             Considerations on the IPv6 Host Density Metric

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Abstract

   This memo provides an analysis of the Host Density metric as it is
   currently used to guide registry allocations of IPv6 unicast address
   blocks. This document contrasts the address efficiency as currently
   adopted in the allocation of IPv4 network addresses and that used by
   the IPv6 protocol. Note that for large allocations there are very
   significant variations in the target efficiency metric between the
   two approaches.

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1. Introduction

   Metrics of address assignment efficiency are used in the context of
   the Regional Internet Registries' (RIRs') address allocation
   function. Through the use of a common address assignment efficiency
   metric, individual networks can be compared to a threshold value in
   an objective fashion. The common use of this metric is to form part
   of the supporting material for an address allocation request,
   demonstrating that the network has met or exceeded the threshold
   address efficiency value, and it forms part of the supportive
   material relating to the justification of the allocation of a further
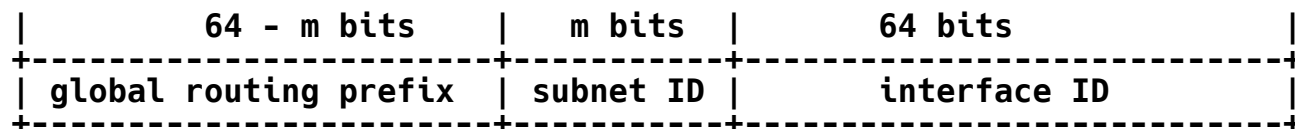   address block.

   Public and private IP networks have significant differences in
   purpose, structure, size, and technology. Attempting to impose a
   single efficiency metric across this very diverse environment is a
   challenging task. Any address assignment efficiency threshold value
   has to represent a balance between stating an achievable outcome for
   any competently designed and operated service platform while without
   setting a level of consumption of address resources that imperils the
   protocol's longer term viability through consequent address scarcity.
   There are a number of views relating to address assignment
   efficiency, both in terms of theoretic analyses of assignment
   efficiency and in terms of practical targets that are part of current
   address assignment practices in today's Internet.

   This document contrasts the address efficiency metric and threshold
   value as currently adopted in the allocation of IPv4 network
   addresses and the framework used by the address allocation process
   for the IPv6 protocol.

2. IPv6 Address Structure

   Before looking at address allocation efficiency metrics, it is
   appropriate to summarize the address structure for IPv6 global
   unicast addresses.

   The general format for IPv6 global unicast addresses is defined in
   [RFC4291] as follows (Figure 1).

```
    |        64 - m bits       |  m bits   |        64 bits             |
    +--------------------------+-----------+----------------------------+
    | global routing prefix    | subnet ID |        interface ID        |
    +--------------------------+-----------+----------------------------+
```

                          IPv6 Address Structure

                                Figure 1

Within the current policy framework for allocation of IPv6 addresses
in the context of the public Internet, the value for 'm' in the
figure above, referring to the subnet ID, is commonly a 16-bit field.
Therefore, the end-site global routing prefix is 48 bits in length,
the per-customer subnet ID is 16 bits in length, and the interface ID
is 64 bits in length [RFC3177].

In relating this address structure to the address allocation
function, the efficiency metric is not intended to refer to the use
of individual 128-bit IPv6 addresses nor that of the use of the 64-
bit subnet prefix. Instead, it is limited to a measure of efficiency
of use of the end-site global routing prefix. This allocation model
assumes that each customer is allocated a minimum of a single /48
address block. Given that this block allows 2^16 possible subnets,
it is also assumed that a /48 allocation will be used in the overall
majority of cases of end-customer address assignment.

The following discussion makes the assumption that the address
allocation unit in IPv6 is an address prefix of 48 bits in length,
and that the address assignment efficiency in this context is the
efficiency of assignment of /48 address allocation units. However,
the analysis presented here refers more generally to end-site address
allocation practices rather than /48 address prefixes in particular,
and is applicable in the context of any size of end-site global
routing prefix.

