Network Working Group
Internet-Draft
Intended status: Informational
Expires: March 22, 2012

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September 19, 2011

ARIN Draft Policy 2011-5: Shared Transition Space
draft-bdgks-arin-shared-transition-space-03

Abstract

This memo discusses the applicability of a Shared Transition Space, an IPv4 prefix designated for local use within service provider networks during the period of IPv6 transition. This address space has been proposed at various times in the IETF, and more recently come to consensus within the ARIN policy development community where it was recommended for adoption as Draft Policy 2011-5.

Status of this Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on March 22, 2012.

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1. Introduction

As the Internet community approaches exhaustion of unallocated IPv4 numbers, the value of globally unique addresses is becoming manifest. More than ever network operators recognize the need to transition to the IPv6 address family. However, the immediate necessity of continued IPv4 connectivity poses a near-term challenge - without adequate IPv4 resources, most network operators must deploy more efficient addressing architectures and many must deploy address-sharing technologies.

In order to facilitate these operators' need for near-term IPv4 connectivity, [I-D.weil-shared-transition-space-request] proposes the reservation of a /10 IPv4 prefix for use in Service Provider (SP) networks. Referred to as Shared Transition Space, this address block would facilitate SP deployment of non-unique address plans that do not conflict with traditional Private [RFC1918] address space. By using the Shared Transition Space operators may deploy CGN [I-D.ietf-behave-lsn-requirements] internal networks, extranet [RFC4364] communities, and/or SP-local services without consuming Global Unicast Addresses.

However, given the Feb 2011 depletion of the IANA Free Pool inventory [NRO-IANA-exhaust] it is not currently possible for the IANA to reserve an IPv4 /10 prefix as recommended in [I-D.weil-shared-transition-space-request]. Thus the ARIN community has proposed in Draft Policy [ARIN-2011-5] the reservation of a Shared Transition Space from the ARIN inventory of unallocated IPv4 numbers. After much discussion by the ARIN community, [ARIN-2011-5] reached consensus and was recommended by the ARIN Advisory Council for approval by the ARIN Board of Trustees.

Following the community's recommendation of [ARIN-2011-5] the ARIN Board requested clarification from the IAB with regard to responsibilities outlined in [RFC2860]. The ARIN Board received a response in [IAB-response] indicating that the IETF holds responsibility for the reservation of specialized address blocks. Thus, the ARIN Board believes that it is not within ARIN's authority to unilaterally make specialized allocations of the sort proposed in Draft Policy 2011-5. [PPML-022778]

This memo explains the intended use and discusses the merits and drawbacks of using Shared Transition Space.

2. Applicability

2.1. Intended Use of Shared Transition Space

The Shared Transition Space is intended for use by service providers and should not be thought of as additional RFC1918 space. There are a number of specific use-cases for the Shared Transition Space. This section discusses the primary scenarios envisioned at the time of this writing. Equipment vendors and non-ISP network operators should be aware that using the Shared Transition Space outside of its intended scope may result in unpredictable behavior.

2.1.1. CGN

The primary use-case for the Shared Transition Space will be deployment in CGN [I-D.ietf-behave-lsn-requirements] internal networks. A key benefit of CGN is the ability to share a smaller number of Global Unicast Addresses (GUA) amongst a larger number of end-sites.

In one CGN deployment scenario sometimes referred to as NAT444 [I-D.shirasaki-nat444], the CGN internal network is numbered with IPv4 addresses that are not globally routed while the end-sites are numbered with Private [RFC1918] addresses. In this scenario the Shared Transition Space will be used to provide contextually unique IPv4 addresses to end-site CPE devices and intermediate infrastructure. [I-D.shirasaki-nat444-isp-shared-addr]

2.1.2. SP Services & Infrastructure

In networks that contain local services (such as nameservers, content repositories or caches, etc) the Shared Transition Space will offer an alternative to GUA. For instance, video content servers that are available only to customers directly connected to the SP network might be addressed from the Shared Transition Space, preserving GUA for services that require global connectivity. Where these services are accessed by customers who have their own IPv4-only equipment, use of the Shared Transition Space will reduce or eliminate the need for NAT. Similarly, those infrastructure elements which touch IPv4-only customer-managed equipment could also be numbered from the Shared Transition Space. In cases where the provider manages both endpoints, IPv6 should be used.

2.1.3. Note of Caution

In any case, care must be taken to ensure the Shared Transition Space is not used in scenarios where routing may be ambiguous. For instance, when multiple provider networks may be simultaneously reachable the use of Shared Transition Space might result in address conflicts etc. Conversely, operators may choose to allow (not

filter) ICMP messages from the Shared Transition Space in order to enable Path MTU Discovery etc. This topic requires further investigation so that best practices may be developed.

2.2. Alternatives

A number of possible alternatives to Shared Transition Space have been proposed and/or discussed by the Internet community. See, for instance, [RFC6319] for a discussion of alternatives and potential issues. This section outlines these possible alternatives and briefly discusses their applicability.

2.2.1. Global Unicast Addresses

Every discussion of the Shared Transition Space begins with an assumption that Global Unicast Addresses (GUA) are a preferable choice for numbering. This is almost always technically true. However, given the fundamental driver of IPv4 address exhaustion, GUA is not a pragmatic alternative to the Shared Transition Space.

Additionally, if various organizations use various GUA ranges to number CGN zones, it will be difficult for other networks and/or systems to deterministically know if the endpoints are using true Internet reachable IPs, or if the source network may be using them as CGN zone space. This situation would likely lead to additional technical issues during various leakage conditions, filter rule issues (routing) and for CDN or other third party providers who may be present within the source network, to name a few.

2.2.2. Private

In each of the use-cases for Shared Transition Space, it may be possible to instead use Private [RFC1918] address space. In situations where all endpoints in the network are managed by a single organization, this may be a viable option. However when end-sites are administered by different organizations and/or individuals, the possibility of address conflict becomes a significant risk to operations. Private [RFC1918] address space is not generally intended to be used for purposes which cross administrative domains. Further, these recommendations involve use of the Shared Transition Space to provide services in one administrative domain to leaf networks which are generally single-homed to the serving administrative domain. This is also a significant difference from the intent of Private [RFC1918] address space.

A study of DNS traffic [v6ops-msg06187] has shown that effectively all of the existing Private [RFC1918] address space is currently being used by end-sites attached to the Internet. While individual

network environments may vary in this regard, most SP operators face the risk that their use of Private address space will conflict with their customer end-sites. defined private space is not generally intended to be used for purposes which cross administrative domains.

In the event of conflict, it is possible that the end-site CPE will fail and/or not function correctly. Some CPE implementations are known to support overlapping addresses on the "inside" and "outside" interfaces, however many others are known to fail under such circumstances. For SP operators, the Shared Transition Space offers a less risky alternative to GUA that retains the benefit of non-conflict.

Also, the use of Private [RFC1918] address space on interfaces and hosts often causes default behaviors on such hosts which may not be desirable when the endpoint is actually connected to the Internet. There are often behavioral expectations for Internet connected endpoints, regardless of them being subject to a NAT.

Incorrect affiliation of the WAN side interface being in a "protected" zone and/or on a trusted network may not be desirable. With NAT444 deployments, it is important that the endpoint (i.e. CPE) behave like any other Internet node. One example of this from our testing was observed behaviors where some CPEs did not filter and/or firewall correctly when Private [RFC1918] address space was used on both WAN and LAN interfaces.

2.2.3. Class E

One proposed alternative to Shared Transition Space is the re-classification and use of the 240.0.0.0/4 "Class E" address space as unicast. This has been proposed, for instance, by [I-D.fuller-240space] and [I-D.wilson-class-e]. While this alternative might be possible in tightly constrained environments, where all of the network elements are known to support Class E address space, it is not generally useful in the use-cases described above. At this time, a significant number of IPv4 stack implementations treat the Class E address space as reserved and will not route, forward, and/or originate traffic for that range. For example, [CISCO] states that: "No addresses are allowed with the highest-order bits set to 1111." For the scenarios described herein, it should be noted that this alternative would create additional SP dependencies on customer selected CPE support for Class E addressing.

2.2.4. Prefix Squatting

An unfortunate alternative to the Shared Transition Space is "prefix squatting", in which the operator re-uses another organization’s IPv4

allocation for their own numbering needs. When this approach results in the other organization's prefix being announced globally by the "squatting" operator, it is often referred to as "prefix hijacking". However, this discussion is focused on scenarios in which the prefix is not announced globally but is, rather, used for internal numbering only.

In this scenario, the allocation may not be routed globally by the legitimate address holder, making it attractive for such purposes. Or it may be routed but "uninteresting" to the SP network's endpoints. In either case there is a potential for conflict in the event that any end-site actually wishes to communicate with the legitimate address holder. Indeed, various RIRs attempt to discover and "recycle" abandoned or unused IPv4 address space, making it more likely that such conflicts will be experienced in time. As such, this alternative is to be discouraged with prejudice.

It is important to note that there are no behavioral advantages to using "squat space" over using assigned "shared space". Both options subject the CPE to the same general behaviors (GUA space, but not globally reachable). The only real difference is the negative impacts of squatting (as noted above) and the advantages of a community coordinated and standardized prefix.

The primary reason that any network would be likely to adopt "prefix squatting" is if they are faced with the operational realities of CGN before/without the allocation of a shared transition space.

2.2.5. Regional Re-use of Allocated Prefix

Similar to "Prefix Squatting" but significantly less dangerous, this alternative involves the reuse by an operator of their own address allocations. In this scenario, a network operator might use the same prefix for multiple "regions" and/or extranet communities. For instance, in CGN deployments the operator might reuse the same GUA prefix across multiple geographic regions (e.g. without announcing it globally).

Here again, it is important to note that there are no behavioral advantages gained over a "shared space" but there is the added community cost of each network having to dedicate a unique block of addresses to this purpose, consuming far more resources than a single block of "shared space".

2.2.6. Consortium

In the event that the Internet community doesn't set aside an IPv4 prefix for Shared Transition Space, it is possible that a number of

SP operators can come together and designate an address block to be "shared" amongst them for an identical purpose. This would have the same technical merits as an IETF and/or RIR sponsored Shared Transition Space, however it would lack the efficiency of a community coordinated and standardized prefix for such purposes, gain no behavioral advantages, remove the deterministic nature of managing a single range and also subjects the Internet (users of the space) to additional risk since any member of the consortium who has contributed space could later pull out and potentially cause disruptions in multiple networks.

3. Analysis of Benefits

3.1. Continued Operation Post-exhaustion

Availability of a Shared Transition Space helps SPs continue to meet the demands of IPv4 addressing and/or connectivity post exhaustion. For environments where CGN in a NAT444 scenario is necessary, addresses from this space can be used to provide addressing for the network between the CGN device(s) and CPE which will enable IPv4 flow continuity for customers using these services. In other circumstances, the shared transition space allows SPs to number devices in the network which do not require global reachability without the need for fulfillment thorough an RIR.

3.2. Delayed Need for CGN Deployment

If operators are required to use their individually allocated GUA where "shared space" would have applied, e.g. for internal services, they will face exhaustion sooner and thus be forced to deploy CGN sooner as well. Operators may be able to postpone the deployment of CGN by using "shared space" for internal uses, because that allows more efficient use of their remaining GUA in places where global uniqueness is truly mandatory.

Further, without this shared transition space, some service providers may be forced to reclaim GUA from existing customers in order to deploy CGN and address the required infrastructure. Having this transition space will enable deployment of CGN where it is required, in a manner that is less disruptive and with impact to fewer customers.

3.3. Recovery of Existing Addresses

The shared transition space can also be used to number and reclaim IPv4 addresses within provider networks which do not require global reachability. This option can be used by many networks worldwide, it

provides an option for using currently assigned space much more efficiently.

3.3.1. Re-deployment Where Needed

Operators can re-deploy recovered addresses for customers that need them (including new / static / GUA customers), hosted servers, etc. or to facilitate other efforts that might provide even more efficient use of GUA space within the network. The freed addresses can be assigned to endpoints which require IPv4 global reachablity and thus help delay and/or remove the need for CGN.

3.3.2. Return or Transfer

In cases where the operator is not deploying CGN and doesn't need the recovered addresses, they can be made available to others that do need them for connectivity to the public IPv4 Internet. This may be through voluntary return to the RIR, or through transfer to another network operator. For example, in the ARIN region, there are transfer mechanisms defined in the ARIN NRPM 8.3 [ARIN-NRPM-8.3].

3.4. Impact on Allocations of RIR Inventory

While making Shared Transition Space available to the community may or may not lessen the demand on the RIRs for allocations, it will help ensure that the address resources which remain in inventory are used most efficiently, maximizing the use of that inventory for services that require Global Unicast Addresses.

3.5. Benefit of Standardization

Standardizing on a single block will help the community develop standard ways of selecting, routing, filtering and managing shared space. This task would be much more difficult or impractical for any of the alternative options.

Standard internal routing policy and filtering can be applied uniformly inside network environments. Additionally, exchange points between networks can have standard policies applied allowing operators to protect each other from CGN zone IPs leaking between networks. This may not be possible with squat space since many operators will not divulge what space may be used and with Private [RFC1918] address space where each operator may only be able to free up certain portions of the space which are not likely to be consistent between networks.

3.6. IPv6 Deployments

Operators will need to grapple with the need to provide IPv4 based flow continuity to customers post exhaustion. By removing the burden of operators needing to find adequate IPv4 address space to meet the needs that a Shared Transition Space can fulfill, they can concentrate on the real task at hand: Deploying IPv6.

4. Analysis of Detractors' Arguments

4.1. It Breaks

4.1.1. NAT is Bad

NAT is understood to be less than optimal [RFC6269], especially when implemented as CGN [I-D.donley-nat444-impacts]. That said, it is a necessary technology for many networks and cannot be completely avoided. Since the number of IPv4 Internet endpoints will exceed the number of IPv4 addresses which are available for Internet connectivity, NATs are needed.

While the authors agree that "NAT is bad", it must also be understood that shared transition space does not change the fundamental motivations or issues with NAT and so those problems will not be discussed at length here.

4.1.2. Breaks Assumptions about Address Scope

Some host or CPE functions incorrectly assume global reachability based on the type of address that is configured, potentially causing issues when deployed in a NAT444 scenario. Whether an operator uses this proposed Shared Transition Space or some other GUA space (e.g. through squatting or reuse), the net effect on hosts and/or CPE making such assumptions about reachability is identical. Conversely, with an identified Shared Transition Space hosts that make these mistaken assumptions can be modified to treat the identified block as having restricted reachability semantics. This would not be possible (or at least not nearly as easy) with the other solutions.

4.1.2.1. 6to4

Although 6to4 can break in CGN scenarios using the Shared Transition Space, recent guidance suggests that it should be turned off by default. [RFC6343] [I-D.ietf-v6ops-6to4-to-historic] Indeed, recent versions of operating systems de-preference 6to4 addresses as described in [I-D.ietf-6man-rfc3484-revise], mitigating effects from incorrect 6to4 instantiation behind a firewall that obstructs its

function.

Since the volume of impacted endpoints will be low, operators can likely manage the disabling of 6to4 when needed. More fundamentally, broken 6to4 should not be an issue if service providers deploy (and user equipment supports) native IPv6 connectivity.

4.1.3. Potential Misuse as Private Space

Shared Transition Space is intended to be used solely by Service Providers for IPv4 to IPv6 transition purposes. [I-D.weil-shared-transition-space-request] The value of a Shared Transition Space may be diminished if commonly misused by end-sites as generic Private addresses. Thus, the reservation must be clearly designated for use by SPs that are providing infrastructure as described herein.

4.2. It's Not Needed

4.2.1. Nobody Will Use It

This argument is simply incorrect. Post IPv4-exaustion, any SP that wishes to continue providing IPv4 connectivity will necessarily deploy network architectures and technologies that require such an address space. Thus, in absense of a designated Shared Transition Space, operators will use GUA space in essentially the same ways described in this memo, with or without IETF or RIR acknowledgement.

4.2.2. ISPs Are Not Actually Growing

While customer growth for some ISPs has slowed, for many service providers new services are growing at a faster rate than has been anticipated. Wireline voice customers for example require two-way communication paths to allow them to function properly. IP enabled televisions is another example of devices that support video and voice services and require IP addresses. The only way to maintain these services, which in many cases are considered lifeline, is to provide them with an IP address that is unique within the service provider network.

Likewise, growth continues to exist in some geographical regions. While some areas have slower growth, as a result of significant penetration of Internet access, there are still many areas with unmet needs, growing populations, or both.

4.2.3. RIR IPv4 Inventory is Not Actually Exhausted

With the IANA inventory essentially exhausted [NRO-IANA-exhaust] it is only a matter of time before each of the RIRs are unable to satisfy requests for IPv4 addresses. [GIH-When] In fact, the APNIC has already allocated all but their final /8 of inventory [APNIC-final-slash8] and is no longer making allocations larger than a /22 prefix. Each of the other RIRs is on a trajectory toward exhaustion in the near future.

4.2.4. ISP IPv4 Inventory is Not Actually Exhausted

While some SPs have existing inventory that will outlast the RIR inventories, this is not universally true. In fact, the distribution of IPv4 number resources amongst operators is highly variable (based on size, history, etc) and in the worst cases is already becoming problematic.

4.3. Address Inventory

4.3.1. Shared Transition Space Uses Up Address Inventory

While true that this Shared Transition Space will remove a block of global unicast IPv4 addresses from the free pool, it must also be noted that the use of the same "shared space" repeatedly across multiple networks will very likely increase the available pool of unique IPv4 addresses through operational efficiency. For example, if just two operators use their own GUA /10, the Internet community effectively loses a /9 of unique space while if both operators use the same "shared" /10, the Internet community loses that single /10. This benefit becomes more significant as more operators use the Shared Transition Space.

It remains to be seen whether the reservation of a Shared Transition Space will actually delay the impending exhaustion of RIRs' IPv4 inventory. Certainly, the availability of this Shared Transition Space will satisfy a number of demands that would otherwise become requests for GUA resources. However, whether this translates to an actual reduction in requests is up to the RIRs and requesting organizations. Regardless of the allocation of Shared Transition Space, RIR IPv4 exhaustion may happen at roughly the same time. However, as noted above, Shared Transition Space does provide the opportunity for more efficient use of the remaining RIR IPv4 addresses. Additionally, the reservation of a Shared Transition Space will enable continued deployment of IPv4 connectivity by SP networks beyond the free pool depletion horizon; another clear benefit.

4.3.2. /10 is not Enough

Although previous requests for Shared Transition Space asked for a full /8, it has been determined by many operators that a /10 will in fact be sufficient. A /10 provides for roughly 4 million hosts and although many of the largest SPs have subscriber counts in the tens of millions, none will be placing all of their subscribers behind a single CGN. In the event that a /10 does not provide enough addresses for an operators entire CGN deployment, it could be re-used multiple times in distinct "NAT zones" or regions.

4.4. IPv6 Arguments

4.4.1. Use IPv6 Instead

Although IPv6 is the strategic long term answer for IPv4 address exhaustion, it does not immediately solve IPv4 connectivity requirements. There is an entire eco-system which exists on the Internet today and is not IPv6 ready at this time [I-D.arkko-ipv6-only-experience]. IPv4 flow continuity will be required for at least several years.

Many businesses have long procurement and fulfillment cycles which will need to be used to upgrade networks to support IPv6. Also, the consumer (home) space is years away from being all IPv6 capable. Many homes are filled with IPv4 only consumer electronics, computers, TVs, accessories and other systems.

There are still a number of products that are either not IPv6 compliant, or for which the necessary criteria for being "IPv6 compliant" is unclear or undefined. Some examples include security products, a large number of software applications, and there are still production systems (both inside companies and as products) being rolled out that are not IPv6 aware.

