IPv4 Address Report

This report is auto-generated by a daily script. The report you are seeing here was generated at 03-Aug-2007 07:58 UTC+1000.

Projected IANA Unallocated Address Pool Exhaustion: 13-Apr-2010

Projected RIR Unallocated Address Pool Exhaustion: 09-Feb-2011

Note: 8 May 2007

Regular visitors to this page would see that the projected date of IANA unallocated pool exhaustion has moved closer by some months, as of the 8th May. The reason for this change of the projection is the use of a different mathematical predictive model, as of this date. Previous reports used a best fit of an exponential model to the most recent 1200 days of data in order to generate the predictive model. As indicated in Figure 22 of this report, this exponential model now deviates significantly from the data. The predictive model is now based on a quadratic equation, as this offers a closer fit to the underlying data set.

Note: 21 May 2007

IANA has recently (May 2007) reassigned the address block 196.0.0.0/8 from "various" to Afrinic. This implies that Afrinic is anticipated to assign address space from 41/8 and 196/8 to the 80% assignment threshold before requesting further address blocks from IANA.

IANA has recently (April 2007) marked 46.0.0.0/8 as "IANA-Reserved", adding an additional /8 address block into the IANA unallocated address pool. At this the remaining difference between the data used for this this modelling exercise and the IANA registry data is the address block 7.0.0.0/8, which whois.arin.net records as being allocated to the US DoD NIC.

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What's the question again?

Its often been said that anything can be proved with statistics, and that may well be the case. As this article is describing an exercise in statistical analysis, in order to make some predictions about when certain events may take place, then some care must be taken to ensure that the question is clearly phrased, and that the data being analyzed is clearly relevant to the question.

So perhaps the best way to commence this article is to ask what is the question being posed here? Is it an effort to predict the date of the end of IPv4? Or is this a prediction of the date when complete IPv4 address exhaustion will occur? This article does not attempt to encompass such ambitious forms of prediction. The exercise being undertaken here is far more modest. The question being posed is: **"What is the anticipated date when the current policy regime concerning the distribution of IPv4 address is no longer relevant?"** Or, in other words, we are looking for some indicators as to the time when our current policies for IPv4 address distribution are expected to run out because the unallocated address pool on which these policies are based is exhausted.

The predictive exercise described here points to a time when the current address distribution mechanisms will no longer apply. The current address allocation policies used by the Regional Internet Registries (RIRs) are critically based on a continual supply of previously unused addresses being assigned to meet the needs of applicants. This is achieved by the RIRs continually drawing addresses from the unallocated address pool. At the point in time when the unallocated address pool is exhausted the current distribution mechanism for addresses as used by the address registries would appear to have reached a logical conclusion. As to what mechanisms would be appropriate beyond that date to support the continued distribution of addresses, that is not a topic to be considered in this particular report.

IPv4 Address Distribution Structure

An address goes through a number of stages on the path to deployment. Originally the address block is a parameter set of the underlying protocol, and the intended purpose of segments of the address space is described in an address architecture.

IPv4 Address Architecture

In the case of IPv4 there have been a number of iterations of address architecture, starting with the original specification of the so-called 8/24 split, using 8 bits to identify the network and 24 bits to identify the end host, then the adoption of the Class-based address system, to the current classless setup, where addresses in the range 0.0.0.0 through to 223.255.255.255 are assigned for use as global unicast addresses, addresses in the range 224.0.0.0 though to 239.255.255.255 are assigned for multicast use, and the remaining addresses, from 240.0.0.0 through to 255.255.255.254 are reserved for future definition by the IETF **[RFC3330]**.

The Internet Assigned Numbers Authority (IANA)

The role of the IANA in this activity is to manage the unallocated IPv4 unicast address pool. IANA does not perform end-user or ISP address assignments, but performs allocations of address blocks to RIRs under defined criteria of RIR use. The criteria for IANA allocation of address space to an RIR is described in **[IPv4 Policy]**. Address space is allocated to the RIRs in units of /8 address blocks, and the specific address blocks allocated to the RIR is an IANA decision. The block is allocated to the RIR when the RIR's available space falls below the equivalent of a /9, or falls below the working space required for 9 months of allocations. The allocation made by IANA is a minimum of a /8 block, and enough to restore the RIR's address pool to encompass a further 18 months of allocations.

