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Considerations on the IPv6 Host density Metric
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Status of this Memo

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Abstract

This memo provides an analysis of the Host Density metric as 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. It is noted that for large allocations there are very significant variations in the target efficiency metric between the two approaches. The memo notes that the IPv6 address assignment efficiency metric would benefit from a detailed technical review,

particularly relating to large scale deployments of public infrastructure.

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1. Introduction

Metrics of address assignment efficiency are used in the context of the public Internet as a part of the address allocation function. Through the use of an address assignment efficiency metric individual networks can be compared to a target model 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 the target address efficiency metric and that the allocation of a further address block is justified.

Public IP networks have significant differences in purpose, structure, size and technology. Attempting to impose a single metric across this very diverse environment is a challenging task. Any address assignment efficiency metric has to represent a balance between stating an achievable metric for any competently designed and operated service platform, while not specifying a metric that allows for an address usage rate that imperils the protocol's longer term viability. 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 as currently adopted in the allocation of IPv4 network addresses and that used by the IPv6 protocol. It is noted that for large allocations there are very significant variations in the target efficiency metric.

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 RFC3513 [RFC3513] 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 is commonly used as a 16 bit value, such that the 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.

In relating this address structure to the address allocation function, the efficiency metric is not intended to refer to the 128 bit IPv6 address, nor the 64 bit routing prefix, but is limited to the 48 bit global routing prefix. This allocation model assumes that each customer is allocated a minimum of a /48 address block, and, 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 the address assignment efficiency in this context is the efficiency of assignment of /48 address allocation units.

3. The Host Density Ratio

The "Host Density Ratio" is first described in RFC 1715 [RFC1715], and subsequently updated in RFC3194 [RFC3194].

The "H Ratio", as defined in RFC1715, is:

```
                  log (number of objects)
              H = -----------------------
                     available bits
```

Figure 2

The argument presented in RFC 1715 draws on a number of examples to support the assertion that this metric reflected a useful measure of address assignment efficiency, and furthermore that the optimal point for such a utilization efficiency metric lies between 0.14 and 0.26

As an aside, the table in RFC1715, indicating a range of addressed objects for a 64 bit address range was given as between 9 E+8 and 4 E+16, while 128 bits yielded values of 8 E+17 through to 2 E+33. This data was used to support the argument that 64 bits of address space was insufficient. Given that IPv6 is now operating in a mode where the IPv6 address unit is somewhere between 48 and 64 bits in effective length (as distinct from 128, because of the subsequent definition of the interface identifier), there is a somewhat ironic twist to this particular definition of address density.

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

The metric was 'normalized' in RFC3194, and a new metric, the "HD-Ratio" was introduced, with the definition:

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

Figure 3

HD values are directly proportional to the H ratio, and the values of the ratio range from 0 to 1. The analysis described in RFC 3194 then applied this HD-Ratio metric to the examples given in RFC 1715, and on the basis of these examples, postulated that HD-Ratios of 0.85 or higher forced the network into some form of renumbering, while 0.80 or lower was considered to be an acceptable network efficiency metric.

The HD ratio is referenced within the IPv6 address allocation policies used by the Regional Internet Registries, and the 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 than 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 levels that indicates at what point a network's address resource may be considered to be "fully utilized".

The objective here is to allow the network service provider to deploy addresses across both network infrastructure and to 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. 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 address structure that 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 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 RFC 1715. It is noted that the examples used in the HD-Ratio are drawn from, among other sources, the 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 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 route confederations, but this is not a 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.

It should also be noted that large scale IP deployments typically use a relatively flat routing hierarchy. 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. This implies that per-POP or per-region address aggregations according to some fixed address hierarchy is not a common feature of large IP networks.

[Author's Note:
It has been suggested that this evaluation of the number of levels of hierarchy in deployed IP networks could be supported by reference to generic network deployments, and to other sources of address deployment data in deployed public IP networks. This is a token holder for inclusion of such data in future revisions of this document.
]

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 n**e. 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.

As noted above, the most common form of structure used in IP networks is a three level structure. For larger networks a four level structure may be used, where the network is the union of a number of distinct operating entities, each of which use a three level internal structure.

Table 3 of Attachment A (Figure 9) shows an example of address efficiency outcomes using a per-level efficiency metric of 0.75 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, then the following table Figure 4indicates 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 Levels	/23	4
0.94HD Ratio	/23	4

Figure 4

It is noted 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)

Address Utilization Efficiency Levels

Prefix Length (bits)	Methods: 1	2	3	4	5	6	7
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

Methods: 1 - "Limited Levels" using a base efficiency of 0.75
2 - HD-Ratio value of 0.98
3 - HD-Ratio value of 0.94
4 - HD-Ratio value of 0.90
5 - HD-Ratio value of 0.86
6 - HD-Ratio value of 0.82
7 - HD-Ratio value of 0.80

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 than that consumed when using an HD-Ratio of 0.94.