4.4.2. Delay of IPv6 Deployment

The whole Internet needs to get to IPv6 more or less at the same time in order to avoid significant deployment of transition technologies. This proposal may help delay some transition technology deployment while IPv6 deployments move ahead. More IPv6 should mean less transition technology.

5. ARIN Draft Policy 2011-5

5.1. History

5.1.1. Shared Address Space

Proposals for additional Private space date back at least to [I-D.hain-1918bis] in April 2004. Some of these proposals and surrounding discussion may have considered similar use-cases as described herein. However, they were fundamentally intended to increase the size of the [RFC1918] pool, whereas a defining characteristic of Shared Transition Space is that it is distinctly not part of the Private [RFC1918] address pool.

Rather, the Shared Transition Space is reserved for more narrow deployment scenarios, specifically for use by SPs to meet the needs of ongoing IPv4 connectivity during the period of IPv6 transition. This key feature emerged in more recent proposals such as [I-D.shirasaki-isp-shared-addr] in June 2008 where a proposal to set aside "ISP Shared Space" was made. During discussion of these more recent proposals, many of the salient points where commented upon, including challenges with RFC1918 in the ISP NAT Zone, Avoidance of IP Address Conflicts, and challenges with 240/4.

This effort was followed up by [I-D.weil-opsawg-provider-address-space] in July 2010 which was re-worked in November 2010 as [I-D.weil-shared-transition-space-request]. These latter efforts continued to point out the operators' need for Shared Transition Space, with full acknowledgement that challenges may arise with NAT444 as per [I-D.donley-nat444-impacts] and that such space does not reduce the need for IPv6 deployment.

Most recently, following exhaustion of the IANA's /8 pool [NRO-IANA-exhaust], this proposal has been discussed by various RIR policy development participants. As described herein, the body of ARIN policy development participants has reached consensus and recommended a Shared Address Space policy for adoption [ARIN-2011-5].

This history shows that operators and other industry contributors have consistently identified the need for a Shared Transition Space assignment, based on pragmatic operational needs. The previous work has also described the awareness of the challenges of this space, but points to this option as the most manageable and workable solution for IPv6 transition space.

5.1.2. Proposal

The following is a brief history of the proposal for Shared Address Space within ARIN, ultimately resulting in the recommendation of ARIN

Draft Policy 2011-5 [ARIN-2011-5].

In January 2011, a policy was proposed to the ARIN policy development community called ARIN-prop-127: Shared Transition Space for IPv4 Address Extension [ARIN-prop-127]. This policy proposal would reserve an IPv4 /10 prefix by ARIN, to be shared by any Service Providers who wish to use it with no further registration actions required.

After generating much discussion (over 100 posts) on the ARIN Public Policy Mailing List (PPML), the ARIN Advisory Council (AC) accepted the proposal as Draft Policy 2011-5 [ARIN-AC-28Jan2011], formally announced on PPML 3 February 2011 [ARIN-2011-5-AC].

On 14 February 2011, ARIN staff made the following statement with regard to 2011-5: "In keeping with the spirit of RFC 2860 with respect to the assignment of specialized address blocks, ARIN Staff will consult with the IANA and the IAB regarding implementation of this draft policy." [ARIN-2011-5-Staff]

In the ensuing PPML discussion there was a roughly two to one ratio of those clearly in support of the policy versus those clearly against. ARIN Draft Policy 2011-5 was then discussed at the ARIN XXVII public policy meeting on 12 April 2011. Following the discussion, there was a straw poll of the room. With a total number of people in the meeting room and remote of 116; in favor of it were 30 and against it were 15. [ARIN27.2011-5]

Seeing an obvious need in the service provider community, the AC voted to send the Draft Policy to last call [ARIN-AC-13Apr2011] for final comments 18 April through 2 May 2011. [ARIN-2011-5-LC] Following a strong show of support from the operator community during last call, the AC voted [ARIN-AC-19May2011] to recommend adoption of 2011-5 to the ARIN Board of Trustees with a vote of 10 in favor and 2 abstentions. [ARIN-2011-5-Rec]

Following this recommendation, ARIN staff consulted with the IAB and IANA as committed. The IAB response [IAB-response] stated, in short, that they believed the adoption of [ARIN-2011-5] was in conflict with the provisions in [RFC2860] and requested that the community re-review the operational and technical merits of shared transition space in the IETF. That process is now underway, with this draft an attempt at more fully analyzing said operational and technical merits.

5.2. Policy Text

Draft Policy ARIN-2011-5

Shared Transition Space for IPv4 Address Extension

Date: 20 January 2011

Policy statement:

Updates 4.10 of the NRPM:

A second contiguous /10 IPv4 block will be reserved to facilitate IPv4 address extension. This block will not be allocated or assigned to any single organization, but is to be shared by Service Providers for internal use for IPv4 address extension deployments until connected networks fully support IPv6. Examples of such needs include: IPv4 addresses between home gateways and NAT444 translators.

Rationale:

The Internet community is rapidly consuming the remaining supply of unallocated IPv4 addresses. During the transition period to IPv6, it is imperative that Service Providers maintain IPv4 service for devices and networks that are currently incapable of upgrading to IPv6. Consumers must be able to reach the largely IPv4 Internet after exhaustion. Without a means to share addresses, people or organizations who gain Internet access for the first time, or those who switch providers, or move to another area, will be unable to reach the IPv4 Internet.

Further, many CPE router devices used to provide residential or small-medium business services have been optimized for IPv4 operation, and typically require replacement in order to fully support the transition to IPv6 (either natively or via one of many transition technologies). In addition, various consumer devices including IP-enabled televisions, gaming consoles, medical and family monitoring devices, etc. are IPv4-only, and cannot be upgraded. While these will eventually be replaced with dual-stack or IPv6 capable devices, this transition will take many years. As these are typically consumer-owned devices, service providers do not have control over the speed of their replacement cycle. However, consumers have an expectation that they will continue to receive IPv4 service, and that such devices will continue to have IPv4 Internet connectivity after the IPv4 pool is exhausted, even if the customer contracts for new service with a new provider.

Until such customers replace their Home Gateways and all IPv4-only

devices with IPv6-capable devices, Service Providers will be required to continue to offer IPv4 services through the use of an IPv4 address sharing technology such as NAT444. A recent study showed that there is no part of RFC1918 space which would not overlap with some IPv4 gateways, and therefore to prevent address conflicts, new address space is needed.

Service providers are currently presented with three options for obtaining sufficient IPv4 address space for NAT444/IPv4 extension deployments: (1) Request allocations under the NRPM; (2) share address space with other providers (this proposal); or (3) use address space allocated to another entity (i.e. 'squat'). Of the three options, option 2 (this proposal) is preferable, as it will minimize the number of addresses used for IPv4 extension deployments while preserving the authority of IANA and RIRs.

Timetable for implementation: immediately

6. Acknowledgements

The authors would like to thank the following individuals for their contributions: John Curran, David Farmer, Jeffrey Finkelstein, William Herrin, and Dan Wing.

The authors would also like to thank the following people for their review, comments, and support: Gary Buhrmaster, Chris Donley, Wes George, Chris Metz, Richard Von Scherr, and Lane Wigley.

7. IANA Considerations

Upon notification by the IAB that that an address reservation should be made, ARIN is willing to proceed with the implementation of its Draft Policy 2011-5 which would result in ARIN reserving IPv4 /10 block for shared transition. The IANA is to record the allocation of the IPv4 address block for this purpose. Alternatively, the IAB may direct the IANA to request return of sufficient address space from ARIN's available IPv4 number resource pool to allow the IANA to perform this reservation directly.

8. Security Considerations

This memo makes reference to a number of deployment scenarios that have unique security considerations, and the reader is advised to investigate these independently.

While this memo does not introduce any specific technical issues that may be subject to detailed security considerations, it does reccommend the reservation of a new IPv4 address space that might have unique properties when deployed. As such, all implementors of this Shared Transition Space are encouraged to consider carefully the best practices associated with the use of this space, including considerations relating to filtering, routing, etc.

9. Informative References

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OPSAWG WG
Internet-Draft
Intended Status: Informational
Expires: 24 November 2011

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May 24, 2011

Inter-Carrier OAM Requirements
draft-georgiades-opsawg-intercar-oam-req-00.txt

Abstract

This draft considers inter-carrier OAM requirements for supporting end-to-end OAM functionality and mechanisms development in a multi-operator environment. It attempts to summarize and discuss the already proposed OAM requirements addressed in IETF [RFC5706, RFC5860], ITU-T [Y.1710, Y.1730], MEF [MEFOAM] and IEEE [IEEE1, IEEE2] which were mainly proposed on a per transport technology basis, and introduce the need for a distinction and additional requirements for the inter-carrier OAM operations.

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1 Introduction

OAM functionality is important in network operation for ease of monitoring including fault notification and isolation, for verifying network performance, and to reduce operational costs. To pursue end-to-end services delivery crossing domains that are heterogeneous in terms of technologies (circuit transport networks and connection-oriented packet transport networks) as well as accommodate for the different commercial administration/operation policies of carriers, the distinction of inter-carrier OAM requirements (as opposed to OAM requirements per technology) must be addressed.

OAM operations have been considered for different data transport technologies by different standardization bodies. Some solution examples include ATM OAM ITU-T I.610 [I.610], IEEE 802.3-2008 [IEEE1], ITU-T Y.1730 [Y.1730], ITU-T Y.1710 [Y.1710], IETF RFC 5706 [RFC5706], IETF RFC 5860 [RFC5860]. These protocols have been designed by different working groups to handle three main functions namely: (A) Failure Detection and Diagnostics, (B) Recovery, and (C) Performance Monitoring for a particular technology including SONET & SDH, ATM, MPLS and Carrier Ethernet. Inter-operability considerations between different OAM mechanisms proposed for the different transport technologies have been left for future studies. Although some of the proposed OAM protocols do mention interoperability considerations, requirement details and solutions for these are usually out of the scope. Moreover considering common syntax among protocols to resolve interoperability issues has proven difficult.

OAM functions have been proposed mainly for fault management but also performance monitoring. [Y.1731] lists the following functions for Ethernet fault management: Continuity Check, Loopback, Link Trace, Alarm Indication Signal, Remote Defect Indication, Locked Signal, Test Signal, Automatic Protection Switching, Maintenance Communication Channel, Experimental OAM and Vendor Specific OAM. For Ethernet performance monitoring [Y.1731] lists the following necessary functions: loss measurement, delay measurement and throughput measurement.

A similar approach was followed for the development of other OAM mechanism mainly on a per technology basis. Inter-operability and inter-carrier issues have not been addressed thoroughly.

1.1 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].

OAM

Operation, Administration and Maintenance Maintenance Entity (ME) It represents an entity that requires management.

MEG

Maintenance Entity Group (MEG) consists of the MEs that belong to the same service inside a common OAM domain. For a Point-to-Point EVC, a MEG contains a single ME. For a Multipoint-to-Multipoint EVC of n UNIs, a MEG contains n*(n-1)/2 MEs.

OAM transparency

This term refers to the ability to allow transparent carrying of OAM packets belonging to higher level MEGs across other lower level MEGs when the MEGs are nested.

In-service OAM

It refers to OAM actions which are carried out while the data traffic is not interrupted with an expectation that data traffic remains transparent to OAM actions.

On-demand OAM

It refers to OAM actions which are initiated via manual intervention for a limited time to carry out diagnostics.

Proactive OAM

It refers to OAM actions which are carried out continuously to permit proactive reporting of fault and/or performance results.

In-Service OAM

It refers to OAM actions which are carried out during data delivery e.g. for monitoring performance.

Out-of-service OAM

It refers to OAM actions which are carried out while the data traffic is interrupted.

On-path service NSP

A transit NSP who is used as a traffic carrier or service provider of a particular service.

Service-based OAM

Service Level OAM relates to any operations which are associated with a particular service. A good example is the delivery of the agreed throughput (service issue) as opposed to allocated bandwidth for the link/segment (network resource issue).

Network-based OAM

Network-based OAM relates to any operations which are associated with a particular network links, network segments, network resources etc. A good example is the delivery of the agreed bandwidth on a network segment (network resource issue) as opposed to the actual throughput delivered (service issue).

Carrier

A carrier is an organization that provides communications and networking services; Also referred to as a Network Service Provider (NSP) in the draft.

Region

A region is considered to be a collection of network elements under a single technology.

Domain

A domain is considered to be any collection of network elements within a common sphere of address management or path computational responsibility. Examples of such domains include IGP areas and Autonomous Systems;

2. Inter-carrier OAM Requirements

Requirements for Operational, Administration and Maintenance have already been defined in detail by ITU-T, IETF and MEF, regarding the single-domain scenario.

OAM Requirements considered so far depend mainly on the data transport network technology they aim to support. Y.1710 for example has defined OAM requirements for OAM functionality for MPLS networks. Similarly Y.1730 defined requirements for OAM functions in Ethernet-based networks.

Different OAM protocols have been recommended and used for different data transport technologies. Also different Networks Service

Providers (NSPs) may chose to use different OAM models to monitor their operation, maintenance and fault detection, checking network devices possibly from different vendors, different models and different releases. This gives rise to several considerations when dealing with interconnected heterogeneous networks and inter-NSP scenarios particularly in cases where the end-to-end OAM control information is of interest.

Current OAM functionalities do not guarantee interoperability among different transport technologies and certain technologies (e.g. Ethernet transport) are not sufficient to adequately support advanced end-to-end services in inter-carrier scenarios.

This draft aims to emphasize on end-to-end inter-carrier OAM requirements and the need to consider a twofold set of requirements derived both from technological aspects but also technical requirements derived from inter-carrier business considerations.

More specifically OAM inter-carrier requirements will need to consider interoperability issues among different transport technologies such as IP/MPLS, MPLS-TP, Ethernet, OTN etc. Inter-technology OAM requirements and inter-operability requirements between technologies has not been defined thoroughly within the different standardization bodies (IETF, ITU-T, MEF, IEEE) which tend to focus more on a per technology basis.

In addition, inter carrier networking involves, besides the technological aspects, commercial aspects that by nature exist in any cooperation between different business entities and are necessary for inter-carrier operation, administration and management raise other technical requirements. Furthermore some network events that are detected and measured by end to end OAM such as failures may require customer compensation and, in consequence, inter carrier reimbursements. The current OAM system does not clearly provide trusted means for determining the location and the duration of failures in the environment of multi carrier where each carrier uses different systems for measuring and logging the events.

To handle different possible scenarios for OAM it is important to categorize the network scope that OAM support will be designed for. The network scope may contain homogenous technological domains (or regions), heterogeneous domains, and even different carriers (network operators). Moreover it may be composed by elements belonging to different technologies and having different switching capabilities. The major data transport technologies are considered including Multi-Protocol Label Switching - Transport Profile (MPLS-TP), Wavelength Switched Optical Networks (WSON) and corresponding switching capabilities like Packet Switching Capability (PSC) and Lambda

Switching Capability (LSC) respectively.

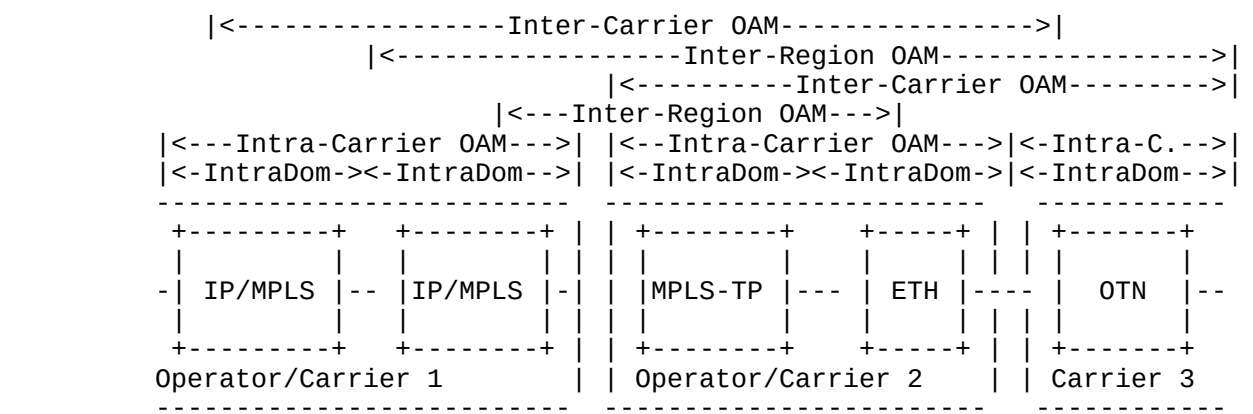

Figure 1 End-to-end OAM Operation Areas Definitions

Figure 1 shows how in a real end-to-end network scenarios, different OAM areas of operation are depicted and the granularity level can be summarized as follows:

i) Inter-Carrier OAM (between different network operators, same or different technologies)
ii) Inter-Region OAM (between regions of different technologies, same or different carriers)
iii) Intra-Carrier OAM (within a single carrier, between homogenous or heterogeneous regions i.e. different technologies)
iv) Intra-Domain OAM (i.e. single technology, single domain)

Such identification of the OAM signaling range granularity proves necessary for accommodating for single/multi-operator environment, single/multi-regions or a combination of these. Intra-domain OAM e.g. section or link OAM etc. are not in the scope of this draft.

It is worth noting that, until now, little attention has been paid to the inter-region/inter-carrier cases and no clear distinction from intra-region/intra-carrier requirements has been made by standardization bodies.

Another important differentiation which is depicted in this draft and it is of great importance particularly in inter-carrier operations is Service Level OAM vs. Network Level OAM.

Service Level OAM relates to any operations which are associated with a particular service. A good example will be the delivery of the agreed throughput (service issue) as opposed to allocated bandwidth for the link/segment (network resource issue). Network-based OAM

relates to any operations which are associated with a particular network links, network segments, network resources etc. A good example will be the delivery of the agreed bandwidth on a network segment (network resource issue) as opposed to the actual throughput delivered (service issue).

3.1. OAM single region/single carrier transport network requirements

Both IETF and ITU-T have identified OAM requirements for a single region transport network, for different technologies. In general the requirements can be grouped under these two main categories: architectural requirements and functional requirements. Most of the single domain OAM requirements are relevant for the inter domain as well. The most important architectural requirements are:

A. Independence of the OAM level from service and underlying networks. In other terms, as reported in [RFC 5860] "The set of OAM functions must be a self-sufficient set that does not require external capabilities to achieve the OAM objectives"

B. Bidirectional application of OAM mechanisms should be possible.

C. Application of OAM functions to unidirectional point-to-point and point-to-multipoint connections should be possible.

The functional requirements might be split into two further sub-categories with regard to the task they are facing with: fault detection and locating and performance monitoring. The main OAM mechanisms required by the joint ITU-T - IETF working group for fault management are:

A. Continuity check / verification

B. Alarm suppression C. Lock indication D. Diagnostic test E. Trace-route F. Remote defect indication

The main OAM mechanisms required by the joint ITU-T - IEFT working group for performance monitoring are:

A. Packet loss measurement

B. Delay and jitter measurement

On the other hand MEF, more focused on service OAM, has specified the following list of requirements:

A. Service OAM should discover other elements in the Metro Ethernet Networks (MEN)

B. Service OAM should monitor the connectivity status of other elements (active, not-active, partially active).

C. Performance monitoring should estimate Frame Loss Ratio (FLR) Performance, Frame Delay Performance, and Frame Delay Variation (FDV) Performance.