3. The Host Density Ratio

The "Host Density Ratio" was first described in [RFC1715] and
subsequently updated in [RFC3194].

The "H Ratio", as defined in RFC 1715, is:

$$H = \frac{\log (\text{number of objects})}{\text{available bits}}$$

Figure 2

The argument presented in [RFC1715] draws on a number of examples to
support the assertion that this metric reflects a useful generic
measure of address assignment efficiency in a range of end-site
addressed networks, and furthermore that the optimal point for such a
utilization efficiency metric lies in an H Ratio value between 0.14
and 0.26. Lower H Ratio values represent inefficient address use,
and higher H Ratio values tend to be associated with various forms of
additional network overhead related to forced re-addressing
operations.

This particular metric has a maximal value of log base 10 of 2, or
0.30103.

The metric was 'normalized' in RFC 3194, and a new metric, the "HD-
Ratio" was introduced, with the following definition:

$$HD = \frac{\log(\text{number of allocated objects})}{\log(\text{maximum number of allocatable objects})}$$

                             Figure 3

HD-Ratio values are proportional to the H ratio, and the values of
the HD-Ratio range from 0 to 1. The analysis described in [RFC3194]
applied this HD-Ratio metric to the examples given in [RFC1715] and,
on the basis of these examples, postulated that HD-Ratio values of
0.85 or higher force the network into some form of renumbering. HD-
Ratio values of 0.80 or lower were considered an acceptable network
efficiency metric.

The HD-Ratio is referenced within the IPv6 address allocation
policies used by the Regional Internet Registries, and their IPv6
address allocation policy documents specify that an HD-Ratio metric
of 0.8 is an acceptable objective in terms of address assignment
efficiency for an IPv6 network.

By contrast, the generally used address efficiency metric for IPv4 is
the simple ratio of the number of allocated (or addressed) objects to
the maximum number of allocatable objects. For IPv4, the commonly
applied value for this ratio is 0.8 (or 80%).

A comparison of these two metrics is given in Table 1 of Attachment
A.

4. The Role of an Address Efficiency Metric

The role of the address efficiency metric is to provide objective
metrics relating to a network's use of address space that can be used
by both the allocation entity and the applicant to determine whether
an address allocation is warranted, and provide some indication of
the size of the address allocation that should be undertaken. The
metric provides a target address utilization level that indicates at
what point a network's address resource may be considered "fully
utilized".

The objective here is to allow the network service provider to deploy
addresses across both network infrastructure and the network's
customers in a manner that does not entail periodic renumbering, and

in a manner that allows both the internal routing system and inter-
domain routing system to operate without excessive fragmentation of
the address space and consequent expansion of the number of route
objects carried within the routing systems. This entails use of an
addressing plan where at each level of structure within the network
there is a pool of address blocks that allows expansion of the
network at that structure level without requiring renumbering of the
remainder of the network.

It is recognized that an address utilization efficiency metric of
100% is unrealistic in any scenario. Within a typical network
address plan, the network's address space is exhausted not when all
address resources have been used, but at the point when one element
within the structure has exhausted its pool, and when augmentation of
this pool by drawing from the pools of other elements would entail
extensive renumbering. While it is not possible to provide a
definitive threshold of what overall efficiency level is obtainable
in all IP networks, experience with IPv4 network deployments suggests
that it is reasonable to observe that at any particular level within
a hierarchically structured address deployment plan an efficiency
level of between 60% to 80% is an achievable metric in the general
case.

This IPv4 efficiency threshold is significantly greater than that
observed in the examples provided in conjunction with the HD-Ratio
description in [RFC1715]. Note that the examples used in the HD-
Ratio are drawn from, among other sources, the Public Switched
Telephone Network (PSTN). This comparison with the PSTN warrants
some additional examination. There are a number of differences
between public IP network deployments and PSTN deployments that may
account for this difference. IP addresses are deployed on a per-
provider basis with an alignment to network topology. PSTN addresses
are, on the whole, deployed using a geographical distribution system
of "call areas" that share a common number prefix. Within each call
area, a sufficient number blocks from the number prefix must be
available to allow each operator to draw their own number block from
the area pool. Within the IP environment, service providers do not
draw address blocks from a common geographic number pool but receive
address blocks from the Regional Internet Registry on a 'whole of
network' basis. This difference in the address structure allows an
IP environment to achieve an overall higher level of address
utilization efficiency.

