reception. In the latter case, information needs to be stored in the network.

The capabilities to distribute information are basic and fundamental needs for an autonomous network ([RFC7575]). This document describes typical use cases of information distribution in ANI and requirements to ANI, such that rich information distribution can be natively supported. The document proposes extensions to the autonomic nodes and suggests an implementation based on GRASP ([I-D.ietf-anima-grasp]) extensions as a protocol on the wire.

Status of This Memo

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1. Introduction

In an autonomic network, autonomic functions (AFs) running on autonomic nodes constantly exchange information, e.g. AF control/management signaling or AF data exchange. This document discusses the information distribution capability of such exchanges between AFs.

Depending on the number of participants, the information can be distributed in in the following scenarios:

- 1) Point-to-point (P2P) Communication: information is exchanged between parties, i.e. two nodes.
- 2) One-to-Many Communication: information exchanges involve an information source and multiple receivers.

The approaches to information distribution can be chiefly categorized into two basic modes:

- 1) An instantaneous mode (push): a source sends the actual content (e.g. control/management signaling, synchronization data and so on) to all interested receiver(s) immediately. Generally, some preconfiguration is required, as nodes interested in this information must be already known to all nodes in the sense that any receiving node must be able to decide, to which nodes this data is to be sent.
- 2) An asynchronous mode (delayed pull): here, a source publishes the content in some form in the network, which may later be looked for, found and retrieved by some endpoints in the AN. Here, depending on the size of the content, either the whole content or only its metadata might be published into the AN. In the latter case the metadata (e.g. a content descriptor, e.g. a key, and a location in the ANI) may be used for the actual retrieval. Importantly, the source, i.e. here publisher, needs to be able to determine the node, where the information (or its metadata) can be stored.

To avoid repetitive implementations by each AF developer, this document opts for a common support for information distribution

implemented as a basic ANI capability, therefore available to all AFs. In fact, GRASP already provides part of the capabilities.

Regardless, an AF may still define and implement its own information distribution capability. Such a capability may then be advertised using the common information distribution capability defined in this document. Overall, ANI nodes and AFs may decide, which of the information distribution mechanisms they want to use for which type of information, according to their own preferences (e.g. semantic routing table, etc.)

This document first analyzes requirements for information distribution in autonomic networks (Section 3) and then discuss the relevant node behavior (Section 4). After that, the required GRASP extensions are formally introduced (Section 5).

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## 2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

## 3. Requirements for Information Distribution in ANI

The question of information distribution in an autonomic network can be discussed through particular use cases or more generally. Depending on the situation it can be quite simple or might require more complex provisions.

Indeed, in the simplest case, the information can be sent:

- 1) at once (in one packet, in one flow),
- 2) straightaway (send-and-forget),
- 3) to all nodes.

Presuming 1), 2) and 3) hold, information distribution in smaller or scarce topologies can be implemented using broadcast, i.e. unconstrained flooding. For reasons well-understood, this approach has its limits in larger and denser networks. In this case, a graph can be constructed such that it contains every node exactly once (e.g. a spanning tree), still allowing to distribute any information to all nodes straightaway. Multicast tree construction protocols could be used in this case. There are reasonable use cases for such scenarios, as presented in Appendix D.

A more complex scenario arises, if only 1) and 2) hold, but the information only concerns a subset of nodes. Then, some kind of selection becomes required, to which nodes the given information should be distributed. Here, a further distinction is necessary; notably, if the selection of the target nodes is with respect to the nature or position of the node, or whether it is with respect to the information content. If the first, some knowledge about the node types, its topological position, etc (e.g. the routing information within ANI) can be used to distinguish nodes accordingly. For instance, edge nodes and forwarding nodes can be distinguished in this way. If the distribution scope is primarily to be defined by the information elements, then a registration / join / subscription or label distribution mechanism is unavoidable. This would be the case, for instance, if the AFs can be dynamically deployed on nodes, and the information is majorily destined to the AFs. Then, depending on the current AF deployment, the distribution scope must be adjusted as well.

If only 1) holds, but the information content might be required again and again, or might not yet be fully available, then more complex mechanisms might be required to store the information within the network for later, for further redistribution, and for notification of interested nodes. Examples for this include distribution of reconfiguration information for different AF instances, which might not require an immediate action, but only an eventual update of the parameters. Also, in some situations, there could be a significant delay between the occurrence of a new event and the full content availability (e.g. if the processing requires a lot of time).