D. OAM frames should be prevented from "leaking" outside the appropriate OAM domain to which they apply.

E. The OAM frames should traverse the same paths as the service frames

F. The OAM should be independent of but allow interoperability with the underlying transport layer and its OAM capabilities

G. The OAM should be independent of the application layer technologies and OAM capabilities

3.2. OAM for inter-carrier transport networks

This subsection deals with inter-carrier and hence also inter-region issues in the existing standards. The goal is to identify gaps and to discuss new requirements to fill these gaps. In many cases network services traverse several carriers and regions, and in long distance services this is the most probable case. A multi-carrier and multi-regional environment poses special technical and commercial OAM requirements that should be defined and addressed.

In particular, OAM in multi-carrier networks has commercial aspects that do not exist in single carrier networks. Indeed, in case of failure or out-of-SLA service delivery, the violating carrier should compensate its partner carriers or the end customer. Based on the information made available by the OAM tools, the carriers should agree on the root cause.

Unfortunately, at present no reliable means to carry out this OAM based compensation procedure are available in existing standards. Furthermore, the out-of-service duration is a significant factor when calculating the compensation/penalty in case of failure. Yet, currently, each service provider measures the out-of-service duration independently; as a result, it is difficult to agree on the out-of-service duration and, as a consequence, on the amount of compensation. The existing standards for OAM in transport networks do not clearly address the above mentioned problems; therefore, in a multi-carrier environment, the following requirements may be specifically defined by considering that Inter-carrier OAM should address or reference how inter-region or

inter-technology requirements are addressed. Technological inter-operability issues and inter-region OAM issues should be addressed separately to inter-carrier considerations.

A. Inter-carrier OAM system should be supported by MEs that are handled by different operators (carriers).

B. Inter-carrier OAM system should provide in-service reliable means to the network service providers (NSPs) to prove, in case of failure, which is the failing transit carrier or transit NSP etc.

C. Inter-carrier OAM system should provide optional in-service notification messages that could be used to inform on-path service NSPs of other on-path NSPs service degradation. This includes for example any deviation from the SLA agreement and related parameters (Jitter, Packet Loss, Throughput etc.).

D. Inter-carrier OAM system should provide reliable means to measure an NSP’s out-of-service provisioning duration; such measurement could be agreed by all involved parties.

E. Inter-carrier OAM should provide means for confidentiality and privacy between involved carriers.

F. Inter-carrier OAM should have the option of disclosing information forwarded by transit NSPs that are not involved under the same inter-carrier OAM agreement.

4 Conclusions

The exiting OAM standards do not clearly differentiate between inter-carrier, inter-region (inter-technology) as well as different layer defined OAM requirements such as on the network level, service level etc. This draft aimed to achieve this and focuses on the inter-carrier requirements only. The majority of these requirements were derived from the nature of service provisioning between different network service providers.

OAM is an essential tool set for network operation and service provisioning, and in case of inter-carrier it can help to settle responsibility disputes in case of failures and performance degradations. This document reviews the existing OAM standards, identifies gaps, and discusses new requirements for the inter domain and inter carrier scenarios.

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Acknowledgements

This work has been partially supported by the EU ICT STRONGEST and EU ICT ETICS projects. Some technological considerations and requirements resulted from collaboration with the EU ICT MAINS Project.

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Intended status: Informational
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An Overview of the IETF Network Management Standards
draft-ietf-opsawg-management-stds-07

Abstract

This document gives an overview of the IETF network management standards and summarizes existing and ongoing development of IETF standards-track network management protocols and data models. The document refers to other overview documents, where they exist and classifies the standards for easy orientation. The purpose of this document is on the one hand to help system developers and users to select appropriate standard management protocols and data models to address relevant management needs. On the other hand, the document can be used as an overview and guideline by other Standard Development Organizations or bodies planning to use IETF management technologies and data models. This document does not cover OAM technologies on the data-path, e.g. OAM of tunnels, MPLS-TP OAM, and Pseudowire as well as the corresponding management models.

Table of Contents

1. Introduction

1.1. Scope and Target Audience

This document gives an overview of the IETF network management standards and summarizes existing and ongoing development of IETF standards-track network management protocols and data models. The document refers to other overview documents where they exist and classifies the standards for easy orientation.

The target audience of the document is on the one hand IETF working groups, which aim to select appropriate standard management protocols and data models to address their needs concerning network management. On the other hand the document can be used as an overview and guideline by non-IETF Standard Development Organizations (SDO) planning to use IETF management technologies and data models for the realization of management applications. The document can be also used to initiate a discussion between the bodies with the goal to gather new requirements and to detect possible gaps. Finally, this document is directed to all interested parties, which seek to get an overview of the current set of the IETF network management protocols such as network administrators or newcomers to IETF.

Section 2 gives an overview of the IETF core network management standards with a special focus on Simple Network Management Protocol (SNMP), SYSLOG, IP Flow Information Export/Packet Sampling (IPFIX/ PSAMP), and Network Configuration (NETCONF). Section 3 discusses IETF management protocols and mechanisms with a specific focus, e.g. IP address management or IP performance management. Section 4 discusses IETF data models, such as MIB modules, IPFIX Information Elements, SYSLOG Structured Data Elements, and YANG modules designed to address specific set of management issues and provides two complementary overviews for the network management data models standardized at IETF. Section 4.1 focuses on a broader view of models classified into categories such as generic and infrastructure data models as well as data models matched to different layers. Where section 4.2 structures the data models following the management application view and maps them to the network management tasks fault, configuration, accounting, performance, and security management.

Appendix A guides the reader for the high-level selection of management standards. For this, the section classifies the protocols according to high-level criteria such as push versus pull mechanism, passive versus active monitoring, as well as categorizes the protocols concerning the network management task they address and their data model extensibility. If the reader is interested only in a subset of the IETF network management protocols and data models described in this document, Appendix A can be used as a dispatcher to

the corresponding chapter. Appendix B gives an overview of the new work on Energy Management at IETF.

This document mainly refers to Proposed, Draft or Internet Standard documents at IETF (see [RFCSEARCH]). As far as valuable Best Current Practice (BCP) documents are referenced. In exceptional cases and if the document provides substantial guideline for standard usage or fills an essential gap, Experimental and Informational RFCs are noticed and ongoing work is mentioned.

Information on active and concluded IETF working groups (e.g., their charters, published or currently active documents and mail archive) can be found at [IETF-WGS]).

Note that this document does not cover OAM technologies on the data-path including MPLS forwarding plane, and control plane protocols (e.g. OAM of tunnels, MPLS-TP OAM, and Pseudowire) as well as the corresponding management models and MIB modules. For a list of related work see Section 1.2 "Related Work".

1.2. Related Work

[RFC6272] "Internet Protocols for the Smart Grid" gives an overview and guidance on the key protocols of the Internet Protocol Suite. In analogy to [RFC6272] this document gives an overview of the IETF network management standards and its usage scenarios.

[RFC3535] "Overview of the 2002 IAB Network Management Workshop" documented strengths and weaknesses of some IETF management protocols. In choosing existing protocol solutions to meet the management requirements, it is recommended that these strengths and weaknesses be considered, even though some of the recommendations from the 2002 IAB workshop have become outdated, some have been standardized, and some are being worked on at the IETF.

[RFC5706] "Guidelines for Considering Operations and Management of New Protocols and Extensions" recommends working groups to consider operations and management needs, and then select appropriate management protocols and data models. This document can be used to ease surveying the IETF standards-track network management protocols and management data models.

[RFC4221] "Multiprotocol Label Switching (MPLS) Management Overview" describes the management architecture for MPLS and indicates the interrelationships between the different MIB modules used for MPLS network management, where [RFC6371] "Operations, Administration, and Maintenance Framework for MPLS-Based Transport Networks" describes the OAM Framework for MPLS-based Transport Networks.

[I-D.ietf-mpls-tp-oam-analysis] "An Overview of the OAM Tool Set for MPLS-based Transport Networks" provides an overview of the OAM toolset for MPLS-based Transport Networks including a brief summary of MPLS-TP OAM requirements and functions, and of generic mechanisms created in the MPLS data plane to allow the OAM packets run in-band and share their fate with data packets. The protocol definitions for each MPLS-TP OAM tools are defined in separate documents, which are referenced.

[I-D.ietf-opsawg-oam-overview] "An Overview of Operations, Administration, and Maintenance (OAM) Mechanisms" gives an overview of the OAM toolset for detecting and reporting connection failures or measurement of connection performance parameters.

[I-D.ietf-mpls-tp-mib-management-overview] "MPLS-TP MIB-based Management Overview" describes the MIB-based architecture for MPLS-TP, and indicates the interrelationships between different existing MIB modules that can be leveraged for MPLS-TP network management and identifies areas where additional MIB modules are required.

Note that IETF so far has not developed specific technologies for the management of sensor networks. IP-based sensors or constrained devices in such an environment, i.e. with very limited memory and CPU resources, can use e.g. application layer protocols to do simple resource management and monitoring.

1.3. Terminology

This document does not describe standard requirements. Therefore, key words from RFC2119 are not used in the document.

- 3GPP: 3rd Generation Partnership Project, a collaboration between groups of telecommunications associations, to prepare the third-generation (3G) mobile phone system specification.

- Agent: A software module that performs the network management functions requested by network management stations. An agent may be implemented in any network element that is to be managed, such as a host, bridge, or router. The ’management server’ in NETCONF terminology.

- BCP: An IETF Best Current Practice document.

- CLI: Command Line Interface. A management interface that system administrators can use to interact with networking equipment.

- Data model: A mapping of the contents of an information model into a form that is specific to a particular type of data store or repository (see [RFC3444]).

- Event: An occurrence of something in the "real world". Events can be indicated to managers through an event message or notification.

- IAB: Internet Architecture Board

- IANA: Internet Assigned Numbers Authority, an organization that oversees global IP address allocation, autonomous system number allocation, media types, and other Internet Protocol-related code point allocations.

- Information model: An abstraction and representation of entities in a managed environment, their properties, attributes and operations, and the way they relate to each other. Independent of any specific repository, protocol, or platform (see [RFC3444]).

- ITU-T: International Telecommunication Union - Telecommunication Standardization Sector

- Managed object: A management abstraction of a resource; a piece of management information in a MIB module. In the context of SNMP, a structured set of data variables that represent some resource to be managed or other aspect of a managed device.

- Manager: An entity that acts in a manager role, either a user or an application. The counterpart to an agent. A 'management client' in NETCONF terminology.

- Management Information Base (MIB): An information repository with a collection of related objects that represent the resources to be managed.

- MIB module: MIB modules usually contain object definitions, may contain definitions of event notifications, and sometimes include compliance statements in terms of appropriate object and event notification groups. A MIB that is provided by a management agent is typically composed of multiple instantiated MIB modules.

- Modeling language: A modeling language is any artificial language that can be used to express information or knowledge or systems in a structure that is defined by a consistent set of rules. Examples are SMIv2 [STD58], XSD [XSD-1], and YANG [RFC6020].

- Notification: An unsolicited message sent by an agent to a management station to notify an unusual event.

- OAM: Operations, Administration, and Maintenance
- PDU: Protocol Data Unit, a unit of data, which is specified in a protocol of a given layer consisting protocol-control information and possibly layer-specific data.
- Principal: An application, an individual, or a set of individuals acting in a particular role, on whose behalf access to a service or MIB is allowed.
- Relax NG: REgular LAnguage for XML Next Generation, a schema language for XML [RELAX-NG].
- SDO: Standard Development Organization
- SMI: Structure of Managed Information, the notation and grammar for managed information definition used to define MIB modules [STD58].
- STDnn: An Internet Standard published at IETF, also referred as Standard, e.g. [STD62].
- URI: Uniform Resource Identifier, a string of characters used to identify a name or a resource on the Internet [STD66]. Can be classified as locators (URLs), or as names (URNs), or as both.
- XPATH: XML Path Language, a query language for selecting nodes from an XML document [XPATH].

2. Core Network Management Protocols

2.1. Simple Network Management Protocol (SNMP)

2.1.1. Architectural Principles of SNMP

The SNMPv3 Framework [RFC3410], builds upon both the original SNMPv1 and SNMPv2 framework. The basic structure and components for the SNMP framework did not change between its versions and comprises following components:

- managed nodes, each with an SNMP entity providing remote access to management instrumentation (the agent),
- at least one SNMP entity with management applications (the manager), and
- a management protocol used to convey management information between the SNMP entities, and management information.

During its evolution, the fundamental architecture of the SNMP Management Framework remained consistent based on a modular architecture, which consists of:

- o a generic protocol definition independent of the data it is carrying, and
- o a protocol-independent data definition language,
- o an information repository containing a data set of management information definitions (the Management Information Base, or MIB), and
- o security and administration.

As such following standards build up the basis of the current SNMP Management Framework:

- o SNMPv3 protocol [STD62],
- o the modeling language SMIv2 [STD58], and
- o MIB modules for different management issues.

The SNMPv3 Framework extends the architectural principles of SNMPv1 and SNMPv2 by:

- o building on these three basic architectural components, in some cases incorporating them from the SNMPv2 Framework by reference, and
- o by using the same layering principles in the definition of new capabilities in the security and administration portion of the architecture.

2.1.2. SNMP and its Versions

SNMP is based on three conceptual entities: Manager, Agent, and the Management Information Base (MIB). In any configuration, at least one manager node runs SNMP management software. Typically, network devices such as bridges, routers, and servers are equipped with an agent. The agent is responsible for providing access to a local MIB of objects that reflects the resources and activity at its node. Following the manager-agent paradigm, an agent can generate notifications and send them as unsolicited messages to the management application.

SNMPv2 enhances this basic functionality with an Inform PDU, a bulk

transfer capability and other functional extensions like an administrative model for access control, security extensions, and Manager-to-Manager communication. SNMPv2 entities can have a dual role as manager and agent. However, neither SNMPv1 nor SNMPv2 offers sufficient security features. To address the security deficiencies of SNMPv1/v2, SNMPv3 [STD62] has been issued.

[BCP74] "Coexistence between Version 1, Version 2, and Version 3 of the Internet-standard Network Management Framework" gives an overview of the relevant standard documents on the three SNMP versions. The BCP document furthermore describes how to convert MIB modules from SMIv1 to SMIv2 format and how to translate notification parameters as well as describes the mapping between the message processing and security models.

SNMP utilizes the Management Information Base, a virtual information store of modules of managed objects. Generally, standard MIB modules support common functionality in a device. Operators often define additional MIB modules for their enterprise or use the Command Line Interface (CLI) to configure non-standard data in managed devices and their interfaces.

SNMPv2 trap and inform PDUs can alert an operator or an application when some aspect of a protocol fails or encounters an error condition, and the contents of a notification can be used to guide subsequent SNMP polling to gather additional information about an event.

SNMP is widely used for monitoring of fault and performance data and with its stateless nature, SNMP also works well for status polling and determining the operational state of specific functionality. The widespread use of counters in standard MIB modules permits the interoperable comparison of statistics across devices from different vendors. Counters have been especially useful in monitoring bytes and packets going in and out over various protocol interfaces. SNMP is often used to poll basic parameter of a device (e.g. sysUpTime, which reports the time since the last re-initialization of the network management portion of the device) to check for operational liveliness, and to detect discontinuities in counters. Some operators use SNMP also for configuration management in their environment (e.g. for DOCSIS-based systems such as cable modems).

SNMPv1 [RFC1157] has been declared Historic and it is not recommended to use due to its lack of security features. [RFC1901] "Community-based SNMPv2" is an Experimental RFC, which has been declared Historic and it is not recommended to use due to its lack of security features.

SNMPv3 [STD62] is recommended to use due to its security features, including support for authentication, encryption, message timeliness and integrity checking, and fine-grained data access controls. An overview of the SNMPv3 document set is in [RFC3410].

Standards exist to use SNMP over diverse transport and link layer protocols, including Transmission Control Protocol (TCP) [STD7], User Datagram Protocol (UDP) [STD6], Ethernet [RFC4789], and others (see Section 2.1.5.1).

2.1.3. Structure of Managed Information (SMI)

SNMP MIB modules are defined with the notation and grammar specified as the Structure of Managed Information (SMI). The SMI uses an adapted subset of Abstract Syntax Notation One (ASN.1) [ITU-X680].

The SMI is divided into three parts: module definitions, object definitions, and, notification definitions.

- Module definitions are used when describing information modules. An ASN.1 macro, MODULE-IDENTITY, is used to concisely convey the semantics of an information module.

- Object definitions are used when describing managed objects. An ASN.1 macro, OBJECT-TYPE, is used to concisely convey the syntax and semantics of a managed object.

- Notification definitions are used when describing unsolicited transmissions of management information. An ASN.1 macro, NOTIFICATION-TYPE, is used to concisely convey the syntax and semantics of a notification.

SMIv1 is specified in [STD16][RFC1155] "Structure and Identification of Management Information for TCP/IP-based Internets" and [STD16][RFC1212] "Concise MIB Definitions". [RFC1215] specifies conventions for defining SNMP traps. Note that SMIv1 is outdated and is not recommended to use.

SMIv2 is the new notation for managed information definition and should be used to define MIB modules. SMIv2 is specified in following RFCs:

- [RFC2578], part of [STD58], defines Version 2 of the Structure of Management Information (SMIv2),

- [RFC2579], part of [STD58], defines the "Textual Conventions" macro for defining new types and it provides a core set of generally useful "Textual Convention" definitions,

- o [RFC2580], part of [STD58], defines Conformance Statements and requirements for defining agent and manager capabilities, and

- o [BCP74] defines the mapping rules for and the conversion of MIB modules between SMIv1 and SMIv2 formats.

2.1.4. SNMP Security and Access Control Models

2.1.4.1. Security Requirements on the SNMP Management Framework

Several of the classical threats to network protocols are applicable to management problem space and therefore applicable to any security model used in an SNMP Management Framework. This section lists primary and secondary threats, and threats which are of lesser importance (see [RFC3411] for the detailed description of the security threats).

The primary threats against which SNMP Security Models can provide protection are, "modification of information" by an unauthorized entity, and "masquerade", i.e. the danger that management operations not authorized for some principal may be attempted by assuming the identity of another principal.

Secondary threats against which SNMP Security Models can provide protection are "message stream modification", e.g. re-ordering, delay, or replay of messages, and "disclosure", i.e. the danger of eavesdropping on the exchanges between SNMP engines.

There are two threats against which SNMP Security Model does not protect, since they are deemed to be of lesser importance in this context: "Denial of Service" and "Traffic Analysis" (see [RFC3411]).

2.1.4.2. User-Based Security Model (USM)

SNMPv3 [STD62] introduced the User Security Model (USM). USM is specified in [RFC3414] and provides authentication and privacy services for SNMP. Specifically, USM is designed to secure against the primary and secondary threats discussed in Section 2.1.4.1. USM does not secure against Denial of Service and attacks based on Traffic Analysis.

The security services the USM security model supports are:

- o Data Integrity is the provision of the property that data has not been altered or destroyed in an unauthorized manner, nor have data sequences been altered to an extent greater than can occur non-maliciously.

- Data Origin Authentication is the provision of the property that the claimed identity of the user on whose behalf received data was originated is supported.

- Data Confidentiality is the provision of the property that information is not made available or disclosed to unauthorized individuals, entities, or processes.

- Message timeliness and limited replay protection is the provision of the property that a message whose generation time is outside of a specified time window is not accepted.

See [RFC3414] for a detailed description of SNMPv3 USM.

2.1.4.3. View-Based Access Control Model (VACM)

SNMPv3 [STD62] introduced the View-Based Access Control (VACM) facility. The VACM is defined in [RFC3415] and enables the configuration of agents to provide different levels of access to the agent's MIB. An agent entity can restrict access to a certain portion of its MIB, e.g. restrict some principals to view only performance-related statistics, or disallow other principals to read those performance-related statistics. An agent entity can also restrict the access to monitoring (read-only) as opposed to monitoring and configuration (read-write) of a certain portion of its MIB, e.g. allowing only a single designated principal to update configuration parameters.