HD-Ratio Address Consumption

HD-Ratio	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 is that it is probable that a IPv6 address registry will see sufficient distribution of allocation request sizes such that the choice of a threshold HD-Ratio will impact the registries' 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 rates 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 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 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 tail-heavy 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 int eh IPv4 address allocation policy, uses the assumption that as the allocation block becomes larger the network structure remains at a fixed level of levels, or if the number of levels is increased, then efficiency achieved at each level increases significantly. There is little evidence to suggest that increasing 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 NAT to meet the target efficiency value in a hierarchically structure 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 extravagant use of address resources. If the objective of IPv6 is to encompass a number of decades of deployment, and span a public network that ultimately encompasses many billions of end customers, 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.

It is recommended that further study of address efficiency metrics and the relationship between network structure and address efficiency models considered as part of such a study. 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.

This document has also noted the common choice of a fixed length of 16 bits for the subnet ID in the IPv6 unicast address architecture for each customer assignment. While this choice has been used in the block of unicast address space spanned by the IPv6 address prefix 2001::/16, it should not be assumed by vendors or network operators that this particular subnet scheme will be used for other unicast address blocks. The IPv6 address architecture allows this subnet length to be defined as a variable quantity, and it is considered to be a useful exercise to evaluate the effectiveness of a fixed length subnet scheme, and compare it to an subnet scheme with a variable length and a smaller minimum value.

8. Security Considerations

Considerations of various forms of host density metrics creates 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 and Brian Haberman.

10. References

10.1 Normative 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

Prefix	Size	Number of /48 allocations to fill the address block to the threshold level: Fixed Efficiency 0.8	Efficiency	HD-Ratio 0.8	Efficiency	Ratio
/48	1	1	100%	1	100%	1
/47	2	2	100%	2	87%	1
/46	4	4	100%	3	76%	1
/45	8	7	88%	5	66%	1
/44	16	13	81%	9	57%	1
/43	32	26	81%	16	50%	2
/42	64	52	81%	28	44%	2
/41	128	103	80%	49	38%	2
/40	256	205	80%	84	33%	2
/39	512	410	80%	147	29%	3

/38	1,024	820	80%	256	25%	3
/37	2,048	1,639	80%	446	22%	4
/36	4,096	3,277	80%	776	19%	4
/35	8,192	6,554	80%	1,351	16%	5
/34	16,384	13,108	80%	2,353	14%	6
/33	32,768	26,215	80%	4,096	13%	6
/32	65,536	52,429	80%	7,132	11%	7
/31	131,072	104,858	80%	12,417	9%	8
/30	262,144	209,716	80%	21,619	8%	10
/29	524,288	419,431	80%	37,641	7%	11
/28	1,048,576	838,861	80%	65,536	6%	13
/27	2,097,152	1,677,722	80%	114,105	5%	15
/26	4,194,304	3,355,444	80%	198,668	5%	17
/25	8,388,608	6,710,887	80%	345,901	4%	19
/24	16,777,216	13,421,773	80%	602,249	4%	22
/23	33,554,432	26,843,546	80%	1,048,576	3%	26
/22	67,108,864	53,687,092	80%	1,825,677	3%	29
/21	134,217,728	107,374,180	80%	3,178,688	2%	34
/20	268,435,456	214,748,365	80%	5,534,417	2%	39
/19	536,870,912	429,496,730	80%	9,635,980	2%	45
/18	1,073,741,824	858,993,460	80%	16,777,216	2%	51
/17	2,147,483,648	1,717,986,919	80%	29,210,830	1%	59
/16	4,294,967,296	3,435,973,837	80%	50,859,008	1%	68
/15	8,589,934,592	6,871,947,674	80%	88,550,677	1%	78
/14	17,179,869,184	13,743,895,348	80%	154,175,683	1%	89
/13	34,359,738,368	27,487,790,695	80%	268,435,456	1%	102
/12	68,719,476,736	54,975,581,389	80%	467,373,275	1%	118
/11	137,438,953,472	109,951,162,778	80%	813,744,135	1%	135
/10	274,877,906,944	219,902,325,556	80%	1,416,810,831	1%	155
/9	549,755,813,888	439,804,651,111	80%	2,466,810,934	0%	178
/8	1,099,511,627,776	879,609,302,221	80%	4,294,967,296	0%	205
/7	2,199,023,255,552	1,759,218,604,442	80%	7,477,972,398	0%	235
/6	4,398,046,511,104	3,518,437,208,884	80%	13,019,906,166	0%	270
/5	8,796,093,022,208	7,036,874,417,767	80%	22,668,973,294	0%	310