Finally, none of the three might hold. Then, along with the subscription and notification, the actual content might be different from its metadata, i.e. some description of the content and, possibly, its location. The fetching can then be implemented in different, appropriate ways, if necessary as a complex transport session.

In essence, as flooding is usually not an option, and the interest of nodes for particular information elements can change over time, ANI should support autonomies also for the information distribution.

This calls for autonomic mechanisms in the ANI, allowing participating nodes to 1) advertise or publish 2) look for or subscribe to 3) store 4) fetch/retrieve 5) instantaneously push information elements.

In the following cases, situations depicting diverse information distribution needs are discussed.

- 1) Long Communication Intervals. The actual sending of the information is not necessarily instantaneous with some event. Advanced AFs may involve into longer jobs/tasks (e.g. database lookup, authentication etc.) when processing requests, and might not be able to reply immediately. Instead of actively waiting for the reply, a better way for an interested AF might be to get notified, when the reply is finally available.
- 2) Common Interest Distribution. AFs may share interest in common information. For example, the network intent will be distributed to network nodes enrolled, which is usually one-to-many scenario. Intent distribution can also be performed by an instant flooding (e.g. via GRASP) to every network node. However, because of network dynamics, not every node can be just ready at the moment when the network intent is broadcast. Also, a flooding often does not cover all network nodes as there is usually a limitation on the hop number. In fact, nodes may join in the network sequentially. In this situation, an asynchronous communication model could be a better choice where every (newly joining) node can subscribe the intent information and will get notified if it is ready (or updated).
- 3) Distributed Coordination. With computing and storage resources on autonomic nodes, alive AFs not only consume but also generate data information. An example is AFs coordinating with each other as distributed schedulers, responding to service requests and distributing tasks. It is critical for those AFs to make correct decisions based on local information, which might be asymmetric as well. AFs may also need synthetic/aggregated data information (e.g. statistic info, like average values of several AFs, etc.) to make decisions. In these situations, AFs will need an efficient way to form a global view of the network (e.g. about resource consumption, bandwidth and statistics). Obviously, purely relying on instant communication model is inefficient, while a scalable, common, yet distributed data layer, on which AFs can store and share information in an asynchronous way, should be a better choice.

Therefore, for ANI, in order to support various communication scenarios, an information distribution module is required, and both instantaneous and asynchronous communication models should be supported. Some real-world use cases are introduced in Appendix D.

#### 4. Node Behaviors

In this section, how a node should behave in order to support the two identified modes of information distribution is discussed. An ANI is

a distributed system, so the information distribution module must be implemented in a distributed way as well.

#### 4.1. Instant Information Distribution (IID) Sub-module

In this case, An information sender directly specifies the information receiver(s). The instant information distribution sub-module will be the main element.

##### 4.1.1. Instant P2P Communication

IID sub-module performs instant information transmission for ASAs running in an ANI. In specific, IID sub-module will have to retrieve the address of the information receiver specified by an ASA, then deliver the information to the receiver. Such a delivery can be done either in a connectionless or a connection-oriented way.

Current GRASP provides the capability to support instant P2P synchronization for ASAs. A P2P synchronization is a use case of P2P information transmission. However, as mention in Section 3, there are some scenarios where one node needs to transmit some information to another node(s). This is different to synchronization because after transmitting the information, the local status of the information does not have to be the same as the information sent to the receiver. This is not directly support by existing GRASP.

##### 4.1.2. Instant Flooding Communication

IID sub-module finishes instant flooding for ASAs in an ANI. Instant flooding is for all ASAs in an ANI. An information sender has to specify a special destination address of the information and broadcast to all interfaces to its neighbors. When another IID sub-module receives such a broadcast, after checking its TTL, it further broadcast the message to the neighbors. In order to avoid flooding storms in an ANI, usually a TTL number is specified, so that after a pre-defined limit, the flooding message will not be further broadcast again.

In order to avoid unnecessary flooding, a selective flooding can be done where an information sender wants to send information to multiple receivers at once. When doing this, sending information needs to contain criteria to judge on which interfaces the distributed information should and should not be sent. Specifically, the criteria contain:

- o Matching Condition: a set of matching rules such as addresses of recipients, node features and so on.