VACM defines five elements that make up the Access Control Model: groups, security level, contexts, MIB views, and access policy. Access to a MIB module is controlled by means of a MIB view.

See [RFC3415] for a detailed description of SNMPv3 VACM.

2.1.5. SNMP Transport Subsystem and Transport Models

The User-based Security Model (USM) was designed to be independent of other existing security infrastructures to ensure it could function when third-party authentication services were not available. As a result, USM utilizes a separate user and key-management infrastructure. Operators have reported that the deployment of a separate user and key-management infrastructure in order to use SNMPv3 is costly and hinders the deployment of SNMPv3.

SNMP Transport Subsystem [RFC5590] extends the original SNMP architecture and transport model and enables the use of transport protocols to provide message security unifying the administrative security management for SNMP, and other management interfaces.

Transport Models are tied into the SNMP framework through the Transport Subsystem. The Transport Security Model [RFC5591] has been designed to work on top of lower-layer, secure Transport Models.

The SNMP Transport Model defines an alternative to existing standard transport mappings described in [RFC3417] e.g. for SNMP over UDP, in [RFC4789] for SNMP over IEEE 802 networks as well as in the Experimental RFC [RFC3430] defining SNMP over TCP.

2.1.5.1. SNMP Transport Security Model

The SNMP Transport Security Model [RFC5591] is an alternative to the existing SNMPv1 and SNMPv2 Community-based Security Models [BCP74], and the User-based Security Model [STD62][RFC3414].

The Transport Security Model utilizes one or more lower-layer security mechanisms to provide message-oriented security services. These include authentication of the sender, encryption, timeliness checking, and data integrity checking.

A secure transport model sets up an authenticated and possibly encrypted session between the Transport Models of two SNMP engines. After a transport-layer session is established, SNMP messages can be sent through this session from one SNMP engine to the other. The new Transport Model supports the sending of multiple SNMP messages through the same session to amortize the costs of establishing a security association.

The Secure Shell (SSH) Transport Model [RFC5592] and the Transport Layer Security (TLS) Transport Model [RFC6353] are current examples for Transport Security Models.

The SSH Transport Model makes use of the commonly deployed SSH security and key-management infrastructure. [RFC5592] furthermore defines MIB objects for monitoring and managing the SSH Transport Model for SNMP.

The Transport Layer Security (TLS) transport model [RFC6353] uses either the TLS protocol [RFC5246] or the Datagram Transport Layer Security (DTLS) [RFC6347] protocol. The TLS and DTLS protocols provide authentication and privacy services for SNMP applications. TLS transport model supports the sending of SNMP messages over TLS and TCP and over DTLS and UDP. [RFC6353] furthermore defines MIB objects for managing the TLS Transport Model for SNMP.

[RFC5608] describes the use of a 'Remote Authentication Dial-In User Service' (RADIUS) service by SNMP secure Transport Models for authentication of users and authorization of services. Access

control authorization, i.e. how RADIUS attributes and messages are applied to the specific application area of SNMP Access Control Models, and VACM in particular has been specified in [RFC6065].

2.2. SYSLOG Protocol

Syslog is a mechanism for distribution of logging information initially used on Unix systems (see [RFC3164] for BSD Syslog). The IETF SYSLOG protocol [RFC5424] introduces a layered architecture allowing the use of any number of transport protocols, including reliable and secure transports, for transmission of SYSLOG messages.

The SYSLOG protocol enables a machine to send system log messages across networks to event message collectors. The protocol is simply designed to transport and distribute these event messages. By default, no acknowledgements of the receipt are made, except the reliable delivery extensions specified in [RFC3195] are used. The SYSLOG protocol and process does not require a stringent coordination between the transport sender and the receiver. Indeed, the transmission of SYSLOG messages may be started on a device without a receiver being configured, or even actually physically present. Conversely, many devices will most likely be able to receive messages without explicit configuration or definitions.

BSD Syslog had little uniformity for the message format and the content of Syslog messages. The body of a BSD Syslog message has traditionally been unstructured text. This content is human-friendly, but difficult to parse for applications. The IETF has standardized a new message header format, including timestamp, hostname, application, and message ID, to improve filtering, interoperability and correlation between compliant implementations.

The SYSLOG protocol [RFC5424] introduces a mechanism for defining Structured Data Elements (SDEs). The SDEs allow vendors to define their own structured data elements to supplement standardized elements. [RFC5675] defines a mapping from SNMP notifications to SYSLOG messages. [RFC5676] defines a SNMP MIB module to represent SYSLOG messages for sending SYSLOG messages as notifications to SNMP notification receivers. [RFC5674] defines the way alarms are sent in SYSLOG, which includes the mapping of ITU perceived severities onto SYSLOG message fields and a number of alarm-specific definitions from ITU-T X.733 [ITU-X733] and the IETF Alarm MIB [RFC3877].

[RFC5848] "Signed Syslog Messages" defines a mechanism to add origin authentication, message integrity, replay resistance, message sequencing, and detection of missing messages to the transmitted SYSLOG messages to be used in conjunction with the SYSLOG protocol.

The SYSLOG protocol layered architecture provides support for a number of transport mappings. For interoperability purposes and especially in managed networks, where the network path has been explicitly provisioned for UDP syslog traffic, SYSLOG protocol can be used over UDP [RFC5426]. However, to support congestion control and reliability, [RFC5426] strongly recommends the use of the TLS transport.

[RFC3195] "Reliable Delivery for syslog" describes mappings of the SYSLOG protocol to TCP connections, useful for reliable delivery of event messages. As such the specification provides robustness and security in message delivery with encryption and authentication over a connection-oriented protocol that is unavailable to the usual UDP-based SYSLOG protocol.

IETF furthermore defined the TLS transport mapping for SYSLOG in [RFC5425], which provides a secure connection for the transport of SYSLOG messages. [RFC5425] describes the security threats to SYSLOG and how TLS can be used to counter such threats. [RFC6012] defines the Datagram Transport Layer Security (DTLS) Transport Mapping for SYSLOG, which can be used if a connectionless transport is desired.

For information on MIB modules related to SYSLOG see Section 4.2.1.

2.3. IP Flow Information Export (IPFIX) and Packet Sampling (PSAMP) Protocols

The IPFIX protocol [RFC5101], IP Flow Information eXport, defines a push-based data export mechanism for transferring IP flow information in a compact binary format from an exporter to a collector.

The IPFIX architecture [RFC5470] defines the components involved in IP flow measurement and reporting of information on IP flows, particularly, a metering process generating flow records, an exporting process that sends metered flow information using the IPFIX protocol, and a colleting process that receives flow information as IPFIX data records.

After listing the IPFIX requirements in [RFC3917], NetFlow Version 9 [RFC3954] was taken as the basis for the IPFIX protocol and the IPFIX architecture.

IPFIX can run over different transport protocols. The IPFIX protocol [RFC5101] specifies Stream Control Transmission Protocol (SCTP) [RFC4960] as the mandatory transport protocol to implement. Optional alternatives are TCP [STD7] and UDP [STD6].

SCTP is used with its Partial Reliability extension (PR-SCTP)

specified in [RFC3758]. [I-D.ietf-ipfix-export-per-sctp-stream] specifies an extension to [RFC5101], when using the PR-SCTP [RFC3758]. The extension offers several advantages over IPFIX export, e.g. the ability to calculate Data Record losses for PR-SCTP, immediate reuse of Template IDs within an SCTP stream, reduced likelihood of Data Record loss, and reduced demands on the Collecting Process.

IPFIX transmits IP flow information in data records containing IPFIX Information Elements (IEs) defined by the IPFIX information model [RFC5102]. IPFIX information elements are quantities with unit and semantics defined by the information model. When transmitted over the IPFIX protocol, only their values need to be carried in data records. This compact encoding allows efficient transport of large numbers of measured flow values. Remaining redundancy in data records can be further reduced by methods described in [RFC5473] (for further discussion on IPFIX IEs see Section 4).

The IPFIX information model is extensible. New information elements can be registered at IANA (see 'IPFIX Information Elements' in [IANA-PROT]). IPFIX also supports the use of proprietary, i.e. enterprise-specific information elements.

The PSAMP protocol [RFC5476] extends the IPFIX protocol by means of transferring information on individual packets. [RFC5475] specifies a set of sampling and filtering techniques for IP packet selection, based on the PSAMP framework [RFC5474]. The PSAMP information model [RFC5477] provides a set of basic information elements for reporting packet information with the IPFIX/PSAMP protocol.

The IPFIX model of an IP traffic flow is uni-directional. [RFC5103] adds means of reporting bi-directional flows to IPFIX, for example both directions of packet flows of a TCP connection.

When enterprise-specific information elements are transmitted with IPFIX, a collector receiving data records may not know the type of received data and cannot choose the right format for storing the contained information. [RFC5610] provides means of exporting extended type information for enterprise-specific Information Elements from an exporter to a collector.

Collectors may store received flow information in files. The IPFIX file format [RFC5655] can be used for storing IP flow information in a way that facilitates exchange of traffic flow information between different systems and applications.

In terms of IPFIX and PSAMP configurations, the metering and exporting processes are configured out of band. As the IPFIX

protocol is a push mechanism only, IPFIX cannot configure the exporter. The actual configuration of selection processes, caches, exporting processes, and collecting processes of IPFIX and PSAMP compliant monitoring devices is executed using the NETCONF protocol [RFC6241] (see Section 2.4.1). The 'Configuration Data Model for IPFIX and PSAMP' [I-D.ietf-ipfix-configuration-model] has been specified using Unified Modeling Language (UML) class diagrams. The data model is formally defined using the YANG modeling language [RFC6020] (see Section 2.4.2).

At the time of this writing a framework for IPFIX flow mediation is in preparation, which addresses the need for mediation of flow information in IPFIX applications in large operator networks, e.g. for aggregating huge amounts of flow data and for anonymization of flow information (see the problem statement in [RFC5982]).

The IPFIX Mediation Framework [RFC6183] defines the intermediate device between exporters and collectors, which provides an IPFIX mediation by receiving a record stream from e.g. a collecting process, hosting one or more intermediate processes to transform this stream, and exporting the transformed record stream into IPFIX messages via an exporting process.

Examples for mediation functions are flow aggregation, flow selection, and anonymization of traffic information (see [RFC6235]).

Privacy, integrity, and authentication of exporter and collector are important security requirements for IPFIX [RFC3917]. Confidentiality, integrity, and authenticity of IPFIX data transferred from an exporting process to a collecting process must be ensured. The IPFIX and PSAMP protocols do not define any new security mechanism and rely on the security mechanism of the underlying transport protocol, such as TLS [RFC5246] and DTLS [RFC6347].

The primary goal of IPFIX is the reporting of the flow accounting for flexible flow definitions and usage-based accounting. As described in the IPFIX Applicability Statement [RFC5472], there are also other applications such as traffic profiling, traffic engineering, intrusion detection, and QoS monitoring, that require flow-based traffic measurements and can be realized using IPFIX. IPFIX Applicability Statement explains furthermore the relation of IPFIX to other framework and protocols such as PSAMP, RMON (Remote Network Monitoring MIB Section 4.2.1), and IPPM (IP Performance Metrics Section 3.4)). Similar flow information could be also used for security monitoring. The addition of performance metrics in the IPFIX IANA registry [IANA-IPFIX], will extend the IPFIX use case to performance management.

Note that even if the initial IPFIX focus has been around IP flow information exchange, non-IP-related information elements are now specified in IPFIX IANA registration (e.g. MAC (Media Access Control) address, MPLS (Multiprotocol Label Switching) labels, etc.). At the time of this writing, there are requests to widen the focus of IPFIX and to export also non-IP related information elements (such as SIP monitoring IEs).

The IPFIX Structured Data [RFC6313] is an extension to the IPFIX protocol, which supports hierarchical structured data and lists (sequences) of Information Elements in data records. This extension allows the definition of complex data structures such as variable-length lists and specification of hierarchical containment relationships between templates. Furthermore, the extension provides the semantics to express the relationship among multiple list elements in a structured data record.

For information on data models related to the management of the IPFIX and PSAMP protocols see Section 4.2.1 and Section 4.2.2. For information on IPFIX/PSAMP IEs, see Section 4.2.3.

2.4. Network Configuration

2.4.1. Network Configuration Protocol (NETCONF)

The IAB workshop on Network Management [RFC3535] determined advanced requirements for configuration management:

- Robustness: Minimizing disruptions and maximizing stability,
- Support of task-oriented view,
- Extensible for new operations,
- Standardized error handling,
- Clear distinction between configuration data and operational state,
- Distribution of configurations to devices under transactional constraints,
- Single and multi-system transactions and scalability in the number of transactions and managed devices,
- Operations on selected subsets of management data,

- Dump and reload a device configuration in a textual format in a standard manner across multiple vendors and device types,
- Support a human interface and a programmatic interface,
- Data modeling language with a human friendly syntax,
- Easy conflict detection and configuration validation, and
- Secure transport, authentication, and robust access control.

The NETCONF protocol [RFC6241] provides mechanisms to install, manipulate, and delete the configuration of network devices and aims to address the configuration management requirements pointed in the IAB workshop. It uses an XML-based data encoding for the configuration data as well as the protocol messages. The NETCONF protocol operations are realized on top of a simple and reliable Remote Procedure Call (RPC) layer. A key aspect of NETCONF is that it allows the functionality of the management protocol to closely mirror the native command line interface of the device.

The NETCONF working group developed the NETCONF Event Notifications Mechanism as an optional capability, which provides an asynchronous message notification delivery service for NETCONF [RFC5277]. NETCONF notification mechanism enables using general purpose notification streams, where the originator of the notification stream can be any managed device (e.g. SNMP notifications).

NETCONF Partial Locking specification introduces fine-grained locking of the configuration datastore to enhance NETCONF for fine-grained transactions on parts of the datastore [RFC5717].

The NETCONF working group also defined the necessary data model to monitor the NETCONF protocol by using the modeling language YANG [RFC6022] (see Section 2.4.2). The monitoring data model includes information about NETCONF datastores, sessions, locks, and statistics, which facilitate the management of a NETCONF server.

NETCONF connections are required to provide authentication, data integrity, confidentiality, and replay protection. NETCONF depends on the underlying transport protocol for this capability. For example, connections can be encrypted in TLS or SSH, depending on the underlying protocol.

The NETCONF working group defined the SSH transport protocol as the mandatory transport binding [RFC6242]. Other optional transport bindings are TLS [RFC5539], BEEP (over TLS) [RFC4744], and SOAP (over HTTP over TLS) [RFC4743].

The NETCONF Access Control Model (NACM) [RFC6536] provides standard mechanisms to restrict protocol access to particular users with a pre-configured subset of operations and content.

2.4.2. YANG - NETCONF Data Modeling Language

Following the guidelines of the IAB management workshop [RFC3535], the NETMOD working group developed a data modeling language defining the semantics of operational and configuration data, notifications, and operations [RFC6020]. The new data modeling language maps directly to XML-encoded content (on the wire) and will serve as the normative description of NETCONF data models.

YANG has following properties addressing specific requirements on a modeling language for configuration management:

- YANG provides the means to define hierarchical data models. It supports reusable data types and groupings, i.e., a set of schema nodes that can be reused across module boundaries.

- YANG supports the distinction between configuration and state data. In addition, it provides support for modeling event notifications and the specification of operations that extend the base NETCONF operations.

- YANG allows to express constraints on data models by means of type restrictions and XPATH 1.0 [XPATH] expressions. XPATH expressions can also be used to make certain portions of a data model conditional.

- YANG supports the integration of standard and vendor defined data models. YANG's augmentation mechanism allows to seamlessly augment standard data models with proprietary extensions.

- YANG data models can be partitioned into collections of features, allowing low-end devices to only implement the core features of a data model while high-end devices may choose to support all features. The supported features are announced via the NETCONF capability exchange to management applications.

- The syntax of the YANG language is compact and optimized for human readers. An associated XML-based syntax called the YANG Independent Notation (YIN) [RFC6020] is available to allow the processing of YANG data models with XML-based tools. The mapping rules for the translation of YANG data models into Document Schema Definition Languages (DSDL), of which Relax NG is a major component, are defined in [RFC6110].

- Devices implementing standard data models can document deviations from the data model in separate YANG modules. Applications capable of discovering deviations can make allowances that would otherwise not be possible.

A collection of common data types for IETF-related standards is provided in [RFC6021]. This standard data type library has been derived to a large extend from common SMIv2 data types, generalizing them to a less constrained NETCONF framework.

The document "An Architecture for Network Management using NETCONF and YANG" describes how NETCONF and YANG can be used to build network management applications that meet the needs of network operators [RFC6244].

The Experimental RFC [RFC6095] specifies extensions for YANG introducing language abstractions such as class inheritance and recursive data structures.

[RFC6087] gives guidelines for the use of YANG within IETF and other standardization organizations.

Work is underway to standardize a translation of SMIv2 data models into YANG data models preserving investments into SNMP MIB modules, which are widely available for monitoring purposes.

Several independent and open source implementations of the YANG data modeling language and associated tools are available.

While YANG is a relatively recent data modeling language, some data models have already been produced. The specification of the base NETCONF protocol operations has been revised and uses YANG as the normative modeling language to specify its operations [RFC6241]. The IPFIX working group prepared the normative model for configuring and monitoring IPFIX and PSAMP compliant monitoring devices using the YANG modeling language [I-D.ietf-ipfix-configuration-model].

At the time of this writing the NETMOD working group is developing core system and interface data models. Following the example of the IPFIX configuration model, IETF working groups will prepare models for their specific needs.

For information on data models developed using the YANG modeling language see Section 4.2.1 and Section 4.2.2.

3. Network Management Protocols and Mechanisms with specific Focus

This section reviews additional protocols IETF offers for management and discusses for which applications they were designed and/or already successfully deployed. These are protocols that have mostly reached Proposed Standard status or higher within the IETF.

3.1. IP Address Management

3.1.1. Dynamic Host Configuration Protocol (DHCP)

Dynamic Host Configuration Protocol (DHCP) [RFC2131] provides a framework for passing configuration information to hosts on a TCP/IP network and enables as such auto-configuration in IP networks. In addition to IP address management, DHCP can also provide other configuration information, such as default routers, the IP addresses of recursive DNS servers and the IP addresses of NTP servers. As described in [RFC6272] DHCP can be used for IPv4 and IPv6 Address Allocation and Assignment as well as for Service Discovery.

There are two versions of DHCP, one for IPv4 (DHCPv4) [RFC2131] and one for IPv6 (DHCPv6) [RFC3315]. DHCPv4 was defined as an extension to BOOTP (Bootstrap Protocol) [RFC0951]. DHCPv6 was subsequently defined to accommodate new functions required by IPv6 such as assignment of multiple addresses to an interface and to address limitations in the design of DHCPv4 resulting from its origins in BOOTP. While both versions bear the same name and perform the same functionality, the details of DHCPv4 and DHCPv6 are sufficiently different that they can be considered separate protocols.

In addition to the assignment of IP addresses and other configuration information, DHCP options like the Relay Agent Information option (DHCPv4) [RFC3046] and, the Interface-Id Option (DHCPv6) [RFC3315] are widely used by ISPs.

DHCPv6 includes Prefix Delegation [RFC3633], which is used to provision a router with an IPv6 prefix for use in the subnetwork supported by the router.

Following are examples of DHCP options that provide configuration information or access to specific servers. A complete list of DHCP options is available at [IANA-PROT].

- [RFC3646] "DNS Configuration options for DHCPv6" describes DHCPv6 options for passing a list of available DNS recursive name servers and a domain search list to a client.