In terms of considering the number of levels of internal hierarchy in
IP networks, the interior routing protocol, if uniformly deployed,
admits a hierarchical network structure that is only two levels deep,
with a fully connected backbone "core" and a number of satellite
areas that are directly attached to this "core". Additional levels

of routing hierarchy may be obtained using various forms of routing
confederations, but this is not an extremely common deployment
technique. The most common form of network structure used in large
IP networks is a three-level structure using regions, individual
Points of Presence (POPs), and end-customers.

Also, note that large-scale IP deployments typically use a relatively
flat routing structure, as compared to a deeply hierarchical
structure. In order to improve the dynamic performance of the
interior routing protocol the number of routes carried in the
interior routing protocol, is commonly restricted to the routes
corresponding to next-hop destinations for iBGP routes, and customer
routes are carried in the iBGP domain and aggregated at the point
where the routes are announced in eBGP sessions. This implies that
per-POP or per-region address aggregations according to some fixed
address hierarchy is not a necessary feature of large IP networks, so
strict hierarchical address structure within all parts of the network
is not a necessity in such routing environments.

5. Network Structure and Address Efficiency Metric

An address efficiency metric can be expressed using the number of
levels of structure (n) and the efficiency achieved at each level
(e). If the same efficiency threshold is applied at each level of
structure, the resultant efficiency threshold is e^n. This then
allows us to make some additional observations about the HD-Ratio
values. Table 2 of Appendix A (Figure 8) indicates the number of
levels of structure that are implied by a given HD-Ratio value of 0.8
for each address allocation block size, assuming a fixed efficiency
level at all levels of the structure. The implication is that for
large address blocks, the HD-Ratio assumes a large number of elements
in the hierarchical structure, or a very low level of address
efficiency at the lower levels. In the case of IP network
deployments, this latter situation is not commonly the case.

The most common form of interior routing structure used in IP
networks is a two-level routing structure. It is consistent with
this constrained routing architecture that network address plans
appear to be commonly devised using up to a three-level hierarchical
structure, while for larger networks a four-level structure may
generally be used.

Table 3 of Attachment A (Figure 9) shows an example of address
efficiency outcomes using a per-level efficiency metric of 0.75 (75%)
and a progressively deeper network structure as the address block
expands. This model (termed here "limited levels") limits the
maximal number of levels of internal hierarchy to 6 and uses a model
where the number of levels of network hierarchy increases by 1 when
the network increases in size by a factor of a little over one order
of magnitude.

It is illustrative to compare these metrics for a larger network
deployment. If, for example, the network is designed to encompass 8
million end customers, each of which is assigned a 16-bit subnet ID
for their end site, then the following table Figure 4 indicates the
associated allocation size as determined by the address efficiency
metric.

        Allocation: 8M Customers

                                  Allocation   Relative Ratio

        100% Allocation Efficiency   /25   1
        80% Efficiency (IPv4)   /24   2
        0.8 HD-Ratio   /19   64
        75% with Limited Level   /23   4
        0.94 HD-Ratio   /23   4

                            Figure 4

Note that the 0.8 HD-Ratio produces a significantly lower efficiency
level than the other metrics. The limited-level model appears to
point to a more realistic value for an efficiency value for networks
of this scale (corresponding to a network with 4 levels of internal
hierarchy, each with a target utilization efficiency of 75%). This
limited-level model corresponds to an HD-Ratio with a threshold value
of 0.945.

6. Varying the HD-Ratio

   One way to model the range of outcomes of taking a more limited
   approach to the number of levels of aggregateable hierarchy is to
   look at a comparison of various values for the HD-Ratio with the
   model of a fixed efficiency and the "Limited Levels" model. This is
   indicated in Figure 5.