- o Action: what the node needs to do when the Matching Condition is fulfilled. For example, the action could be forwarding or discarding the distributed message.

Sent information must be included in the message distributed from the sender. The receiving node reacts by first checking the carried Matching Condition in the message to decide who should consume the message, which could be either the node itself, some neighbors or both. If the node itself is a recipient, Action field is followed; if a neighbor is a recipient, the message is sent accordingly.

An exemplary extension to support selective flooding on GRASP is described in Section 5.

#### 4.2. Asynchronous Information Distribution (AID) Sub-module

In asynchronous information distribution, sender(s) and receiver(s) are not immediately specified while they may appear in an asynchronous way. Firstly, AID sub-module enables that the information can be stored in the network; secondly, AID sub-module provides an information publication and subscription (Pub/Sub) mechanism for ASAs.

As sketched in the previous section, in general each node requires two modules: 1) Information Storage (IS) module and 2) Event Queue (EQ) module in the information distribution module. Details of the two modules are described in the following sections.

##### 4.2.1. Information Storage

IS module handles how to save and retrieve information for ASAs across the network. The IS module uses a syntax to index information, generating the hash index value (e.g. a hash value) of the information and mapping the hash index to a certain node in ANI. Note that, this mechanism can use existing solutions. Specifically, storing information in an ANIMA network will be realized in the following steps.

- 1) ASA-to-IS Negotiation. An ASA calls the API provided by information distribution module (directly supported by IS sub-module) to request to store the information somewhere in the network. The IS module performs various checks of the request (e.g. permitted information size).
- 2) Storing Peer Mapping. The information block will be handled by the IS module in order to calculate/map to a peer node in the network. Since ANIMA network is a peer-to-peer network, a typical way is to use distributed hash table (DHT) to map information to a

unique index identifier. For example, if the size of the information is reasonable, the information block itself can be hashed, otherwise, some meta-data of the information block can be used to generate the mapping.

- 3) Storing Peer Negotiation Request. Negotiation request of storing the information will be sent from the IS module to the IS module on the destination node. The negotiation request contains parameters about the information block from the source IS module. According to the parameters as well as the local available resource, the requested storing peer will send feedback the source IS module.
- 4) Storing Peer Negotiation Response. Negotiation response from the storing peer is sent back to the source IS module. If the source IS module gets confirmation that the information can be stored, source IS module will prepare to transfer the information block; otherwise, a new storing peer must be discovered (i.e. going to step 7).
- 5) Information Block Transfer. Before sending the information block to the storing peer that already accepts the request, the IS module of the source node will check if the information block can be afforded by one GRASP message. If so, the information block will be directly sent by calling a GRASP API ([I-D.ietf-anima-grasp-api]). Otherwise, a bulk data transmission is needed. For that, there are multiple ways to do it. The first option is to utilize one of existing protocols that is independent of the GRASP stack. For example, a session connectivity can be established to the storing peer, and over the connection the bulky data can be transmitted part by part. In this case, the IS module should support basic TCP-based session protocols such as HTTP(s) or native TCP. The second option is to directly use GRASP itself for bulky data transferring[I-D.carpenter-anima-grasp-bulk].
- 6) Information Writing. Once the information block (or a smaller block) is received, the IS module of the storing peer will store the data block in the local storage is accessible.
- 7) (Optional) New Storing Peer Discovery. If the previously selected storing peer is not available to store the information block, the source IS module will have to identify a new destination node to start a new negotiation. In this case, the discovery can be done by using discovery GRASP API to identify a new candidate, or more complex mechanisms can be introduced.

Similarly, Getting information from an ANI will be realized in the following steps.

- 1) ASA-to-IS Request. An ASA accesses the IS module via the APIs exposed by the information distribution module. The key/index of the interested information will be sent to the IS module. An assumption here is that the key/index should be known to an ASA before an ASA can ask for the information. This relates to the publishing/subscribing of the information, which are handled by other modules (e.g. Event Queue with Pub/Sub supported by GRASP).
- 2) Storing Peer Mapping. IS module maps the key/index of the requested information to a peer that stores the information, and prepares the information request. The mapping here follows the same mechanism when the information is stored.
- 3) Retrieval Negotiation Request. The source IS module sends a request to the storing peer and asks if such an information object is available.
- 4) Retrieval Negotiation Response. The storing peer checks the key/index of the information in the request, and replies to the source IS module. If the information is found and the information block can be afforded within one GRASP message, the information will be sent together with the response to the source IS module.
- 5) (Optional) New Destination Request. If the information is not found after the source IS module gets the response from the originally identified storing peer, the source IS module will have to discover the location of the requested information.