- o [RFC2610] "DHCP Options for Service Location Protocol" describes DHCPv4 options and methods through which entities using the Service Location Protocol can find out the address of Directory Agents in order to transact messages and how the assignment of scope for configuration of SLP User and Service Agents can be achieved.

- o [RFC3319] "DHCPv6 Options for Session Initiation Protocol (SIP) Servers" specifies DHCPv6 options that allow SIP clients to locate a local SIP server that is to be used for all outbound SIP requests, a so-called outbound proxy server.

- o [RFC4280] "DHCP Options for Broadcast and Multicast Control Servers" defines DHCPv6 options to discover the Broadcast and Multicast Service (BCMCS) controller in an IP network.

Built directly on UDP and IP, DHCP itself has no security provisions. There are two different classes of potential security issues related to DHCP: unauthorized DHCP Servers and unauthorized DHCP Clients. The recommended solutions to these risks generally involve providing security at lower layers, e.g. careful control over physical access to the network, security techniques implemented at layer two but also IPSec at layer three can be used to provide authentication.

3.1.2. Ad-Hoc Network Autoconfiguration

Ad-hoc nodes need to configure their network interfaces with locally unique addresses as well as globally routable IPv6 addresses, in order to communicate with devices on the Internet. The IETF AUTOCONF working group developed [RFC5889], which describes the addressing model for ad-hoc networks and how nodes in these networks configure their addresses.

The ad-hoc nodes under consideration are expected to be able to support multi-hop communication by running MANET (Mobile ad-hoc network) routing protocols as developed by the IETF MANET working group.

From the IP layer perspective, an ad hoc network presents itself as a layer 3 multi-hop network formed over a collection of links. The addressing model aims to avoid problems for ad-hoc-unaware parts of the system, such as standard applications running on an ad-hoc node or regular Internet nodes attached to the ad-hoc nodes.

3.2. IPv6 Network Operations

The IPv6 Operations Working Group develops guidelines for the operation of a shared IPv4/IPv6 Internet and provides operational

guidance on how to deploy IPv6 into existing IPv4-only networks, as well as into new network installations.

- [RFC4213] "Basic Transition Mechanisms for IPv6 Hosts and Routers" specifies IPv4 compatibility mechanisms for dual stack and configured tunneling that can be implemented by IPv6 hosts and routers. Dual stack implies providing complete implementations of both IPv4 and IPv6, and configured tunneling provides a means to carry IPv6 packets over unmodified IPv4 routing infrastructures.

- [RFC3574] "Transition Scenarios for 3GPP Networks" lists different scenarios in 3GPP defined packet network that would need IPv6 and IPv4 transition, where [RFC4215] "Analysis on IPv6 Transition in Third Generation Partnership Project (3GPP) Networks" does a more detailed analysis of the transition scenarios that may come up in the deployment phase of IPv6 in 3GPP packet networks.

- [RFC4029] "Scenarios and Analysis for Introducing IPv6 into ISP Networks" describes and analyzes different scenarios for the introduction of IPv6 into an ISP's existing IPv4 network. [RFC5181] "IPv6 Deployment Scenarios in 802.16 Networks" provides a detailed description of IPv6 deployment, integration methods and scenarios in wireless broadband access networks (802.16) in coexistence with deployed IPv4 services. [RFC4057] describes the scenarios for IPv6 deployment within enterprise networks.

- [RFC4038] "Application Aspects of IPv6 Transition" specifies scenarios and application aspects of IPv6 transition considering how to enable IPv6 support in applications running on IPv6 hosts, and giving guidance for the development of IP version-independent applications.

- The ongoing work on an IANA-reserved IPv4 prefix for shared address spaces [I-D.weil-shared-transition-space-request] "IANA Reserved IPv4 Prefix for Shared Address Space" updates RFC 5735 and requests the allocation of an IPv4/10 address block to be used as "Shared Carrier Grade Network Address Translation (CGN) Space" by service providers to number the interfaces that connect CGN devices to Customer Premise Equipment (CPE).

3.3. Policy-based Management

3.3.1. IETF Policy Framework

IETF specified a general policy framework [RFC2753] for managing, sharing, and reusing policies in a vendor independent, interoperable, and scalable manner. [RFC3460] specifies the Policy Core Information Model (PCIM) as an object-oriented information model for representing

policy information. PCIM has been developed jointly in the IETF Policy Framework working group and the Common Information Model (CIM) activity in the Distributed Management Task Force (DMTF). PCIM has been published as extensions to CIM [DMTF-CIM].

The IETF Policy Framework is based on a policy-based admission control specifying two main architectural elements, the Policy Enforcement Point (PEP) and the Policy Decision Point (PDP). For the purpose of network management, policies allow an operator to specify how the network is to be configured and monitored by using a descriptive language. Furthermore, it allows the automation of a number of management tasks, according to the requirements set out in the policy module.

IETF Policy Framework has been accepted by the industry as a standard-based policy management approach and has been adopted by different SDOs e.g. for 3GGP charging standards.

3.3.2. Use of Common Open Policy Service (COPS) for Policy Provisioning (COPS-PR)

[RFC3159] defines the Structure of Policy Provisioning Information (SPPI), an extension to the SMIv2 modeling language used to write Policy Information Base (PIB) modules. COPS-PR [RFC3084] uses the Common Open Policy Service (COPS) protocol [RFC2748] for provisioning of policy information. COPS provides a simple client/server model for supporting policy control over QoS signaling protocols. The COPS-PR specification is independent of the type of policy being provisioned (QoS, security, etc.) but focuses on the mechanisms and conventions used to communicate provisioned information between policy-decision-points (PDPs) and policy enforcement points (PEPs). Policy data is modeled using Policy Information Base (PIB) modules.

COPS-PR has not been widely deployed, and operators have stated that its use of binary encoding (BER) for management data makes it difficult to develop automated scripts for simple configuration management tasks in most text-based scripting languages. In the IAB Workshop on Network Management [RFC3535], the consensus of operators and protocol developers indicated a lack of interest in PIB modules for use with COPS-PR.

As a result, even if COPS-PR and the Structure of Policy Provisioning Information (SPPI) were initially approved as Proposed Standards, the IESG has not approved any PIB modules as IETF standard, and the use of COPS-PR is not recommended.

3.4. IP Performance Metrics (IPPM)

The IPPM working group has defined metrics for accurately measuring and reporting the quality, performance, and reliability of Internet data delivery. The metrics include connectivity, one-way delay and loss, round-trip delay and loss, delay variation, loss patterns, packet reordering, bulk transport capacity, and link bandwidth capacity.

These metrics are designed for use by network operators and their customers, and provide unbiased quantitative measures of performance. The IPPM metrics have been developed inside an active measurement context, that is, the devices used to measure the metrics produce their own traffic. However, most of the metrics can be used inside a passive context as well. At the time of this writing there is no work planned in the area of passive measurement.

As a property individual IPPM performance and reliability metrics need to be well-defined and concrete thus implementable. Furthermore, the methodology used to implement a metric needs to be repeatable with consistent measurements.

IETF IP Performance Metrics have been adopted by different organizations, e.g. Metro Ethernet Forum.

Note that this document does not aim to cover OAM technologies on the data-path and as such the discussion of IPPM-based active vs. passive monitoring as well as the data plane measurement and its diagnostics is rather incomplete. For a detailed overview and discussion of IETF OAM standards and IPPM measurement mechanisms the reader is referred to the documents listed at the end of Section 1.2 "Related Work" but especially to [I-D.ietf-opsawg-oam-overview].

Following are examples of essential IPPM documents:

- IPPM Framework document [RFC2330] defines a general framework for particular metrics developed by IPPM working group and defines the fundamental concepts of ’metric’ and ’measurement methodology’ and discusses the issue of measurement uncertainties and errors as well as introduces the notion of empirically defined metrics and how metrics can be composed.

- [RFC2679] "One-way Delay Metric for IPPM", defines a metric for one-way delay of packets across Internet paths. It builds on notions introduced in the IPPM Framework document.

- [RFC2681] "Round-trip Delay Metric for IPPM", defines a metric for round-trip delay of packets across network paths and follows

closely the corresponding metric for One-way Delay.

- [RFC3393] "IP Packet Delay Variation Metric", refers to a metric for variation in delay of packets across network paths and is based on the difference in the One-Way-Delay of selected packets called "IP Packet Delay Variation (ipdv)".

- [RFC2680] "One-way Packet Loss Metric for IPPM", defines a metric for one-way packet loss across Internet paths.

- [RFC5560] "One-Way Packet Duplication Metric", defines a metric for the case, where multiple copies of a packet are received and discusses methods to summarize the results of streams.

- [RFC4737] "Packet Reordering Metrics", defines metrics to evaluate whether a network has maintained packet order on a packet-by-packet basis and discusses the measurement issues, including the context information required for all metrics.

- [RFC2678] "IPPM Metrics for Measuring Connectivity", defines a series of metrics for connectivity between a pair of Internet hosts.

- [RFC5835] "Framework for Metric Composition", describes a detailed framework for composing and aggregating metrics.

- [BCP170] "Guidelines for Considering New Performance Metric Development" describes the framework and process for developing Performance Metrics of protocols and applications transported over IETF-specified protocols.

To measure these metrics two protocols and a sampling method have been standardized:

- [RFC4656] "A One-way Active Measurement Protocol (OWAMP)", measures unidirectional characteristics such as one-way delay and one-way loss between network devices and enables the interoperability of these measurements. OWAMP is discussed in more detail in [I-D.ietf-opsawg-oam-overview].

- [RFC5357] "A Two-Way Active Measurement Protocol (TWAMP)", adds round-trip or two-way measurement capabilities to OWAMP. TWAMP is discussed in more detail in [I-D.ietf-opsawg-oam-overview].

- [RFC3432] "Network performance measurement with Periodic Streams", describes a periodic sampling method and relevant metrics for assessing the performance of IP networks, as an alternative to the Poisson sampling method described in [RFC2330].

For information on MIB modules related to IP Performance Metrics see Section 4.2.4.

3.5. Remote Authentication Dial In User Service (RADIUS)

RADIUS [RFC2865], the Remote Authentication Dial In User Service, describes a client/server protocol for carrying authentication, authorization, and configuration information between a Network Access Server (NAS), which desires to authenticate its links and a shared Authentication Server. The companion document [RFC2866] 'Radius Accounting' describes a protocol for carrying accounting information between a network access server and a shared accounting server. [RFC2867] adds required new RADIUS accounting attributes and new values designed to support the provision of tunneling in dial-up networks.

The RADIUS protocol is widely used in environments like enterprise networks, where a single administrative authority manages the network, and protects the privacy of user information. RADIUS is deployed in fixed broadband access provider networks as well as in cellular broadband operators' networks.

RADIUS uses attributes to carry the specific authentication, authorization, information, and configuration details. RADIUS is extensible with a known limitation of maximum 255 attribute codes and 253 octets as attribute content length. RADIUS has Vendor-Specific Attributes (VSA), which have been used both for vendor-specific purposes as an addition to standardized attributes as well as to extend the limited attribute code space.

The RADIUS protocol uses a shared secret along with the MD5 (Message-Digest algorithm 5) hashing algorithm to secure passwords [RFC1321]. Based on the known threads additional protection like IPsec tunnels [RFC4301] are used to further protect the RADIUS traffic. However, building and administering large IPsec protected networks may become a management burden, especially when IPsec protected RADIUS infrastructure should provide inter-provider connectivity. A trend has been moving towards TLS-based security solutions [RFC5246] and establishing dynamic trust relationships between RADIUS servers. Since the introduction of TCP transport for RADIUS, it became natural to have TLS support for RADIUS. An ongoing work specifies the 'TLS encryption for RADIUS'.

[RFC2868] 'RADIUS Attributes for Tunnel Protocol Support' defines a number of RADIUS attributes designed to support the compulsory provision of tunneling in dial-up network access. Some applications involve compulsory tunneling i.e. the tunnel is created without any action from the user and without allowing the user any choice in the

matter. In order to provide this functionality, specific RADIUS attributes are needed to carry the tunneling information from the RADIUS server to the tunnel end points. [RFC3868] defines the necessary attributes, attribute values and the required IANA registries.

[RFC3162] 'RADIUS and IPv6' specifies the operation of RADIUS over IPv6 and the RADIUS attributes used to support the IPv6 network access. [RFC4818] describes how to transport delegated IPv6 prefix information over RADIUS.

[RFC4675] 'RADIUS Attributes for Virtual LAN and Priority Support' defines additional attributes for dynamic Virtual LAN assignment and prioritization, for use in provisioning of access to IEEE 802 local area networks usable with RADIUS and DIAMETER.

[RFC5080] 'Common RADIUS Implementation Issues and Suggested Fixes' describes common issues seen in RADIUS implementations and suggests some fixes. Where applicable, unclear statements and errors in previous RADIUS specifications are clarified. People designing extensions to RADIUS protocol for various deployment cases should get familiar with RADIUS Design Guidelines [RFC6158] in order to avoid e.g. known interoperability challenges.

[RFC5090] 'RADIUS Extension for Digest Authentication' defines an extension to the RADIUS protocol to enable support of Digest Authentication, for use with HTTP-style protocols like the Session Initiation Protocol (SIP) and HTTP.

[RFC5580] 'Carrying Location Objects in RADIUS and DIAMETER describes procedures for conveying access-network ownership and location information based on civic and geospatial location formats in RADIUS and DIAMETER.

[RFC5607] specifies required RADIUS attributes and their values for authorizing a management access to a NAS. Both local and remote management are supported, with access rights and management privileges. Specific provisions are made for remote management via Framed Management protocols, such as SNMP and NETCONF, and for management access over a secure transport protocols.

[RFC3579] describes how to use RADIUS to convey Extensible Authentication Protocol (EAP) [RFC3748] payload between the authenticator and the EAP server using RADIUS. RFC3579 is widely implemented, for example, in WLAN and 802.1 X environments. [RFC3580] describes how to use RADIUS with IEEE 802.1X authenticators. In the context of 802.1X and EAP-based authentication, the Vendor Specific Attributes described in [RFC2458]

have been widely accepted by the industry. [RFC2869] 'RADIUS extensions' is another important RFC related to EAP use. RFC2869 describes additional attributes for carrying AAA information between a NAS and a shared Accounting Server using RADIUS. It also defines attributes to encapsulate EAP message payload.

There are different MIB modules defined for multiple purposes to use with RADIUS (see Section 4.2.3 and Section 4.2.5).

3.6. Diameter Base Protocol (DIAMETER)

DIAMETER [RFC3588] provides an Authentication, Authorization and Accounting (AAA) framework for applications such as network access or IP mobility. DIAMETER is also intended to work in local AAA and in roaming scenarios. DIAMETER provides an upgrade path for RADIUS but is not directly backwards compatible.

DIAMETER is designed to resolve a number of known problems with RADIUS. DIAMETER supports server failover, reliable transport over TCP and SCTP, well documented functions for proxy, redirect and relay agent functions, server-initiated messages, auditability, and capability negotiation. DIAMETER also provides a larger attribute space for Attribute-Value Pairs (AVP) and identifiers than RADIUS. DIAMETER features make it especially appropriate for environments, where the providers of services are in different administrative domains than the maintainer (protector) of confidential user information.

Other notable differences to RADIUS are:

- Network and transport layer security (IPsec or TLS),
- Stateful and stateless models,
- Dynamic discovery of peers (using DNS SRV and NAPTR),
- Concept of an application that describes how a specific set of commands and Attribute-Value Pairs (AVPs) are treated by DIAMETER nodes. Each application has an IANA assigned unique identifier,
- Support of application layer acknowledgements, failover methods and state machines,
- Basic support for user-sessions and accounting,
- Better roaming support,

- Error notification, and
- Easy extensibility.

The DIAMETER protocol is designed to be extensible to support e.g. proxies, brokers, mobility and roaming, Network Access Servers (NASREQ), and Accounting and Resource Management. DIAMETER applications extend the DIAMETER base protocol by adding new commands and/or attributes. Each application is defined by a unique IANA assigned application identifier and can add new command codes and/or new mandatory AVPs.

The DIAMETER application identifier space has been divided into Standards Track and 'First Come First Served' vendor-specific applications. Following are examples for DIAMETER applications published at IETF:

- Diameter Base Protocol Application [RFC3588]: Required to support by all Diameter implementations.
- Diameter Base Accounting Application [RFC3588]: A DIAMETER application using an accounting protocol based on a server directed model with capabilities for real-time delivery of accounting information.
- Diameter Mobile IPv4 Application [RFC4004]: A DIAMETER application that allows a DIAMETER server to authenticate, authorize and collect accounting information for Mobile IPv4 services rendered to a mobile node.
- Diameter Network Access Server Application (NASREQ, [RFC4005]): A DIAMETER application used for AAA services in the NAS environment.
- Diameter Extensible Authentication Protocol Application [RFC4072]: A DIAMETER application that carries EAP packets between a NAS and a back-end authentication server.
- Diameter Credit-Control Application [RFC4006]: A DIAMETER application that can be used to implement real-time credit-control for a variety of end user services such as network access, Session Initiation Protocol (SIP) services, messaging services, and download services.
- Diameter Session Initiation Protocol Application [RFC4740]: A DIAMETER application designed to be used in conjunction with SIP and provides a DIAMETER client co-located with a SIP server, with the ability to request the authentication of users and authorization of SIP resources usage from a DIAMETER server.

- Diameter Quality-of-Service Application [RFC5866]: A DIAMETER application allowing network elements to interact with Diameter servers when allocating QoS resources in the network.

- Diameter Mobile IPv6 IKE (MIP6I) Application [RFC5778]: A DIAMETER application, which enables the interaction between a Mobile IP home agent and a Diameter server and is used when the mobile node is authenticated and authorized using IKEv2 [RFC5996].

- Diameter Mobile IPv6 Auth (MIP6A) Application [RFC5778]: A DIAMETER application, which enables the interaction between a Mobile IP home agent and a DIAMETER server and is used when the mobile node is authenticated and authorized using the Mobile IPv6 Authentication Protocol [RFC4285].

The large majority of DIAMETER applications are vendor-specific and mainly used in various SDOs outside IETF. One example SDO using DIAMETER extensively is 3GPP (e.g. 3GPP 'IP Multimedia Subsystem' (IMS) uses DIAMETER based interfaces (e.g. Cx) [3GPPIMS]). Recently, during the standardization of the '3GPP Evolved Packet Core' [3GPPEPC], DIAMETER was chosen as the only AAA signaling protocol.

One part of DIAMETER's extensibility mechanism is an easy and consistent way of creating new commands for the need of applications. RFC3588 proposed to define DIAMETER command code allocations with a new RFC. This policy decision caused undesired use and redefinition of existing Commands Codes within SDOs. Diverse RFCs have been published as simple command code allocations for other SDO purposes (see [RFC3589], [RFC5224], [RFC5431] and [RFC5516]). [RFC5719] changed the Command Code policy and added a range for vendor-specific Command Codes to be allocated on a 'First Come First Served' basis by IANA.

The implementation and deployment experience of DIAMETER has led to the currently ongoing development of an update of the base protocol [I-D.ietf-dime-rfc3588bis], which introduces TLS as the preferred security mechanism and deprecates the in-band security negotiation for TLS.

Some DIAMETER protocol enhancements and clarifications that logically fit better into [I-D.ietf-dime-rfc3588bis], are also needed on the existing RFC3588 based deployments. Therefore, protocol extensions specifically usable in large inter-provider roaming network scenarios are made available for RFC3588. Two currently existing specifications are mentioned below:

- o "Clarifications on the Routing of DIAMETER Requests Based on the Username and the Realm" [RFC5729] defines the behavior required for DIAMETER agents to route requests when the User-Name AVP contains a Network Access Identifier formatted with multiple realms. These multi-realm Network Access Identifiers are used in order to force the routing of request messages through a predefined list of mediating realms.