Prefix Length (bits)
|
|
| Limited   HD-Ratio
| Levels   0.98   0.94   0.90   0.86   0.82   0.80
| | | | | | | |
1   0.750   0.986   0.959   0.933   0.908   0.883   0.871
4   0.750   0.946   0.847   0.758   0.678   0.607   0.574
8   0.750   0.895   0.717   0.574   0.460   0.369   0.330
12   0.563   0.847   0.607   0.435   0.312   0.224   0.189
16   0.563   0.801   0.514   0.330   0.212   0.136   0.109
20   0.422   0.758   0.435   0.250   0.144   0.082   0.062
24   0.422   0.717   0.369   0.189   0.097   0.050   0.036
28   0.316   0.678   0.312   0.144   0.066   0.030   0.021
32   0.316   0.642   0.264   0.109   0.045   0.018   0.012
36   0.237   0.607   0.224   0.082   0.030   0.011   0.007
40   0.237   0.574   0.189   0.062   0.021   0.007   0.004
44   0.178   0.543   0.160   0.047   0.014   0.004   0.002
48   0.178   0.514   0.136   0.036   0.009   0.003   0.001

Figure 5

As shown in this figure, it is possible to select an HD-Ratio value
that models IP level structures in a fashion that behaves more
consistently for very large deployments. In this case, the choice of
an HD-Ratio of 0.94 is consistent with a limited-level model of up to
6 levels of hierarchy with a metric of 75% density at each level.
This correlation is indicated in Table 3 of Attachment A.

6.1. Simulation Results

In attempting to assess the impact of potentially changing the HD-
Ratio to a lower value, it is useful to assess this using actual
address consumption data. The results described here use the IPv4
allocation data as published by the Regional Internet Registries
[RIR-Data]. The simulation work assumes that the IPv4 delegation
data uses an IPv4 /32 for each end customer, and that assignments
have been made based on an 80% density metric in terms of assumed
customer count. The customer count is then used as the basis of an
IPv6 address allocation, using the HD-Ratio to map from a customer
count to the size of an address allocation.

The result presented here is that of a simulation of an IPv6 address
allocation registry, using IPv4 allocation data as published by the
RIRs spanning the period from January 1, 1999 until August 31, 2004.
The aim is to identify the relative level of IPv6 address consumption
using a IPv6 request size profile based on the application of various
HD-Ratio values to the derived customer numbers.

The profile of total address consumption for selected HD-Ratio values
is indicated in Figure 6. The simulation results indicate that the
choice of an HD-Ratio of 0.8 consumes a total of 7 times the address
space of that consumed when using an HD-Ratio of 0.94.

HD-Ratio	Total Address Consumption	
	Prefix Length Notation	Count of /32 prefixes
0.80	/14.45	191,901
0.81	/14.71	160,254
0.82	/15.04	127,488
0.83	/15.27	108,701
0.84	/15.46	95,288
0.85	/15.73	79,024
0.86	/15.88	71,220
0.87	/16.10	61,447
0.88	/16.29	53,602
0.89	/16.52	45,703
0.90	/16.70	40,302
0.91	/16.77	38,431
0.92	/16.81	37,381
0.93	/16.96	33,689
0.94	/17.26	27,364
0.95	/17.32	26,249
0.96	/17.33	26,068
0.97	/17.33	26,068
0.98	/17.40	24,834
0.99	/17.67	20,595

Figure 6

The implication of these results imply that an IPv6 address registry
will probably see sufficient distribution of allocation request sizes
such that the choice of a threshold HD-Ratio will impact the total
address consumption rates, and the variance between an HD-Ratio of
0.8 and an HD-Ratio of 0.99 is a factor of one order of magnitude in
relative address consumption over an extended period of time. The
simulation also indicates that the overall majority of allocations
fall within a /32 minimum allocation size (between 74% to 95% of all
address allocations), and that the selection of a particular HD-Ratio
value has a significant impact in terms of allocation sizes for a

small proportion of allocation transactions (the remainder of
allocations range between a /19 to a /31 for an HD-Ratio of 0.8 and
between a /26 and a /31 for an HD-Ratio of 0.99).