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 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
/7	2,199,023,255,552	7,477,972,398	26
/6	4,398,046,511,104	13,019,906,166	27
/5	8,796,093,022,208	22,668,973,294	27

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 0.75	Efficiency	HD-Ratio 0.94	Efficiency	Ratio
/48	1	1	1	100%	1	100%	1.0
/47	2	1	2	100%	2	100%	1.0
/46	4	1	3	75%	4	100%	0.8
/45	8	1	6	75%	7	88%	0.9
/44	16	1	12	75%	13	81%	0.9
/43	32	1	24	75%	25	78%	1.0
/42	64	1	48	75%	48	75%	1.0
/41	128	1	96	75%	92	72%	1.0
/40	256	1	192	75%	177	69%	1.1
/39	512	2	384	75%	338	66%	1.1
/38	1,024	2	576	56%	649	63%	0.9
/37	2,048	2	1,152	56%	1,244	61%	0.9
/36	4,096	2	2,304	56%	2,386	58%	1.0
/35	8,192	2	4,608	56%	4,577	56%	1.0
/34	16,384	2	9,216	56%	8,780	54%	1.0
/33	32,768	2	18,432	56%	16,845	51%	1.1
/32	65,536	2	36,864	56%	32,317	49%	1.1
/31	131,072	3	73,728	56%	62,001	47%	1.2
/30	262,144	3	110,592	42%	118,951	45%	0.9
/29	524,288	3	221,184	42%	228,210	44%	1.0
/28	1,048,576	3	442,368	42%	437,827	42%	1.0
/27	2,097,152	3	884,736	42%	839,983	40%	1.1
/26	4,194,304	3	1,769,472	42%	1,611,531	38%	1.1
/25	8,388,608	3	3,538,944	42%	3,091,767	37%	1.1
/24	16,777,216	3	7,077,888	42%	5,931,642	35%	1.2
/23	33,554,432	4	14,155,776	42%	11,380,022	34%	1.2
/22	67,108,864	4	21,233,664	32%	21,832,894	33%	1.0
/21	134,217,728	4	42,467,328	32%	41,887,023	31%	1.0
/20	268,435,456	4	84,934,656	32%	80,361,436	30%	1.1
/19	536,870,912	4	169,869,312	32%	154,175,684	29%	1.1

/18	1,073,741,824	4	339,738,624	32%	295,790,403	28%	1.1

/17	2,147,483,648	4	679,477,248	32%	567,482,240	26%	1.2
/16	4,294,967,296	4	1,358,954,496	32%	1,088,730,702	25%	1.2
/15	8,589,934,592	5	2,717,908,992	32%	2,088,760,595	24%	1.3
/14	17,179,869,184	5	4,076,863,488	24%	4,007,346,185	23%	1.0
/13	34,359,738,368	5	8,153,726,976	24%	7,688,206,818	22%	1.1
/12	68,719,476,736	5	16,307,453,952	24%	14,750,041,884	21%	1.1
/11	137,438,953,472	5	32,614,907,904	24%	28,298,371,876	21%	1.2
/10	274,877,906,944	5	65,229,815,808	24%	54,291,225,552	20%	1.2
/9	549,755,813,888	5	130,459,631,616	24%	104,159,249,331	19%	1.3
/8	1,099,511,627,776	5	260,919,263,232	24%	199,832,461,158	18%	1.3
/7	2,199,023,255,552	6	521,838,526,464	24%	383,384,219,730	17%	1.4
/6	4,398,046,511,104	6	782,757,789,696	18%	735,533,451,805	17%	1.1
/5	8,796,093,022,208	6	1,565,515,579,392	18%	1,411,141,697,760	16%	1.1

Table 3: Limited Levels of Structure

Figure 9

Appendix B. Draft Notes

[This section not for RFC publication]

This memo has been reviewed by an ad hoc advisory committee to advise the IAB on a number of matters relating to IPv6. It is proposed that the note be published as an informational RFC, as it does not propose any specific alteration to the IPv6 specification.

With respect to the recommendation made in this document that further study of address efficiency metrics and the relationship between network structure and address efficiency models considered, it is noted that this study could be undertaken in the context of the Open Policy Forums hosted by the Regional Address Registries in addition to any IETF activity. Given the intersection of interests in this work between the IETF and the RIR-hosted policy forums, some level of collaboration in any such study would appear to be strongly advisable.

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