- o "Diameter Extended NAPTR" [RFC6408] describes an improved DNS-based dynamic DIAMETER Agent discovery mechanism without having to do DIAMETER capability exchange beforehand with a number of agents.

There have been a growing number of DIAMETER framework documents at IETF that basically are just a collection of AVPs for a specific purpose or a system architecture with semantical AVP descriptions and a logic for "imaginary" applications. From standardization point of view, this practice allows the development of larger system architecture documents that do not need to reference AVPs or application logic outside IETF. Below are examples of a few recent AVP and framework documents:

- o "Diameter Mobile IPv6: Support for Network Access Server to Diameter Server Interaction" [RFC5447] describes the bootstrapping of the Mobile IPv6 framework and the support of interworking with existing Authentication, Authorization, and Accounting (AAA) infrastructures by using the DIAMETER Network Access Server to home AAA server interface.

- o "Traffic Classification and Quality of Service (QoS) Attributes for Diameter" [RFC5777] defines a number of DIAMETER AVPs for traffic classification with actions for filtering and QoS treatment.

- o "Diameter Proxy Mobile IPv6: Mobile Access Gateway and Local Mobility Anchor Interaction with Diameter Server" [RFC5779] defines AAA interactions between Proxy Mobile IPv6 (PMIPv6) entities (Mobile Access Gateway and Local Mobility Anchor) and a AAA server within a PMIPv6 Domain.

For information on MIB modules related to DIAMETER see Section 4.2.5.

3.7. Control And Provisioning of Wireless Access Points (CAPWAP)

Wireless LAN (WLAN) product architectures have evolved from single autonomous Access Points to systems consisting of a centralized Access Controller (AC) and Wireless Termination Points (WTPs). The general goal of centralized control architectures is to move access

control, including user authentication and authorization, mobility management, and radio management from the single access point to a centralized controller, where an Access Points pulls the information from the Access Controller.

Based on the CAPWAP Architecture Taxonomy work [RFC4118] the CAPWAP working group developed the CAPWAP protocol [RFC5415] to facilitate control, management and provisioning of WTPs specifying the services, functions and resources relating to 802.11 WLAN Termination Points in order to allow for interoperable implementations of WTPs and ACs. The protocol defines the CAPWAP control plane including the primitives to control data access. The protocol document also specifies how configuration management of WTPs can be done and defines CAPWAP operations responsible for debugging, gathering statistics, logging, and firmware management as well as discusses operational and transport considerations.

The CAPWAP protocol is prepared to be independent of Layer 2 technologies, and meets the objectives in "Objectives for Control and Provisioning of Wireless Access Points (CAPWAP)" [RFC4564]. Separate binding extensions enable the use with additional wireless technologies. [RFC5416] defines CAPWAP Protocol Binding for IEEE 802.11.

CAPWAP Control messages, and optionally CAPWAP Data messages, are secured using DTLS [RFC6347]. DTLS is used as a tightly integrated, secure wrapper for the CAPWAP protocol.

For information on MIB modules related to CAPWAP see Section 4.2.2.

3.8. Access Node Control Protocol (ANCP)

The Access Node Control Protocol (ANCP) [RFC6320] realizes a control plane between a service-oriented layer 3 edge device, the Network Access Server (NAS) and a layer 2 Access Node (AN), e.g., Digital Subscriber Line Access Module (DSLAM). As such ANCP operates in a multi-service reference architecture and communicates QoS-, service- and subscriber-related configuration and operation information between a NAS and an Access Node.

The main goal of this protocol is to configure and manage access equipments and allow them to report information to the NAS in order to enable and optimize configuration.

The framework and requirements for an Access Node control mechanism and the use cases for ANCP are documented in [RFC5851].

The ANCP protocol offers authentication, and authorization between AN

and NAS nodes and provides replay protection and data-origin authentication. ANCP protocol solution is also robust against Denial-of-Service (DoS) attacks. Furthermore, the ANCP protocol solution is recommended to offer confidentiality protection. Security Threats and Security Requirements for ANCP are discussed in [RFC5713].

3.9. Application Configuration Access Protocol (ACAP)

The Application Configuration Access Protocol (ACAP) [RFC2244] is designed to support remote storage and access of program option, configuration and preference information. The data store model is designed to allow a client relatively simple access to interesting data, to allow new information to be easily added without server re-configuration, and to promote the use of both standardized data and custom or proprietary data. Key features include "inheritance" which can be used to manage default values for configuration settings and access control lists which allow interesting personal information to be shared and group information to be restricted.

ACAP’s primary purpose is to allow applications access to their configuration data from multiple network-connected computers. Users can then use any network-connected computer, run any ACAP-enabled application and have access to their own configuration data. To enable wide usage client simplicity has been preferred to server or protocol simplicity whenever reasonable.

The ACAP ’authenticate’ command uses Simple Authentication and Security Layer (SASL) [RFC4422] to provide basic authentication, authorization, integrity and privacy services. All ACAP implementations are required to implement the CRAM-MD5 (Challenge-Response Authentication Mechanism) [RFC2195] for authentication, which can be disabled based on the site security policy.

3.10. XML Configuration Access Protocol (XCAP)

The Extensible Markup Language (XML) Configuration Access Protocol (XCAP) [RFC4825] has been designed for and is commonly used with SIP-based solutions, in particular for instant message, presence, and SIP conference. XCAP is a protocol that allows a client to read, write, and modify application configuration data stored in XML format on a server, where the main functionality is provided by so called "XCAP Application Usages".

XCAP is a protocol that can be used to manipulate per-user data. XCAP is a set of conventions for mapping XML documents and document components into HTTP URIs, rules for how the modification of one resource affects another, data validation constraints, and

authorization policies associated with access to those resources. Because of this structure, normal HTTP primitives can be used to manipulate the data. Like ACAP, XCAP supports the configuration needs for a multiplicity of applications.

All XCAP servers are required to implement HTTP Digest Authentication [RFC2617]. Furthermore, XCAP servers are required to implement HTTP over TLS (HTTPS) [RFC2818]. It is recommended that administrators use an HTTPS URI as the XCAP root URI, so that the digest client authentication occurs over TLS.

Following list summarizes important XCAP application usages:

- o XCAP server capabilities [RFC4825] can be read by clients to determine which extensions, application usages, or namespaces a server supports.

- o A resource lists application is any application that needs access to a list of resources, identified by a URI, to which operations, such as subscriptions, can be applied [RFC4826].

- o A Resource List Server (RLS) Services application is a Session Initiation Protocol (SIP) application, where a server receives SIP SUBSCRIBE requests for resources, and generates subscriptions towards the resource list [RFC4826].

- o A Presence Rules application uses authorization policies, also known as authorization rules, to specify what presence information can be given to which watchers, and when [RFC4827].

- o A Pidf-manipulation application defines how XCAP is used to manipulate the contents of PIDF based presence documents [RFC4827].

4. Network Management Data Models

This section provides two complementary overviews for the network management data models standardized at IETF. The first subsection focuses on a broader view of models classified into categories such as generic and infrastructure data models as well as data models matched to different layers. The second subsection is structured following the management application view and focuses mainly on the data models for the network management tasks fault, configuration, accounting, performance, and security management (see [FCAPS]).

Note that IETF does not use the FCAPS view as an organizing principle for its data models. However, FCAPS view is used widely outside of IETF for the realization of management tasks and applications.

Section 4.2 aims to address the FCAPS view to enable people outside of IETF to understand the relevant data models at IETF.

The different data models covered in this section are MIB modules, IPFIX Information Elements, SYSLOG Structured Data Elements, and YANG modules. There are many technology-specific IETF data models, such as transmission and protocol MIBs, which are not mentioned in this document and can be found at [RFCSEARCH].

This section gives an overview of management data models that have reached Draft or Proposed Standard status at the IETF. In exceptional cases, important Informational RFCs are referred. The advancement process for management data models beyond Proposed Standard status, has been defined in [BCP27] with a more pragmatic approach and special considerations on data model specification interoperability. However, most IETF management data models never advanced beyond Proposed Standard.

4.1. IETF Network Management Data Models

The data models defined by the IETF can be broadly classified into the following categories depicted in Figure 1.

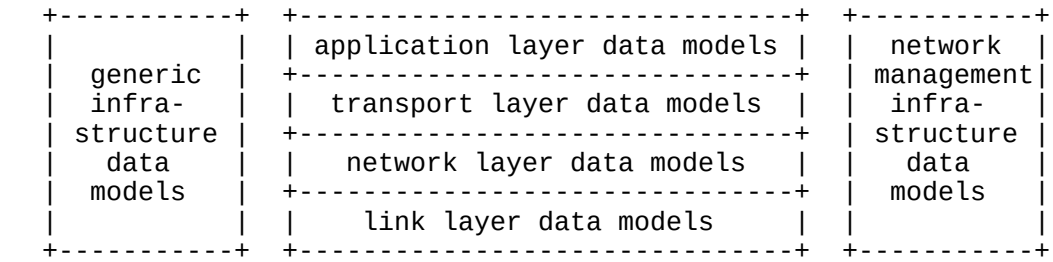

Figure 1: Categories of network management data models

Each of the categories is briefly described below. Note that the classification used here intends to provide orientation and reflects how most data models have been developed in the IETF by the various working groups. This classification does not aim to classify correctly all data models that have been defined by the IETF so far. The network layering model in the middle of Figure 1 follows the four layer model of the Internet as defined in [RFC1021].

The network management object identifiers for use with IETF MIB modules defined at IETF can be found under the IANA registry at [SMI-NUMBERS].

4.1.1. Generic Infrastructure Data Models

Generic infrastructure data models provide core abstractions that many other data models are built upon. The most important example is the interfaces data model defined in the IF-MIB [RFC2863]. It provides the basic notion of network interfaces and allows expressing stacking/layering relationships between interfaces. The interfaces data model also provides basic monitoring objects that are widely used for performance and fault management.

The second important infrastructure data model is defined in the Entity MIB [RFC4133]. It exports the containment hierarchy of the physical entities (slots, modules, ports) that make up a networking device and as such, it is a key data model for inventory management. Physical entities can have pointers to other data models that provide more specific information about them (e.g. physical ports usually point to the related network interface). Entity MIB extensions exist for physical sensors such as temperature sensors embedded on line cards or sensors that report fan rotation speeds [RFC3433]. Another extension models states and alarms of physical entities [RFC4268]. Some vendors have extended the basic Entity MIB with several proprietary data models.

4.1.2. Link Layer Data Models

A number of data models exist in the form of MIB modules covering the link layers IP runs over, such as ADSL [RFC4706], VDSL [RFC5650], GMPLS [RFC4803], ISDN [RFC2127], ATM [RFC2515] [RFC3606], Cable Modems [RFC4546] or Ethernet [RFC4188] [RFC4318] [RFC4363]. These so called transmission data models typically extend the generic network interfaces data model with interface type specific information. Most of the link layer data models focus on monitoring capabilities that can be used for performance and fault management functions and to some lesser extend for accounting and security management functions. The IEEE has meanwhile taken over the responsibility to maintain and further develop data models for the IEEE 802 family of protocols [RFC4663]. The cable modem industry consortium DOCSIS is working with the IETF to publish data models for cable modem networks as IETF standards-track specifications.

4.1.3. Network Layer Data Models

There are data models in the form of MIB modules covering IP/ICMP [RFC4293] [RFC4292] network protocols and their extensions (e.g., Mobile IP), the core protocols of the Internet. In addition, there are data models covering popular unicast routing protocols (OSPF [RFC4750], ISIS [RFC4444], BGP-4 [RFC4273]) and multicast routing protocols (PIM [RFC5060]).

Detailed models also exist for performance measurements in the form of IP performance metrics [RFC2330] (see Section 3.4).

The necessary data model infrastructure for configuration data models covering network layers are currently being defined using NETCONF [RFC6242] and YANG [RFC6020].

4.1.4. Transport Layer Data Models

There are data models for the transport protocols TCP [RFC4022], UDP [RFC4113], and SCTP [RFC3873]. For TCP, a data model providing extended statistics is defined in [RFC4898].

4.1.5. Application Layer Data Models

Some data models have been developed for specific application protocols (e.g., SIP [RFC4780]). In addition, there are data models that provide a generic infrastructure for instrumenting applications in order to obtain data useful primarily for performance management and fault management [RFC2287] [RFC2564]. In general, however, generic application MIB modules have been less successful in gaining widespread deployment.

4.1.6. Network Management Infrastructure Data Models

A number of data models are concerned with the network management system itself. This includes, in addition to a set of SNMP MIB modules for monitoring and configuring SNMP itself [RFC3410], some MIB modules providing generic functions such as the calculation of expressions over MIB objects, generic functions for thresholding and event generation, event notification logging functions and data models to represent alarms [RFC2981] [RFC2982] [RFC3014] [RFC3877]. In addition, there are data models that allow to execute basic reachability and path discovery tests [RFC4560]. Another collection of MIB modules provides remote monitoring functions, ranging from the data link layer up to the application layer. This is known as the RMON family of MIB modules [RFC3577].

The IPFIX protocol [RFC5101] (Section 2.3) is used to export information about network flows collected at so called observation points (typically a network interface). The information elements [RFC5102] carried in IPFIX cover the network and transport layer very well but also provides some link layer specific information elements. Work is underway to further extend the standardized information that can be carried in IPFIX.

The SYSLOG protocol document [RFC5424] (Section 2.2) defines an initial set of Structured Data Elements (SDEs) that relate to content

time quality, content origin, and meta-information about the message, such as language. Proprietary SDEs can be used to supplement the IETF- defined SDEs.

4.2. Network Management Data Models - FCAPS View

This subsection follows the management application view and aims to match the data models to network management tasks for fault, configuration, accounting, performance, and security management ([FCAPS]). As OAM is a general term that refers to a toolset, which can be used for fault detection, isolation, and performance measurement, aspects of FCAPS in the context of the data path, such as fault and performance management, are also discussed in [I-D.ietf-opsawg-oam-overview] "An Overview of Operations, Administration, and Maintenance (OAM) Mechanisms".

Some of the data models do not fit into one single FCAPS category per design but span multiple areas. For example, there are many technology-specific IETF data models, such as transmission and protocol MIBs, which cover multiple FCAPS categories, and therefore are not mentioned in this sub section and can be found at [RFCSEARCH].

4.2.1. Fault Management

Fault management encloses a set of functions to detect, isolate, notify, and correct faults encountered in a network as well as to maintain and examine error logs. The data models below can be utilized to realize a fault management application.

[RFC3418], part of SNMPv3 standard [STD62], is a MIB module containing objects in the system group that are often polled to determine if a device is still operating, and sysUpTime can be used to detect if the network management portion of the system has restarted, and counters have been reinitialized.

[RFC3413], part of SNMPv3 standard [STD62], is a MIB module including objects designed for managing notifications, including tables for addressing, retry parameters, security, lists of targets for notifications, and user customization filters.

The Interfaces Group MIB [RFC2863] builds on the old standard for MIB II [STD17] and is used as a primary MIB module for managing and monitoring the status of network interfaces. The Interfaces Group MIB defines a generic set of managed objects for network interfaces and it provides the infrastructure for additional managed objects specific to particular types of network interfaces, such as Ethernet.

[RFC4560] defines a MIB module for performing ping, traceroute, and lookup operations at a host. For troubleshooting purposes, it is useful to be able to initiate and retrieve the results of ping or traceroute operations when they are performed at a remote host.

The RMON (Remote Network Monitoring) MIB [STD59][RFC2819] can be configured to recognize conditions on existing MIB variables (most notably error conditions) and continuously to check for them. When one of these conditions occurs, the event may be logged, and management stations may be notified in a number of ways (for further discussion on RMON see Section 4.2.4).

DISMAN-EVENT-MIB in [RFC2981] and DISMAN-EXPRESSION-MIB in [RFC2982] provide a superset of the capabilities of the RMON alarm and event groups. These modules provide mechanisms for thresholding and reporting anomalous events to management applications.

The ALARM MIB in [RFC3877] and the Alarm Reporting Control MIB in [RFC3878] specify mechanisms for expressing state transition models for persistent problem states. ALARM MIB defines:
- a mechanism for expressing state transition models for persistent problem states,
- a mechanism to correlate a notification with subsequent state transition notifications about the same entity/object, and
- a generic alarm reporting mechanism (extends ITU-T work on X.733 [ITU-X733]).

[RFC3878] in particular defines objects for controlling the reporting of alarm conditions and extends ITU-T work on M.3100 Amendment 3 [ITU-M3100].

Other MIB modules that may be applied to fault management with SNMP include:

- NOTIFICATION-LOG-MIB [RFC3014] describes managed objects used for logging SNMP Notifications.

- ENTITY-STATE-MIB [RFC4268] describes extensions to the Entity MIB to provide information about the state of physical entities.

- ENTITY-SENSOR-MIB [RFC3433] describes managed objects for extending the Entity MIB to provide generalized access to information related to physical sensors, which are often found in networking equipment (such as chassis temperature, fan RPM, power supply voltage).

The SYSLOG protocol document [RFC5424] defines an initial set of Structured Data Elements (SDEs) that relate to content time quality,

content origin, and meta-information about the message, such as language. Proprietary SDEs can be used to supplement the IETF-defined SDEs.

The IETF has standardized MIB Textual-Conventions for facility and severity labels and codes to encourage consistency between SYSLOG and MIB representations of these event properties [RFC5427]. The intent is that these textual conventions will be imported and used in MIB modules that would otherwise define their own representations.

An IPFIX MIB module [RFC5815] has been defined for monitoring IPFIX meters, exporters and collectors (see Section 2.3). The ongoing work on PSAMP MIB module extends the IPFIX MIB modules by managed objects for monitoring PSAMP implementations [I-D.ietf-ipfix-psamp-mib].

The NETCONF working group defined the data model necessary to monitor the NETCONF protocol [RFC6022] with the modeling language YANG. The monitoring data model includes information about NETCONF datastores, sessions, locks, and statistics, which facilitate the management of a NETCONF server. NETCONF monitoring document also defines methods for NETCONF clients to discover the data models supported by a NETCONF server and defines the operation <get-schema> to retrieve them.

4.2.2. Configuration Management

Configuration management focuses on establishing and maintaining consistency of a system and defines the functionality to configure its functional and physical attributes as well as operational information throughout its life. Configuration management includes configuration of network devices, inventory management, and software management. The data models below can be used to utilize configuration management.

MIB modules for monitoring of network configuration (e.g. for physical and logical network topologies) already exist and provide some of the desired capabilities. New MIB modules might be developed for the target functionality to allow operators to monitor and modify the operational parameters, such as timer granularity, event reporting thresholds, target addresses, etc.

[RFC3418], part of [STD62], contains objects in the system group useful e.g. for identifying the type of device, and the location of the device, the person responsible for the device. The SNMPv3 standard [STD62] furthermore includes objects designed for configuring principals, access control rules, notification destinations, and for configuring proxy-forwarding SNMP agents, which can be used to forward messages through firewalls and Network Address Translation (NAT) devices.

The Entity MIB [RFC4133] supports mainly inventory management and is used for managing multiple logical and physical entities matched to a single SNMP agent. This module provides a useful mechanism for identifying the entities comprising a system and defines event notifications for configuration changes that may be useful to management applications.

[RFC3165] defines a set of managed objects that enable the delegation of management scripts to distributed managers.

For configuring IPFIX and PSMAP devices, the IPFIX working group developed the IPFIX configuration data model [I-D.ietf-ipfix-configuration-model], by using the YANG modeling language and in close collaboration with the NETMOD working group (see Section 2.4.2). The model specifies the necessary data for configuring and monitoring selection processes, caches, exporting processes, and collecting processes of IPFIX and PSAMP compliant monitoring devices.