The conclusion here is that the choice of the HD-Ratio will have some
impact on one quarter of all allocations, while the remainder are
serviced using the minimum allocation unit of a /32 address prefix.
Of these 'impacted' allocations that are larger than the minimum
allocation, approximately one tenth of these allocations are 'large'
allocations. These large allocations have a significant impact on
total address consumption, and varying the HD-Ratio for these
allocations between 0.8 to 0.99 results in a net difference in total
address consumption of approximately one order of magnitude. This is
a heavy-tail distribution, where a small proportion of large address
allocations significantly impact the total address consumption rate.
Altering the HD-Ratio will have little impact on more than 95% of the
IPv6 allocations but will generate significant variance within the
largest 2% of these allocations, which, in turn, will have a
significant impact on total address consumption rates.

7. Considerations

The HD-Ratio with a value of 0.8 as a model of network address
utilization efficiency produces extremely low efficiency outcomes for
networks spanning of the order of 10^{6} end customers and larger.

The HD-Ratio with a 0.8 value makes the assumption that as the
address allocation block increases in size, the network within which
the addresses will be deployed adds additional levels of hierarchical
structure. This increasing depth of hierarchical structure to
arbitrarily deep hierarchies is not a commonly observed feature of
public IP network deployments.

The fixed efficiency model, as used in the IPv4 address allocation
policy, uses the assumption that as the allocation block becomes
larger, the network structure remains at a fixed level of levels; if
the number of levels is increased, then efficiency achieved at each
level increases significantly. There is little evidence to suggest
that increasing a number of levels in a network hierarchy increases
the efficiency at each level.

It is evident that neither of these models accurately encompass IP
network infrastructure models and the associated requirements of
address deployment. The fixed efficiency model places an excessive
burden on the network operator to achieve very high levels of
utilization at each level in the network hierarchy, leading to either
customer renumbering or deployment of technologies such as Network
Address Translation (NAT) to meet the target efficiency value in a

hierarchically structured network. The HD-Ratio model using a value
of 0.8 specifies an extremely low address efficiency target for
larger networks, and while this places no particular stress on
network architects in terms of forced renumbering, there is the
concern that this represents an extremely inefficient use of address
resources. If the objective of IPv6 is to encompass a number of
decades of deployment, and to span a public network that ultimately
encompasses many billions of end customers and a very high range and
number of end use devices and components, then there is legitimate
cause for concern that the HD-Ratio value of 0.8 may be setting too
conservative a target for address efficiency, in that the total
address consumption targets may be achieved too early.

This study concludes that consideration should be given to the
viability of specifying a higher HD-Ratio value as representing a
more relevant model of internal network structure, internal routing,
and internal address aggregation structures in the context of IPv6
network deployment.

8. Security Considerations

Considerations of various forms of host density metrics create no new
threats to the security of the Internet.

9. Acknowledgements

The document was reviewed by Kurt Lindqvist, Thomas Narten, Paul
Wilson, David Kessens, Bob Hinden, Brian Haberman, and Marcelo
Bagnulo.

10. References

10.1. Normative References

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[RFC3177]   IAB and IESG, "IAB/IESG Recommendations on IPv6 Address
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[RFC4291]   Hinden, R. and S. Deering, "IP Version 6 Addressing
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10.2. Informative References

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Appendix A. Comparison Tables

   The first table compares the threshold number of /48 end user
   allocations that would be performed for a given assigned address
   block in order to consider that the utilization has achieved its
   threshold utilization level.