IS module can reuse distributed databases and key value stores like NoSQL, Cassandra, DHT technologies. storage and retrieval of information are all event-driven responsible by the EQ module.

#### 4.2.2. Event Queue

The Event Queue (EQ) module is to help ASAs to publish information to the network and subscribe to interested information in asynchronous scenarios. In an ANI, information generated on network nodes is an event labeled with an event ID, which is semantically related to the topic of the information. Key features of EQ module are summarized as follows.

- 1) Event Group: An EQ module provides isolated queues for different event groups. If two groups of AFs could have completely different purposes, the EQ module allows to create multiple queues where only AFs interested in the same topic will be aware of the corresponding event queue.

- 2) Event Prioritization: Events can have different priorities in ANI. This corresponds to how much important or urgent the event implies. Some of them are more urgent than regular ones. Prioritization allows AFs to differentiate events (i.e. information) they publish or subscribe to.
- 3) Event Matching: an information consumer has to be identified from the queue in order to deliver the information from the provider. Event matching keeps looking for the subscriptions in the queue to see if there is an exact published event there. Whenever a match is found, it will notify the upper layer to inform the corresponding ASAs who are the information provider and subscriber(s) respectively.

The EQ module on every network node operates as follows.

- 1) Event ID Generation: If information of an ASA is ready, an event ID is generated according to the content of the information. This is also related to how the information is stored/saved by the IS module introduced before. Meanwhile, the type of the event is also specified where it can be of control purpose or user plane data.
- 2) Priority Specification: According to the type of the event, the ASA may specify its priority to say how this event is to be processed. By considering both aspects, the priority of the event will be determined.
- 3) Event Enqueue: Given the event ID, event group and its priority, a queue is identified locally if all criteria can be satisfied. If there is such a queue, the event will be simply added into the queue, otherwise a new queue will be created to accommodate such an event.
- 4) Event Propagation: The published event will be propagated to the other network nodes in the ANIMA domain. A propagation algorithm can be employed to optimize the propagation efficiency of the updated event queue states.
- 5) Event Match and Notification: While propagating updated event states, EQ module in parallel keeps matching published events and its interested consumers. Once a match is found, the provider and subscriber(s) will be notified for final information retrieval.

The category of event priority is defined as the following. In general, there are two event types:

- 1) Network Control Event: This type of events are defined by the ANI for operational purposes on network control. A pre-defined priority levels for required system messages is suggested. For highest level to lowest level, the priority value ranges from NC\_PRIOR\_HIGH to NC\_PRIOR\_LOW as integer values. The NC\_PRIOR\_\* values will be defined later according to the total number system events required by the ANI.
- 2) Custom ASA Event: This type of events are defined by the ASAs of users. This specifies the priority of the message within a group of ASAs, therefore it is only effective among ASAs that join the same message group. Within the message group, a group header/leader has to define a list of priority levels ranging from CUST\_PRIOR\_HIGH to CUST\_PRIOR\_LOW. Such a definition completely depends on the individual purposes of the message group. When a system message is delivered, its event type and event priority value have to be both specified.

Event contains the address where the information is stored, after a subscriber is notified, it directly retrieves the information from the given location.

#### 4.3. Summary

In summary, the general requirements for the information distribution module on each autonomic node are realized by two sub-modules handling instant communications and asynchronous communications, respectively. For instantaneous mode, node requirements are simple, calling for support for additional signaling. With minimum efforts, reusing the existing GRASP is possible.

For asynchronous mode, information distribution module uses new primitives on the wire, and implements an event queue and an information storage mechanism. An architectural consideration on ANI with the information distribution module is briefly discussed in Appendix E.