At the time of this writing the NETMOD working group is developing core system and interface models in YANG.

The CAPWAP protocol exchanges Type Length Values (TLV). The base TLVs are specified in [RFC5415], while the TLVs for IEEE 802.11 are specified in [RFC5416]. CAPWAP Base MIB [RFC5833] specifies managed objects for modeling the CAPWAP Protocol and provides configuration and WTP status-monitoring aspects of CAPWAP, where CAPWAP Binding MIB [RFC5834] defines managed objects for modeling of CAPWAP protocol for IEEE 802.11 wireless binding.
Note: RFC 5833 and RFC 5834 have been published as Informational RFCs to provide the basis for future work on a SNMP management of the CAPWAP protocol.

4.2.3. Accounting Management

Accounting management collects usage information of network resources. Note that IETF does not define any mechanisms related to billing and charging. Many technology specific MIBs (link layer, network layer, transport layer or application layer) contain counters but are not primarily targeted for accounting, and therefore not included in this section.

[RFC4670] 'RADIUS Accounting Client MIB for IPv6' defines RADIUS Accounting Client MIB objects that support version-neutral IP addressing formats.

[RFC4671] 'RADIUS Accounting Server MIB for IPv6' defines RADIUS Accounting Server MIB objects that support version-neutral IP

addressing formats.

IPFIX/PSAMP Information Elements:

As expressed in Section 2.3, the IPFIX architecture [RFC5470] defines components involved in IP flow measurement and reporting of information on IP flows. As such, IPFIX records provide fine-grained measurement data for flexible and detailed usage reporting and enable usage-based accounting.

The IPFIX Information Elements (IE) have been initially defined in the IPFIX Information Model [RFC5102] and registered at the IANA [IANA-IPFIX]. The IPFIX IEs are composed of two types:

- o IEs related to identification of IP flows such as header information, derived packet properties, IGP and BGP next hop IP address, BGP AS, etc., and

- o IEs related to counter and timestamps, such as per-flow counters (e.g. octet count, packet count), flow start times, flow end times, and flow duration, etc.

The Information Elements specified in the IPFIX information model [RFC5102] are used by the PSAMP protocol where applicable. Packet Sampling (PSAMP) Parameters defined in the PSAMP protocol specification are registered at [IANA-PSAMP]. An additional set of PSAMP Information Elements for reporting packet information with the IPFIX/PSAMP protocol such as Sampling-related IEs are specified in the PSAMP Information Model [RFC5477]. These IEs fulfill the requirements on reporting of different sampling and filtering techniques specified in [RFC5475].

4.2.4. Performance Management

Performance management covers a set of functions that evaluate and report the performance of network elements and the network, with the goal to maintain the overall network performance at a defined level. Performance management functionality includes monitoring and measurement of network performance parameters, gathering statistical information, maintaining and examining activity logs. The data models below can be used for performance management tasks.

The RMON (Remote Network Monitoring) MIB [STD59][RFC2819] defines objects for collecting data related to network performance and traffic from remote monitoring devices. An organization may employ many remote monitoring probes, one per network segment, to monitor its network. These devices may be used by a network service provider to access a client network, often geographically remote. Most of the

objects in the RMON MIB module are suitable for the monitoring of any type of network, while some of them are specific to the monitoring of Ethernet networks.

RMON allows a probe to be configured to perform diagnostics and to collect network statistics continuously, even when communication with the management station may not be possible or efficient. The alarm group periodically takes statistical samples from variables in the probe and compares them to previously configured thresholds. If the monitored variable crosses a threshold, an event is generated.

[RFC3577] 'Introduction to the Remote Monitoring (RMON) Family of MIB Modules' describes the documents associated with the RMON framework and how they relate to each other.

The RMON-2 MIB [RFC4502] extends RMON by providing RMON analysis up to the application layer and defines performance data to monitor. The SMON MIB [RFC2613] extends RMON by providing RMON analysis for switched networks.

RMON MIB Extensions for High Capacity Alarms [RFC3434] describes managed objects for extending the alarm thresholding capabilities found in the RMON MIB and provides similar threshold monitoring of objects based on the Counter64 data type.

RMON MIB Extensions for High Capacity Networks [RFC3273] defines objects for managing RMON devices for use on high-speed networks.

RMON MIB Extensions for Interface Parameters Monitoring [RFC3144] describes an extension to the RMON MIB with a method of sorting the interfaces of a monitored device according to values of parameters specific to this interface.

[RFC4710] describes Real-Time Application Quality of Service Monitoring (RAQMON), which is part of the RMON protocol family. RAQMON supports end-to-end QoS monitoring for multiple concurrent applications and does not relate to a specific application transport. RAQMON is scalable and works well with encrypted payload and signaling. RAQMON uses TCP to transport RAQMON PDUs.

[RFC4711] proposes an extension to the Remote Monitoring MIB [STD59][RFC2819] and describes managed objects used for RAQMON. [RFC4712] specifies two transport mappings for the RAQMON information model using TCP as a native transport and SNMP to carry the RAQMON information from a RAQMON Data Source (RDS) to a RAQMON Report Collector (RRC).

Application Performance Measurement MIB [RFC3729] uses the

architecture created in the RMON MIB and defines objects by providing measurement and analysis of the application performance as experienced by end-users. [RFC3729] enables the measurement of the quality of service delivered to end-users by applications.

Transport Performance Metrics MIB [RFC4150] describes managed objects used for monitoring selectable performance metrics and statistics derived from the monitoring of network packets and sub-application level transactions. The metrics can be defined through reference to existing IETF, ITU, and other standards organizations' documents.

The IPPM working group has defined [RFC4148] "IP Performance Metrics (IPPM) Metrics Registry". Note that with the publication of [RFC6248], [RFC4148] and the corresponding IANA registry for IPPM metrics have been declared Obsolete and shouldn't be used.

The IPPM working group defined an Information Model and XML Data Model for Traceroute Measurements [RFC5388], which defines a common information model dividing the information elements into two semantically separated groups (configuration elements and results elements) with an additional element to relate configuration elements and results elements by means of a common unique identifier. Based on the information model, an XML data model is provided to store the results of traceroute measurements.

SIP Package for Voice Quality Reporting [RFC6035] defines a SIP event package that enables the collection and reporting of metrics that measure the quality for Voice over Internet Protocol (VoIP) sessions.

4.2.5. Security Management

The security management provides the set of functions to protect the network and system from unauthorized access and includes functions such as creating, deleting, and controlling security services and mechanisms; key management, reporting security-relevant events, and authorizing user access and privileges. Based on their support for authentication and authorization, RADIUS and DIAMETER are seen as security management protocols. The data models below can be used to utilize security management.

[RFC3414], part of [STD62], specifies the procedures for providing SNMPv3 message level security and includes a MIB module for remotely monitoring and managing the configuration parameters for the USM security model.

[RFC3415], part of [STD62], describes the procedures for controlling access to management information in the SNMPv3 architecture and includes a MIB module, which defines managed objects to access

portions of an SNMP engine's Local Configuration Datastore (LCD). As such, this MIB module enables remote management of the configuration parameters of the View-based Access Control Model.

NETCONF Access Control Model (NACM) [RFC6536] addresses the need for access control mechanisms for the operation and content layers of NETCONF, as defined in [RFC6241]. As such NACM proposes standard mechanisms to restrict NETCONF protocol access for particular users to a pre-configured subset of all available NETCONF protocol operations and content within a particular server.

There are numerous MIB modules defined for multiple purposes to use with RADIUS:

- [RFC4668] 'RADIUS Authentication Client MIB for IPv6' defines RADIUS Authentication Client MIB objects that support version-neutral IP addressing formats and defines a set of extensions for RADIUS authentication client functions.

- [RFC4669] 'RADIUS Authentication Server MIB for IPv6' defines RADIUS Authentication Server MIB objects that support version-neutral IP addressing formats and defines a set of extensions for RADIUS authentication server functions.

- [RFC4672] 'RADIUS Dynamic Authorization Client MIB' defines the MIB module for entities implementing the client side of the Dynamic Authorization Extensions to RADIUS [RFC5176].

- [RFC4673] 'RADIUS Dynamic Authorization Server MIB' defines the MIB module for entities implementing the server side of the Dynamic Authorization Extensions to RADIUS [RFC5176].

The MIB Module definitions in [RFC4668], [RFC4669], [RFC4672], [RFC4673] are intended to be used only for RADIUS over UDP and do not support RADIUS over TCP. There is also a recommendation that RADIUS clients and servers implementing RADIUS over TCP should not reuse earlier listed MIB modules to perform statistics counting for RADIUS over TCP connections.

Currently there are no standardized MIB modules for DIAMETER applications, which can be considered as a lack on the management side of DIAMETER nodes. There are ongoing efforts to produce standard MIBs for the 'Diameter Base Protocol' and the 'Diameter Credit-Control Application'.

5. IANA Considerations

This document does not introduce any new code-points or namespaces for registration with IANA.

Note to RFC Editor: this section may be removed on publication as an RFC.

6. Security Considerations

This document gives an overview of IETF network management standards and summarizes existing and ongoing development of IETF standards-track network management protocols and data models. As such it does not have any security implications in or of itself.

For each specific technology discussed in the document a summary of its security usage has been given in corresponding chapters. In a few cases, e.g. for SNMP, a detailed description of developed security mechanisms has been provided.

The attention of the reader is particularly drawn to the security discussion in following document sections:

- SNMP Security and Access Control Models in Section 2.1.4.1,
- User-Based Security Model (USM) in Section 2.1.4.2,
- View-Based Access Control Model (VACM) in Section 2.1.4.3,
- SNMP Transport Security Model in Section 2.1.5.1,
- Secure SYSLOG message delivery in Section 2.2,
- Use of secure NETCONF message transport and the NETCONF Access Control Model (NACM) in Section 2.4.1,
- Message authentication for Dynamic Host Configuration Protocol (DHCP) in Section 3.1.1,
- Security for Remote Authentication Dial In User Service (RADIUS) in conjunction with EAP and IEEE 802.1X authenticators in Section 3.5,
- Built in and transport security for Diameter Base Protocol (DIAMETER) in Section 3.6,
- Transport security for Control And Provisioning of Wireless Access Points (CAPWAP) in Section 3.7,

- Built in security for Access Node Control Protocol (ANCP) in Section 3.8,
- Security for Application Configuration Access Protocol (ACAP) in Section 3.9,
- Security for XML Configuration Access Protocol (XCAP) in Section 3.10, and
- Data models for the Security Management in Section 4.2.5.

The authors would like to refer also to detailed security consideration sections for specific management standards described in this document, which contain comprehensive discussion of security implications of the particular management protocols and mechanisms. Among others security consideration sections of following documents should be carefully read before implementing the technology.

- For SNMP security in general, subsequent security consideration sections in [STD62], which includes RFCs 3411-3418,
- Security consideration section in Section 8. of [BCP74] for the coexistence between SNMP v1, v2, and v3,
- Security considerations for the SNMP Transport Security Model in Section 8. of [RFC5591],
- Security considerations for the Secure Shell Transport Model for SNMP in Section 9 of [RFC5592],
- Security considerations for the TLS Transport Model for SNMP in Section 9. of [RFC6353],
- Security considerations for the TLS Transport Mapping for Syslog in Section 6 of [RFC5425],
- Security considerations for the IPFIX Protocol Specification in Section 11. of [RFC5101],
- Security considerations for the NETCONF protocol in Section 9. of [RFC6241] and the SSH transport in Section 6. of [RFC6242],
- Security considerations for the NETCONF Access Control Model (NACM) in Section 3.7. of [RFC6536],
- Security considerations for DHCPv4 and DHCPv6 in Section 7. of [RFC2131] and Section 23. of [RFC3315],

- Security considerations for RADIUS in Section 8. of [RFC2865],
- Security considerations for DIAMETER in Section 13. of [RFC3588],
- Security considerations for the CAPWAP protocol in Section 12. of [RFC5415],
- Security considerations for the ANCP protocol in Section 11. of [RFC6320], and
- Security considerations for the XCAP protocol in Section 14. of [RFC4825].

7. Contributors

Following persons made significant contributions to and reviewed this document:

- Ralph Droms (Cisco) - revised the section on IP address management and DHCP.
- Jouni Korhonen (Nokia Siemens Networks) - contributed the sections on RADIUS and DIAMETER.
- Al Morton (AT&T) - contributed to the section on IP Performance Metrics.
- Juergen Quittek (NEC) - contributed the section on IPFIX/PSAMP.
- Juergen Schoenwaelder (Jacobs University Bremen) - contributed the sections on IETF Network Management Data Models and YANG.

8. Acknowledgements

The editor would like to thank to Fred Baker, Alex Clemm, Miguel A. Garcia, Simon Leinen, Christopher Liljenstolpe, Tom Petch, Randy Presuhn, Dan Romascanu, Juergen Schoenwaelder, Tina Tsou, and Henk Uijterwaal, for their valuable suggestions, comments in the OPSAWG sessions and mailing list.

The editor would like to especially thank Dave Harrington, who created the document "Survey of IETF Network Management Standards" a few years ago, which has been used as a starting point and enhanced with a special focus on the description of the IETF network management standards and management data models.

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Appendix A. High Level Classification of Management Protocols and Data Models

The following subsections aim to guide the reader for the fast selection of the management standard in interest and can be used as a dispatcher to forward to the appropriate chapter. The subsections below classify the protocols on one hand according to high-level criteria such as push versus pull mechanism, and passive versus active monitoring. On the other hand, the protocols are categorized concerning the network management task they address or the data model extensibility they provide. Based on the reader's requirements a reduced set of standard protocols and associated data models can be selected for further reading.

As an example, someone outside of IETF typically would look for the TWAMP protocol in the Operations and Management Area working groups as it addresses performance management. However, the protocol TWAMP has been developed by the IPPM working group in the Transport Area.

Note that not all protocols have been listed in all classification sections. Some of the protocols, especially the protocols with specific focus in Section 3 cannot be clearly classified. Note also

that COPS and COPS-PR are not listed in the tables, as COPS-PR is not recommended to use (see Section 3.3).

A.1. Protocols classified by the Standard Maturity at IETF

This section classifies the management protocols according their standard maturity at the IETF. The IETF standard maturity levels Proposed, Draft or Internet Standard, are defined in [RFC2026]. An Internet Standard is characterized by a high degree of technical maturity and by a generally held belief that the specified protocol or service provides significant benefit to the Internet community.

The table below covers the standard maturity of the different protocols listed in this document. Note that only the main protocols (and not their extensions) are noted. An RFC search tool listing the current document status is available at [RFCSEARCH].

Protocol	Maturity Level
SNMP [STD62][RFC3411] (Section 2.1)	Internet Standard
SYSLOG [RFC5424] (Section 2.2)	Proposed Standard
IPFIX [RFC5101] (Section 2.3)	Proposed Standard
PSAMP [RFC5476] (Section 2.3)	Proposed Standard
NETCONF [RFC6241] (Section 2.4.1)	Proposed Standard
DHCP for IPv4 [RFC2131] (Section 3.1.1)	Draft Standard
DHCP for IPv6 [RFC3315] (Section 3.1.1)	Proposed Standard
OWAMP [RFC4656] (Section 3.4)	Proposed Standard
TWAMP [RFC5357] (Section 3.4)	Proposed Standard
RADIUS [RFC2865] (Section 3.5)	Draft Standard
DIAMETER [RFC3588] (Section 3.6)	Proposed Standard
CAPWAP [RFC5416] (Section 3.7)	Proposed Standard
ANCP [RFC6320] (Section 3.8)	Proposed Standard
Ad-hoc network configuration [RFC5889] (Section 3.1.2)	Informational
ACAP [RFC2244] (Section 3.9)	Proposed Standard

XCAP [RFC4825] (Section 3.10)	Proposed Standard

Table 1: Protocols classified by Standard Maturity at IETF

A.2. Protocols Matched to Management Tasks

This subsection classifies the management protocols matching to the management tasks for fault, configuration, accounting, performance, and security management.

Fault Mgmt	Configuration Mgmt	Accounting Mgmt	Performance Mgmt	Security Mgmt
SNMP notification with trap operation (S. 2.1.1)	SNMP configuration with set operation (S. 2.1.1)	SNMP monitoring with get operation (S. 2.1.1)	SNMP monitoring with get operation (S. 2.1.1)	
IPFIX (S. 2.3)	CAPWAP (S. 3.7)	IPFIX (S. 2.3)	IPFIX (S. 2.3)	
PSAMP (S. 2.3)	NETCONF (S. 2.4)	PSAMP (S. 2.3)	PSAMP (S. 2.3)	
SYSLOG (S. 2.2)	ANCP (S. 3.8)	RADIUS Accounting (S. 3.5)		RADIUS Authent.& Authoriz. (S. 3.5)
	AUTOCONF (S. 3.1.2)	DIAMETER Accounting (S. 3.6)		DIAMETER Authent.& Authoriz. (S. 3.6)
	ACAP (S. 3.9)			
	XCAP (S. 3.10)			
	DHCP (S. 3.11)			

Table 2: Protocols Matched to Management Tasks

Note: Corresponding section numbers are given in parenthesis.

A.3. Push versus Pull Mechanism

A pull mechanism is characterized by the Network Management System (NMS) pulling the management information out of network elements, when needed. A push mechanism is characterized by the network elements pushing the management information to the NMS, either when the information is available, or on a regular basis.

Client/Server protocols, such as DHCP, ANCP, ACAP, and XCAP are not listed in Table 3.

Protocols supporting the Pull mechanism	Protocols supporting the Push mechanism
SNMP (except notifications) (Section 2.1)	SNMP notifications (Section 2.1)
NETCONF (except notifications) (Section 2.4.1)	NETCONF notifications (Section 2.4.1)
CAPWAP (Section 3.7)	SYSLOG (Section 2.2)
	IPFIX (Section 2.3)
	PSAMP (Section 2.3)
	RADIUS accounting (Section 3.5)
	DIAMETER accounting (Section 3.6)

Table 3: Protocol classification by Push versus Pull Mechanism

A.4. Passive versus Active Monitoring

Monitoring can be divided into two categories, passive and active monitoring. Passive monitoring can perform the network traffic monitoring, monitoring of a device or the accounting of network resource consumption by users. Active monitoring, as used in this document, focuses mainly on active network monitoring and relies on the injection of specific traffic (also called "synthetic traffic"), which is then monitored. The monitoring focus is indicated in the table below as "network", "device" or "accounting".

This classification excludes non-monitoring protocols, such as configuration protocols: Ad-hoc network autoconfiguration, ANCP, and XCAP. Note that some of the active monitoring protocols, in the context of the data path, e.g. ICMP Ping and Traceroute [RFC1470], Bidirectional Forwarding Detection (BFD) [RFC5880], and PWE3 Virtual Circuit Connectivity Verification (VCCV) [RFC5085] are covered in [I-D.ietf-opsawg-oam-overview].

Protocols supporting passive monitoring	Protocols supporting active monitoring
IPFIX (network) (Section 2.3)	OWAMP (network) (Section 3.4)
PSAMP (network) (Section 2.3)	TWAMP (network) (Section 3.4)
SNMP (network and device) (Section 2.1)	
NETCONF (device) (Section 2.4.1)	
RADIUS (accounting) (Section 3.5)	
DIAMETER (accounting) (Section 3.6)	
CAPWAP (device) (Section 3.7)	

Table 4: Protocols for passive and active monitoring and their monitoring focus

The application of SNMP to passive traffic monitoring (e.g. with RMON-MIB) or active monitoring (with IPPM MIB) depends on the MIB modules used. However, SNMP protocol itself does not have operations, which support active monitoring. NETCONF can be used for passive monitoring, e.g. with the NETCONF Monitoring YANG module [RFC6022] for the monitoring of the NETCONF protocol. CAPWAP monitors the status of a Wireless Termination Point.