   Fixed Efficiency Value   0.8
   HD-Ratio Value   0.8

		Number of /48 allocations to fill the address block to the threshold level			
Prefix	Size	Fixed Efficiency 0.8		HD-Ratio 0.8	
/48	1	1	100%	1	100%
/47	2	2	100%	2	87%
/46	4	4	100%	3	76%
/45	8	7	88%	5	66%
/44	16	13	81%	9	57%
/43	32	26	81%	16	50%
/42	64	52	81%	28	44%
/41	128	103	80%	49	38%
/40	256	205	80%	84	33%
/39	512	410	80%	147	29%
/38	1,024	820	80%	256	25%
/37	2,048	1,639	80%	446	22%
/36	4,096	3,277	80%	776	19%
/35	8,192	6,554	80%	1,351	16%
/34	16,384	13,108	80%	2,353	14%
/33	32,768	26,215	80%	4,096	13%
/32	65,536	52,429	80%	7,132	11%
/31	131,072	104,858	80%	12,417	9%
/30	262,144	209,716	80%	21,619	8%
/29	524,288	419,431	80%	37,641	7%
/28	1,048,576	838,861	80%	65,536	6%
/27	2,097,152	1,677,722	80%	114,105	5%
/26	4,194,304	3,355,444	80%	198,668	5%
/25	8,388,608	6,710,887	80%	345,901	4%
/24	16,777,216	13,421,773	80%	602,249	4%
/23	33,554,432	26,843,546	80%	1,048,576	3%
/22	67,108,864	53,687,092	80%	1,825,677	3%
/21	134,217,728	107,374,180	80%	3,178,688	2%
/20	268,435,456	214,748,365	80%	5,534,417	2%
/19	536,870,912	429,496,730	80%	9,635,980	2%
/18	1,073,741,824	858,993,460	80%	16,777,216	2%
/17	2,147,483,648	1,717,986,919	80%	29,210,830	1%

```
/16      4,294,967,296     3,435,973,837   80%     50,859,008   1%
/15      8,589,934,592     6,871,947,674   80%     88,550,677   1%
/14     17,179,869,184    13,743,895,348   80%    154,175,683   1%
/13     34,359,738,368    27,487,790,695   80%    268,435,456   1%
/12     68,719,476,736    54,975,581,389   80%    467,373,275   1%
/11    137,438,953,472   109,951,162,778   80%    813,744,135   1%
/10    274,877,906,944   219,902,325,556   80%  1,416,810,831   1%
/9     549,755,813,888   439,804,651,111   80%  2,466,810,934   0%
/8   1,099,511,627,776   879,609,302,221   80%  4,294,967,296   0%
/7   2,199,023,255,552 1,759,218,604,442   80%  7,477,972,398   0%
/6   4,398,046,511,104 3,518,437,208,884   80% 13,019,906,166   0%
/5   8,796,093,022,208 7,036,874,417,767   80% 22,668,973,294   0%
```

            Table 1. Comparison of Fixed Efficiency Threshold vs
                      HD-Ratio Threshold

                              Figure 7

   One possible assumption behind the HD-Ratio is that the
   inefficiencies that are a consequence of large-scale deployments are
   an outcome of an increased number of levels of hierarchical structure
   within the network. The following table calculates the depth of the
   hierarchy in order to achieve a 0.8 HD-Ratio, assuming a 0.8
   utilization efficiency at each level in the hierarchy.

Prefix	Size	0.8 HD-Ratio	Structure Levels
/48	1	1	1
/47	2	2	1
/46	4	3	2
/45	8	5	2
/44	16	9	3
/43	32	16	4
/42	64	28	4
/41	128	49	5
/40	256	84	5
/39	512	147	6
/38	1,024	256	7
/37	2,048	446	7
/36	4,096	776	8
/35	8,192	1,351	9
/34	16,384	2,353	9
/33	32,768	4,096	10
/32	65,536	7,132	10
/31	131,072	12,417	11
/30	262,144	21,619	12
/29	524,288	37,641	12
/28	1,048,576	65,536	13

```
/27          2,097,152           114,105        14
/26          4,194,304           198,668        14
/25          8,388,608           345,901        15
/24         16,777,216           602,249        15
/23         33,554,432         1,048,576        16
/22         67,108,864         1,825,677        17
/21        134,217,728         3,178,688        17
/20        268,435,456         5,534,417        18
/19        536,870,912         9,635,980        19
/18      1,073,741,824        16,777,216        19
/17      2,147,483,648        29,210,830        20
/16      4,294,967,296        50,859,008        20
/15      8,589,934,592        88,550,677        21
/14     17,179,869,184       154,175,683        22
/13     34,359,738,368       268,435,456        22
/12     68,719,476,736       467,373,275        23
/11    137,438,953,472       813,744,135        23
/10    274,877,906,944     1,416,810,831        24
/9     549,755,813,888     2,466,810,934        25
/8   1,099,511,627,776     4,294,967,296        25
```