### 5. Extending GRASP for Information Distribution

#### 5.1. Realizing Instant P2P Transmission

This could be a new message in GRASP. In fragmentary CDDL, an Un-solicited Synchronization message follows the pattern:

```
unsolicited_synch-message = [M_UNSOOLIDSYNCH, session-id,  
objective]
```

A node MAY actively send a unicast Un-solicited Synchronization message with the Synchronization data, to another node. This MAY be sent to port GRASP\_LISTEN\_PORT at the destination address, which might be obtained by GRASP Discovery or other possible ways. The synchronization data are in the form of GRASP Option(s) for specific synchronization objective(s).

## 5.2. Realizing Instant Selective Flooding

Since normal flooding is already supported by GRASP, this section only defines the selective flooding extension.

In fragmentary CDDL, the selective flooding follows the pattern:

```
selective-flood-option = [O_SELECTIVE_FLOOD, +O_MATCH-CONDITION,
match-object, action]

    O_MATCH-CONDITION = [O_MATCH-CONDITION, Obj1, match-rule, Obj2]
    Obj1 = text

    match-rule = GREATER / LESS / WITHIN / CONTAIN

    Obj2 = text

    match-object = NEIGHBOR / SELF

    action = FORWARD / DROP
```

The option field encapsulates a match-condition option which represents the conditions regarding to continue or discontinue flood the current message. For the match-condition option, the Obj1 and Obj2 are to objects that need to be compared. For example, the Obj1 could be the role of the device and Obj2 could be "RSG". The match rules between the two objects could be greater, less than, within, or contain. The match-object represents of which Obj1 belongs to, it could be the device itself or the neighbor(s) intended to be flooded. The action means, when the match rule applies, the current device just continues flood or discontinues.

## 5.3. Realizing Subscription as An Event

In fragmentary CDDL, a Subscription Objective Option follows the pattern:

```
subscription-objection-option = [SUBSCRIPTION, 2, 2, subobj]
objective-name = SUBSCRIPTION

objective-flags = 2
```

```
loop-count = 2
subobj = text
```

This option MAY be included in GRASP M\_Synchronization, when included, it means this message is for a subscription to a specific object.

#### 5.4. Un\_Subscription Objective Option

In fragmentary CDDL, a Un\_Subscribe Objective Option follows the pattern:

```
Unsubscribe-objection-option = [UNSUBSCRIB, 2, 2, unsubobj]
objective-name = SUBSCRIPTION
objective-flags = 2
loop-count = 2
unsubobj = text
```

This option MAY be included in GRASP M\_Synchronization, when included, it means this message is for a un-subscription to a specific object.

#### 5.5. Publishing Objective Option

In fragmentary CDDL, a Publish Objective Option follows the pattern:

```
publish-objection-option = [PUBLISH, 2, 2, pubobj]
objective-name = PUBLISH
objective-flags = 2
loop-count = 2
pubobj = text
```

This option MAY be included in GRASP M\_Synchronization, when included, it means this message is for a publish of a specific object data.

## 6. Security Considerations

The distribution source authentication could be done at multiple layers:

- o Outer layer authentication: the GRASP communication is within ACP ([I-D.ietf-anima-autonomic-control-plane]). This is the default GRASP behavior.
- o Inner layer authentication: the GRASP communication might not be within a protected channel, then there should be embedded protection in distribution information itself. Public key infrastructure might be involved in this case.

## 7. IANA Considerations

TBD.

## 8. Acknowledgements

Valuable comments were received from Brian Carpenter, Michael Richardson, Roland Bless, Mohamed Boucadair, Diego Lopez, Toerless Eckert and other participants in the ANIMA working group.

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

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## Appendix A. Open Issues [RFC Editor: To Be removed before becoming RFC]

1. More reference to the use cases in the introduction.
2. Better explanation of the required context of the Connected-Car case: Not applicable unless the ACP will be extended to the car,

which may not be desirable with the current ACP design, but maybe refocussing on an "autonomous fleet" use-case (e.g.: all cars operated by some taxi like service).