RADIUS and DIAMETER are considered as passive monitoring protocols as they perform accounting, i.e. counting the number of packets/bytes for a specific user.

A.5. Supported Data Model Types and their Extensibility

The following table matches the protocols to the associated data model types. Furthermore, the table indicates how the data model can be extended based on the available content today and whether the protocol contains a built-in mechanism for proprietary extensions of the data model.

Protocol	Data Modeling	Data Model Extensions	Proprietary Data Modeling Extensions
SNMP (Section 2.1)	MIB modules defined with SMI (Section 2.1.3)	New MIB modules specified in new RFCs	Enterprise specific MIB modules
SYSLOG (Section 2.2)	Structured Data Elements (SDE) (Section 4.2.1)	With the procedure to add Structured Data ID in [RFC5424]	Enterprise specific SDEs
IPFIX (Section 2.3)	IPFIX Information Elements, IPFIX IANA registry at [IANA-IPFIX] (Section 2.3)	With the procedure to add Information Elements specified in [RFC5102]	Enterprise specific Information Elements [RFC5101]
PSAMP (Section 2.3)	PSAMP Information Elements, as an extension to IPFIX [IANA-IPFIX], and PSAMP IANA registry at [IANA-PSAMP] (Section 2.3)	With the procedure to add Information Elements specified in [RFC5102]	Enterprise specific Information Elements [RFC5101]
NETCONF (Section 2.4.1)	YANG modules (Section 2.4.2)	New YANG modules specified in new RFCs following the guideline in [RFC6087]	Enterprise specific YANG modules
IPPM OWAMP/TWAMP (Section 3.4)	IPPM metrics (*) (Section 3.4)	New IPPM metrics (Section 3.4)	Not applicable
RADIUS (Section 3.5)	Type-Length-Values (TLV)	RADIUS related registries at [IANA-AAA] and [IANA-PROT]	Vendor Specific Attributes [RFC2865]

DIAMETER (Section 3.6)	Attribute-Value Pairs (AVP)	DIAMETER related registry at [IANA-AAA]	Vendor Specific Attributes [RFC2865]
CAPWAP (Section 3.7)	Type-Length-Values (TLV)	New bindings specified in new RFCs	Vendor specific TLVs

Table 5: Data Models and their Extensibility

(*): With the publication of [RFC6248] the latest IANA registry for IPFIX metrics has been declared Obsolete.

Appendix B. New Work related to IETF Management Standards

B.1. Energy Management (EMAN)

Energy management is becoming an additional requirement for network management systems due to several factors including the rising and fluctuating energy costs, the increased awareness of the ecological impact of operating networks and devices, and the regulation of governments on energy consumption and production.

The basic objective of energy management is operating communication networks and other equipments with a minimal amount of energy while still providing sufficient performance to meet service level objectives. Today, most networking and network-attached devices neither monitor nor allow control energy usage as they are mainly instrumented for functions such as fault, configuration, accounting, performance, and security management. These devices are not instrumented to be aware of energy consumption. There are very few means specified in IETF documents for energy management, which includes the areas of power monitoring, energy monitoring, and power state control.

A particular difference between energy management and other management tasks is that in some cases energy consumption of a device is not measured at the device itself but reported by a different place. For example, at a Power over Ethernet (PoE) sourcing device or at a smart power strip, where one device is effectively metering another remote device. This requires a clear definition of the relationship between the reporting devices and identification of remote devices for which monitoring information is provided. Similar considerations will apply to power state control of remote devices, for example, at a PoE sourcing device that switches on and off power at its ports. Another example scenario for energy management is a gateway to low resourced and lossy network devices in wireless a

building network. Here the energy management system talks directly to the gateway but not necessarily to other devices in the building network.

At the time of this writing the EMAN working group works on the management of energy-aware devices, covered by the following items:

- Requirements for energy management, specifying energy management properties that will allow networks and devices to become energy aware. In addition to energy awareness requirements, the need for control functions will be discussed. Specifically the need to monitor and control properties of devices that are remote to the reporting device should be discussed.

- Energy management framework, which will describe extensions to current management framework, required for energy management. This includes: power and energy monitoring, power states, power state control, and potential power state transitions. The framework will focus on energy management for IP-based network equipment (routers, switches, PCs, IP cameras, phones and the like). Particularly, the relationships between reporting devices, remote devices, and monitoring probes (such as might be used in low-power and lossy networks) need to be elaborated. For the case of a device reporting on behalf of other devices and controlling those devices, the framework will address the issues of discovery and identification of remote devices.

- Energy-aware Networks and Devices MIB document, for monitoring energy-aware networks and devices, will address devices identification, context information, and potential relationship between reporting devices, remote devices, and monitoring probes.

- Power and Energy Monitoring MIB document will document defining managed objects for monitoring of power states and energy consumption/production. The monitoring of power states includes: retrieving power states, properties of power states, current power state, power state transitions, and power state statistics. The managed objects will provide means of reporting detailed properties of the actual energy rate (power) and of accumulated energy. Further, it will provide information on electrical power quality.

- Battery MIB document will define managed objects for battery monitoring, which will provide means of reporting detailed properties of the actual charge, age, and state of a battery and of battery statistics.

- Applicability statement will describe the variety of applications that can use the energy framework and associated MIB modules. Potential examples are building networks, home energy gateway, etc. Finally, the document will also discuss relationships of the framework to other architectures and frameworks (such as Smart Grid). The applicability statement will explain the relationship between the work in this WG and other existing standards e.g. from the IEC, ANSI, DMTF, etc. Note that the EMAN WG will be looking into existing standards such as those from the IEC, ANSI, DMTF and others, and reuse existing work as much as possible.

Appendix C. Change Log

RFC EDITOR: Please remove this appendix before publication.

C.1. 06-07

- Addressed IESG requests.

C.2. 05-06

- Added a description for each DIAMETER application.
- Extend text for XCAP and added descriptions for XCAP application usages.
- Addressed GEN-area review comments.
- Fixed nits and references.

C.3. 04-05

- Fixed nits.

C.4. 03-04

- Resolved many bugs, nits and open issues.
- Reduced text on old and less used RFCs.
- Formulated text on drafts, which are not expected to be published in IETF 83 time frame, as ongoing work and deleted the reference.
- Reduced I-D references and edited remaining ones as easily replaceable with RFC references.
- Removed textual references that RFCs are Proposed or Draft standard.

- Removed the categories for Draft, Proposed and Full standards in section 4.2.

C.5. 02-03

- Added the new subsection 4.1 giving a broader overview of IETF management data models.
- Reduced text on RMON in section 4.2.4 Performance Management
- Resolved bugs, nits and open issues
- Added RFC references

C.6. 01-02

- Resolved bugs, nits and open issues
- Reduced subsections RADIUS and DIAMETER with text on expired drafts.
- Extended dispatcher tables in Appendix A
- Added a note indicating that IETF has not developed so far specific technologies for the management of sensor networks.
- Added a note that IETF has not used the FCAPS view as an organizing principle for its data models.
- Added draft-weil-shared-transition-space-request assuming that it’ll get published pretty fast
- Added RFC references
- Removed text on expired drafts

C.7. 00-01

- Reduced text for the Security Requirements on SNMP and referenced to RFC 3411
- Reduced subsection on VACM
- Merged subsection on "RADIUS Authentication and Authorization with SNMP Transport Models" into the section "SNMP Transport Security Model"

- Section on Dynamic Host Configuration Protocol (DHCP) revised by Ralph Droms
- Subsections on DHCP and Autoconf assembled in section "IP Address Management"
- Removed subsection on "Extensible Provision Protocol (EPP)"
- Introduced new Appendix on "High Level Classification of Management Protocols and Data Models"
- Deleted detailed positive comments
- Resolved some of the I-D references with the correct reference to the published RFC number
- Added RFC references
- Removed text on expired drafts
- Resolved bugs, nits and open issues

C.8. draft-ersue-opsawg-management-fw-03-00

- Diverse bug fixing
- Incorporated comments from Juergen Schoenwaelder
- Reduced detailed text on pro and contra on management technologies
- Extended Terminology section with terms and abbreviations
- Explained the structure based on the management application view
- Definition of ’MIB module’ aligned in different sections
- Text on SNMP security reduced
- All protocol sections discuss now security and AAA as far as relevant
- Added IPFIX IEs, SYSLOG SDEs, and YANG modules to the data model definition
- Added text on YANG data modules to section 4.2.
- Added text on IPFIX IEs to section 4.3.

- Added numerous references

C.9. Change Log from draft-ersue-opsawg-management-fw

C.9.1. 02-03

- Rearranged the document structure using a flat structure putting all protocols onto the same level.
- Incorporated contributions for RADIUS/DIAMETER, IPFIX/PSAMP, YANG, and EMAN.
- Added diverse references.
- Added Contributors and Acknowledgements sections.
- Bug fixing and issue solving.

C.9.2. 01-02

- Added terminology section.
- Changed the language for neutral standard description addressing diverse SDOs.
- Extended NETCONF and NETMOD related text.
- Extended section for 'IPv6 Network Operations'.
- Bug fixing.

C.9.3. 00-01

- Extended text for SNMP
- Extended RADIUS and DIAMETER sections.
- Added references.
- Bug fixing.

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February 16, 2012

IANA Reserved IPv4 Prefix for Shared Address Space
draft-weil-shared-transition-space-request-15

Abstract

This document requests the allocation of an IPv4 /10 address block to be used as Shared Address Space to accommodate the needs of Carrier Grade Network Address Translation (CGN) devices. It is anticipated that Service Providers will use this Shared Address Space to number the interfaces that connect CGN devices to Customer Premise Equipment (CPE).

Shared Address Space is distinct from RFC1918 private address space because it is intended for use on Service Provider networks. However, it may be used in a manner similar to RFC 1918 private address space on routing equipment that is able to do address translation across router interfaces when the addresses are identical on two different interfaces. Details are provided in the text of this document.

As this document proposes the allocation of an additional special-use IPv4 address block, it updates RFC 5735.

Status of this Memo

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1. Introduction

IPv4 address space is nearly exhausted. However, ISPs must continue to support IPv4 growth until IPv6 is fully deployed. To that end, many ISPs will deploy Carrier Grade NAT (CGN) such as that described in [RFC6264]. Because CGNs are used on networks where public address space is expected, and currently available private address space causes operational issues when used in this context, ISPs require a new IPv4 /10 address block. This address block will be called the Shared Address Space and will be used to number the interfaces that connect CGN devices to Customer Premise Equipment (CPE).

Shared Address Space is similar to [RFC1918] private address space in that it is not global routable address space and can be used by multiple pieces of equipment. However, Shared Address Space has limitations in its use that the current [RFC1918] private address space does not have. In particular, Shared Address Space can only be used in Service Provider networks or on routing equipment that is able to do address translation across router interfaces when the addresses are identical on two different interfaces.

This document requests the allocation of an IPv4 /10 address block to be used as Shared Address Space. In conversations with many ISPs, a /10 is the smallest block that will allow them to deploy CGNs on a regional basis without requiring nested CGNs. For Instance, as described in [I-D.shirasaki-isp-shared-addr], a /10 is sufficient to service Points of Presence in the Tokyo area.

As this document proposes the allocation of an additional special-use IPv4 address block, it updates [RFC5735].

2. Requirements Language

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. Alternatives to Shared Address Space

The interfaces that connect CGN devices to CPE might conceivably be numbered from any of the following address spaces:

- legitimately assigned globally unique address space
- usurped globally unique address space (i.e., squat space)
- [RFC1918] space
- Shared Address Space

A Service Provider can number the interfaces in question from legitimately assigned globally unique address space. While this solution poses the fewest problems, it is impractical because globally unique IPv4 address space is in short supply. While the Regional Internet Registries (RIR) have enough address space to allocate a single /10 to be shared by all Service Providers, they do not have enough address space to make a unique assignment to each Service Provider.

Service Providers MUST NOT number the interfaces in question from usurped globally unique address space (i.e., squat space). If a Service Provider leaks advertisements for squat space into the global Internet, the legitimate holders of that address space may be adversely impacted, as would those wishing to communicate with them. Even if the Service Provider did not leak advertisements for squat space, the Service Provider and its subscribers might lose connectivity to the legitimate holders of that address space.

A Service Provider can number the interfaces in question from [RFC1918] space if either of the following conditions are true:

- The Service Provider knows that the CPE/NAT works correctly when the same [RFC1918] address block is used both on its inside and outside interfaces.
- The Service Provider knows that the [RFC1918] address block that it uses to number interfaces between the CGN and CPE is not used on the subscriber side of the CPE.

Unless at least one of the conditions above is true, the Service Provider cannot safely use [RFC1918] address space and must resort to Shared Address Space. This is typically the case in an unmanaged service, where subscribers provide their own CPE and number their own internal network.

4. Use of Shared CGN Space

Shared Address Space is IPv4 address space designated for Service Provider use with the purpose of facilitating CGN deployment. Also, Shared Address Space can be used as additional non-globally routable space on routing equipment that is able to do address translation across router interfaces when the addresses are identical on two different interfaces.

Devices MUST be capable of performing address translation when identical Shared Address Space ranges are used on two different interfaces.

Packets with Shared Address Space source or destination addresses MUST NOT be forwarded across Service Provider boundaries. Service Providers MUST filter such packets on ingress links. As above, one exception to the above proscriptions is in the case of business relationships such as hosted CGN service.

When running a single DNS infrastructure, Service Providers MUST NOT include Shared Address Space in zone files. When running a split DNS infrastructure, Service Providers MUST NOT include Shared Address Space in external-facing zone files.

Reverse DNS queries for Shared Address Space addresses MUST NOT be forwarded to the global DNS infrastructure. DNS Providers SHOULD filter requests for Shared Address Space reverse DNS queries on recursive nameservers. This is done to avoid having to set up something similar to AS112.net for RFC 1918 private address space that a host has incorrectly sent for a DNS reverse-mapping queries on the public Internet [RFC6304].

Because CGN service requires non-overlapping address space on each side of the home NAT and CGN, entities using Shared Address Space for purposes other than for CGN service, as described in this document, are likely to experience problems implementing or connecting to CGN service at such time as they exhaust their supply of public IPv4 addresses.

5. Risk

5.1. Analysis

Some existing applications discover the outside address of their local CPE, determine whether the address is reserved for special-use, and behave differently based on that determination. If a new IPv4 address block is reserved for special-use and that block is used to number CPE outside interfaces, some of the above-mentioned applications may fail.

For example, assume that an application requires its peer (or some other device) to initiate an incoming connection directly with its CPE outside address. That application discovers the outside address of its CPE and determines whether that address is reserved for special-use. If the address is reserved for special-use, the application rightly concludes the that address is not reachable from the global Internet and behaves in one manner. If the address is not reserved for special-use, the application assumes that the address is reachable from the global Internet and behaves in another manner.

While the assumption that a non-special-use address is reachable from the global Internet is generally safe, it is not always true (e.g., when the CPE outside interface is numbered from globally unique address space but that address is not advertised to the global Internet as when it is behind a CGN). Such an assumption could cause certain applications to behave incorrectly in those cases.

5.2. Empirical Data

The primary motivation for the allocation of Shared Address Space is as address space for CGNs; the use and impact of CGNs has been previously described in [RFC6269] and [I-D.donley-nat444-impacts]. Some of the services adversely impacted by CGNs are:

1. Console gaming - some games fail when two subscribers using the same outside public IPv4 address try to connect to each other.

2. Video streaming - performance is impacted when using one of several popular video streaming technologies to deliver multiple video streams to users behind particular CPE routers.

3. Peer-to-peer - some peer-to-peer applications cannot seed content due to the inability to open incoming ports through the CGN. Likewise, some SIP client implementations cannot receive incoming calls unless they first initiate outgoing traffic or open an incoming port through the CGN using [I-D.ietf-pcp-base] or similar mechanism.

4. Geo-location - geo-location systems identify the location of the CGN server, not the end host.

5. Simultaneous logins - some websites (particularly banking and social networking websites) restrict the number of simultaneous logins per outside public IPv4 address.

6. 6to4 - 6to4 requires globally reachable addresses, and will not work in networks that employ addresses with limited topological span such as those employing CGNs.

Based on testing documented in [I-D.donley-nat444-impacts], the CGN impacts on 1-5 are comparable regardless of whether globally unique, Shared Address Space, or [RFC1918] addresses are used. There is, however, a difference between the three alternatives in the treatment of 6to4.

As described in [RFC6343], CPE routers do not attempt to initialize 6to4 tunnels when they are configured with [RFC1918] or [RFC5735] WAN addresses. When configured with globally unique or Shared Address Space addresses, such devices may attempt to initiate 6to4, which would fail. Service Providers can mitigate this issue using 6to4-PMT [I-D.kuarsingh-v6ops-6to4-provider-managed-tunnel] or blocking the route to 192.88.99.1 and generating an IPv4 'destination unreachable' message [RFC6343]. When the address range is well-defined, as with Shared Address Space, CPE router vendors can include Shared Address Space in their list of special-use addresses (e.g., [RFC5735]) and treat Shared Address Space similarly to [RFC1918] space. When the CGN-CPE address range is not well-defined, as in the case of globally unique space, it will be more difficult for CPE router vendors to mitigate against this issue.

Thus, when comparing the use of [RFC1918] and Shared Address Space, Shared Address Space poses an additional impact on 6to4 connectivity, which can be mitigated by Service Provider or CPE router vendor action. On the other hand, the use of [RFC1918] address space poses more of a challenge vis-a-vis Shared Address Space when the subscriber and Service Provider use overlapping [RFC1918] space, which will be outside the Service Provider's control in the case of unmanaged service. Service Providers have indicated that it is more challenging to mitigate the possibility of overlapping [RFC1918] address space on both sides of the CPE router than it is to mitigate the 6to4 impacts of Shared Address Space.

6. Security Considerations

Similar to other [RFC5735] special use IPv4 addresses, Shared Address Space does not directly raise security issues. However, the Internet does not inherently protect against abuse of these addresses. Attacks have been mounted that depend on the unexpected use of similar special-use addresses. Network operators are encouraged to review this document and determine what security policies should be associated with this address block within their specific operating environments and should consider including Shared Address Space in Ingress Filter lists [RFC3704] unless their Internet service incorporates a CGN.

To mitigate against potential misuse of Shared Address Space, except where required for hosted CGN service or similar business relationship,

- Routing information about Shared Address Space networks MUST NOT be propagated across Service Provider boundaries. Service Providers MUST filter incoming advertisements regarding Shared Address Space.

- Packets with Shared Address Space source or destination addresses MUST NOT be forwarded across Service Provider boundaries. Service Providers MUST filter such packets on ingress links.

- Service Providers MUST NOT include Shared Address Space in external-facing DNS zone files.

- Reverse DNS queries for Shared Address Space addresses MUST NOT be forwarded to the global DNS infrastructure.

- DNS Providers SHOULD filter requests for Shared Address Space reverse DNS queries on recursive nameservers.

7. IANA Considerations

IANA is asked to record the allocation of an IPv4 /10 for use as Shared Address Space.

The Shared Address Space address range is: x.x.0.0/10. [Note to RFC Editor: this address range to be added before publication]

8. References

8.1. Normative References

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8.2. Informative References

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Appendix A. Acknowledgments

Thanks to the following people (in alphabetical order) for their guidance and feedback:

Stan Barber

John Brzozowski

Isaiah Connell

Greg Davies

Owen DeLong

Kirk Erichsen

Wes George

Chris Grundemann

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