            Table 2: Number of Structure Levels Assumed by HD-Ratio

                                Figure 8

An alternative approach is to use a model of network deployment where
the number of levels of hierarchy increases at a lower rate than that
indicated in a 0.8 HD-Ratio model. One such model is indicated in
the following table. This is compared to using an HD-Ratio value of
0.94.

Per-Level Target Efficiency: 0.75

Prefix	Size	Stepped Levels	Stepped Efficiency 0.75		HD-Ratio 0.94	
/48	1	1	1	100%	1	100%
/47	2	1	2	100%	2	100%
/46	4	1	3	75%	4	100%
/45	8	1	6	75%	7	88%
/44	16	1	12	75%	13	81%
/43	32	1	24	75%	25	78%
/42	64	1	48	75%	48	75%
/41	128	1	96	75%	92	72%
/40	256	1	192	75%	177	69%
/39	512	2	384	75%	338	66%
/38	1,024	2	576	56%	649	63%
/37	2,048	2	1,152	56%	1,244	61%

```
/36             4,096  2              2,304  56%               2,386  58%
/35             8,192  2              4,608  56%               4,577  56%
/34            16,384  2              9,216  56%               8,780  54%
/33            32,768  2             18,432  56%              16,845  51%
/32            65,536  2             36,864  56%              32,317  49%
/31           131,072  3             73,728  56%              62,001  47%
/30           262,144  3            110,592  42%             118,951  45%
/29           524,288  3            221,184  42%             228,210  44%
/28         1,048,576  3            442,368  42%             437,827  42%
/27         2,097,152  3            884,736  42%             839,983  40%
/26         4,194,304  3          1,769,472  42%           1,611,531  38%
/25         8,388,608  3          3,538,944  42%           3,091,767  37%
/24        16,777,216  3          7,077,888  42%           5,931,642  35%
/23        33,554,432  4         14,155,776  42%          11,380,022  34%
/22        67,108,864  4         21,233,664  32%          21,832,894  33%
/21       134,217,728  4         42,467,328  32%          41,887,023  31%
/20       268,435,456  4         84,934,656  32%          80,361,436  30%
/19       536,870,912  4        169,869,312  32%         154,175,684  29%
/18     1,073,741,824  4        339,738,624  32%         295,790,403  28%
/17     2,147,483,648  4        679,477,248  32%         567,482,240  26%
/16     4,294,967,296  4      1,358,954,496  32%       1,088,730,702  25%
/15     8,589,934,592  5      2,717,908,992  32%       2,088,760,595  24%
/14    17,179,869,184  5      4,076,863,488  24%       4,007,346,185  23%
/13    34,359,738,368  5      8,153,726,976  24%       7,688,206,818  22%
/12    68,719,476,736  5     16,307,453,952  24%      14,750,041,884  21%
/11   137,438,953,472  5     32,614,907,904  24%      28,298,371,876  21%
/10   274,877,906,944  5     65,229,815,808  24%      54,291,225,552  20%
/9    549,755,813,888  5    130,459,631,616  24%     104,159,249,331  19%
/8  1,099,511,627,776  5    260,919,263,232  24%     199,832,461,158  18%
```

                   Table 3: Limited Levels of Structure

                              Figure 9

Author's Address

   Geoff Huston
   APNIC

   EMail: gih@apnic.net

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Acknowledgement