3. Consider use-case/example of firmware update. By abstracting the location of the firmware from the name of the firmware, while providing a way to notify about it, this significantly supports distribution of firmware updates. References to SUIT would be appropriate.
4. Issues discussed in [https://mailarchive.ietf.org/arch/msg/anima/\\_0fYQPBcLPt8xzQee7P4dILsn3A](https://mailarchive.ietf.org/arch/msg/anima/_0fYQPBcLPt8xzQee7P4dILsn3A)
5. Rethink/refine terminology, e.g.: "module" seems to be too prescriptive. Refine proposed extensions.
6. Provide more protocol behavior description instead of only implementation / software module architecture description. Reduce the latter or provide better justification for their presence due to explained interoperability requirements.
7. Better motivation in sections 1..4 of the proposed extensions
8. Consider moving examples from appendices into core-text . Ideally craft a single use-case showing/applying all extensions (most simple use case that uses them all).
9. Refine terminology to better match/reuse-the established terminology from the pre-existing ANIMA documents.

Appendix B. Closed Issues [RFC Editor: To Be removed before becoming RFC]

Appendix C. Change log [RFC Editor: To Be removed before becoming RFC]

draft-ietf-anima-grasp-distribution-00, 2020-02-25:

File name changed following WG adoption.

\_\_Added appendix A&B for open/closed issues. The open issues were comments received during the adoption call.

Appendix D. Real-world Use Cases of Information Distribution

The requirement analysis in Section 3 shows that generally information distribution should be better of as an infrastructure layer module, which provides to upper layer utilizations. In this section, we review some use cases from the real-world where an

information distribution module with powerful functions do plays a critical role there.

#### D.1. Service-Based Architecture (SBA) in 3GPP 5G

In addition to Internet, the telecommunication network (i.e. carrier mobile wireless networks) is another world-wide networking system. The architecture of the 5G mobile networks from 3GPP has been defined to follow a service-based architecture (SBA) where any network function (NF) can be dynamically associated with any other NF(s) when needed to compose a network service. Note that one NF can simultaneously associate with multiple other NFs, instead of being physically wired as in the previous generations of mobile networks. NFs communicate with each other over service-based interface (SBI), which is also standardized by 3GPP [3GPP.23.501].

In order to realize an SBA network system, detailed requirements are further defined to specify how NFs should interact with each other with information exchange over the SBI. We now list three requirements that are related to information distribution here.

- 1) NF Pub/Sub: Any NF should be able to expose its service status to the network and any NF should be able to subscribe the service status of an NF and get notified if the status is available. A concrete example is that a session management function (SMF) can subscribe to the REGISTER notification from an access management function (AMF) if there is a new user equipment trying to access the mobile network [3GPP.23.502].
- 2) Network Exposure Function (NEF): A particular network function that is required to manage the event exposure and distributions. Specifically, SBA requires such a functionality to register network events from the other NFs (e.g. AMF, SMF and so on), classify the events and properly handle event distributions accordingly in terms of different criteria (e.g. priorities) [3GPP.23.502].
- 3) Network Repository Function (NRF): A particular network function where all service status information is stored for the whole network. An SBA network system requires all NFs to be stateless so as to improve the resilience as well as agility of providing network services. Therefore, the information of the available NFs and the service status generated by those NFs will be globally stored in NRF as a repository of the system. This clearly implies storage capability that keeps the information in the network and provides those information when needed. A concrete example is that whenever a new NF comes up, it first of all registers itself at NRF with its profile. When a network service requires a

certain NF, it first inquires NRF to retrieve the availability information and decides whether or not there is an available NF or a new NF must be instantiated [3GPP.23.502].

(Note: 3GPP CT adopted HTTP2.0/JSON to be the protocol communicating between NFs, but autonomic networks can also load HTTP2.0 with in ACP.)

#### D.2. Vehicle-to-Everything (V2X)

Connected car is one of scenarios interested in automotive manufacturers, carriers and vendors. 5G Automotive Alliance - an industry collaboration organization defines many promising use cases where services from car industry should be supported by the 5G mobile network. Here we list two examples as follows [5GAA.use.cases].

- 1) Software/Firmware Update: Car manufacturers expect that the software/firmware of their car products can be remotely updated/upgraded via 5G network, instead of onsite visiting their 4S stores/dealers offline as nowadays. This requires the network to provide a mechanism for vehicles to receive the latest software updates during a certain period of time. In order to run such a service for a car manufacturer, the network shall not be just like a network pipe anymore. Instead, information data have to be stored in the network, and delivered in a publishing/subscribing fashion. For example, the latest release of a software will be first distributed and stored at the access edges of the mobile network, after that, the updates can be pushed by the car manufacturer or pulled by the car owner as needed.
- 2) Real-time HD Maps: Autonomous driving clearly requires much finer details of road maps. Finer details not only include the details of just static road and streets, but also real-time information on the road as well as the driving area for both local urgent situations and intelligent driving scheduling. This asks for situational awareness at critical road segments in cases of changing road conditions. Clearly, a huge amount of traffic data that are real-time collected will have to be stored and shared across the network. This clearly requires the storage capability, data synchronization and event notifications in urgent cases from the network, which are still missing at the infrastructure layer.

#### D.3. Summary

Through the general analysis and the concrete examples from the real-world, we realize that the ways information are exchanged in the coming new scenarios are not just short and instant anymore. More advanced as well as diverse information distribution capabilities are

required and should be generically supported from the infrastructure layer. Upper layer applications (e.g. ASAs in ANIMA) access and utilize such a unified mechanism for their own services.

Appendix E. Information Distribution Module in ANI

This appendix describes how the information distribution module fits into the ANI and what extensions of GRASP are required.

(preamble)

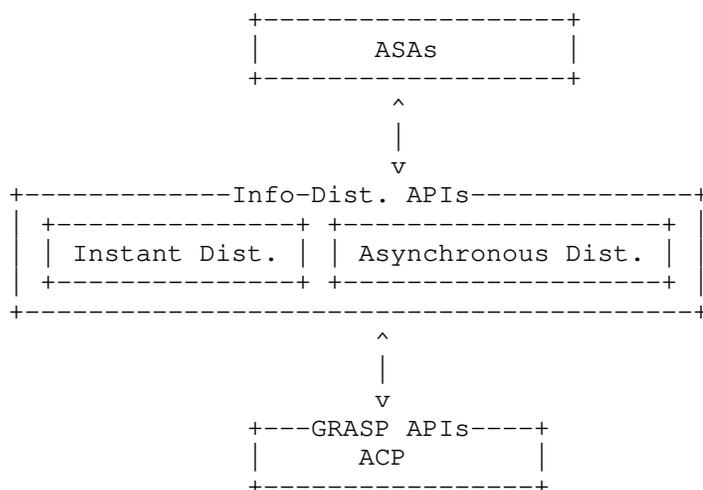


Figure E.1 Information Distribution Module and GRASP Extension.

As the Fig 1 shows, the information distribution module two sub-modules for instant and asynchronous information distributions, respectively, and provides APIs to ASAs. Specific Behaviors of modules are described in Section 5.

Appendix F. Asynchronous ID Integrated with GRASP APIs

Actions triggered to the information distribution module will eventually invoke underlying GRASP APIs. Moreover, EQ and IS modules are usually correlated. When an AF(ASA) publishes information, not only such an event is translated and sent to EQ module, but also the information is indexed and stored simultaneously. Similarly, when an AF(ASA) subscribes information, not only subscribing event is triggered and sent to EQ module, but also the information will be retrieved by IS module at the same time.

- o Storing and publishing information: This action involves both IS and EQ modules where a node that can store the information will be discovered first and related event will be published to the network. For this, GRASP APIs `discover()`, `synchronize()` and `flood()` are combined to compose such a procedure. In specific, `discover()` call will specific its objective being to "store\_data" and the return parameters could be either an `ASA_locator` who will accept to store the data, or an error code indicating that no one could afford such data; after that, `synchronize()` call will send the data to the specified `ASA_locator` and the data will be stored at that node, with return of processing results like `store_data_ack`; meanwhile, such a successful event (i.e. data is stored successfully) will be flooded via a `flood()` call to interesting parties (such a multicast group existed).
- o Subscribing and getting information: This action involves both IS and EQ modules as well where a node that is interested in a topic will subscribe the topic by triggering EQ module and if the topic is ready IS module will retrieve the content of the topic (i.e. the data). GRASP APIs such as `register_objective()`, `flood()`, `synchronize()` are combined to compose the procedure. In specific, any subscription action received by EQ module will be translated to `register_objective()` call where the interested topic will be the parameter inside of the call; the registration will be (selectively) flooded to the network by an API call of `flood()` with the option we extended in this draft; once a matched topic is found (because of the previous procedure), the node finding such a match will call API `synchronize()` to send the stored data to the subscriber.

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