The Regional Internet Registries (RIRs)

The Regional Internet Registries are AFRINIC, APNIC, ARIN LACNIC and the RIPENCC. The RIRs operate as self-regulatory bodies with strong regional industry support and participation. One role of the RIRs is to host open policy fora that, among other functions, sets address allocation policies within the region. The RIRs manage the address distribution function, assigning addresses to ISPs and various forms of Local Internet Registries (LIRs) in a manner that conforms to these regional policies.

The Address Distribution Function

The overall picture of the address distribution function is the definition of unallocated address space as a protocol standards action, and the management role of the unallocated global unicast address space to the IANA. The IANA then allocate this address space to the RIRs, under criteria as agreed between the IANA and the RIRs. The RIRs then pass this address space to Local Internet Registries and ISPS, each RIRs using criteria for this distribution function as determined by the regional policy forum. Further address distribution is perform by the LIR or ISP is a manner that is consistent with regional address policies.

A number of aspects of this function are designed to prevent various forms of failure or distortion of the address distribution function:

- The essential attribute of address distribution that is to be preserved is its uniqueness of allocation.
- Address policies are intended to be applied uniformly and fairly.
- The prevailing address policy regime characterizes addresses as a network attribute, rather than as an asset or tradeable good in its own right.
- Addresses are made available from the unallocated pool to meet demands for their use in networks, and are intended to be assigned for as long as the need condition continues. Unneeded addresses are to be passed back to the registry.
- Addresses are an unpriced public good. Address trading is explicitly not supported in terms of registry support functions relating to title transfer. The policy mechanism is intended to prevent various forms of trading that may lead to market distortions such as hoarding, monopolistic control, cartels, price fixing, for example.

An Analysis of IPv4 Addresses

This exercise looks at the various holding pools associated with the unallocated address pool, and analyses their dynamic behavior over time, as well as modelling the application the relevant policies to these address pools. The exercise also attempts to assess the relative behavior of the pool of allocated and advertised addresses and the associated pool of allocated, but unadvertised addresses, and derive a model of anticipated future demands of allocations from the unallocated address pools.

Again, this is not a report on the prediction of the "exhaustion of IPv4", nor when "IPv4 addresses will run out". This is a more specific report on the procedure used to make an estimate, based on recent consumption trends, as to when the current policies for address distribution that rely on the continued availability of the unallocated address pool may be exhausted. At that point different address distribution policies are necessary to continue to serve the production IPv4 Internet.

The date predicted by this model where the IPv4 unallocated address pool will be exhausted is **09-Feb-2011**. A related prediction is the exhaustion of the IANA IPv4 unallocated address pool, which this model predicts will occur on **13-Apr-2010**.

This model constructs a demand model for IPv4 address space. As a further exercise in projections, it is possible to construct a very approximate estimation of a potential response to the exhaustion of the unallocated number pool. The assumption made in this model is that the unadvertised address pool would come back into play to fuel further demand for IPv4 address space in the context of network demand. A very approximate prediction of the effect of this market on the longevity of the IPv4 address distribution function is also contained in this report. A very approximate estimate of additional time such an option would provide is **14-May-2018**.

Current Status

The IPv4 address space is a 32 bit field. There are 4,294,967,296 unique values, considered in this context as a sequence of 256 "/8s", where each "/8" corresponds to 16,777,216 unique address values.

As noted in RFC 3330 a number of address blocks are reserved for uses outside 'conventional' use in the public Internet as unicast identity tokens. In adding up these special purpose use address reservations there are the equivalent of 36.086 /8 address blocks in this category. This is composed of 16 /8 blocks reserved for use in multicast scenarios, 16 /8 blocks reserved for some unspecified future use, 1 /8 block (0.0.0.0/8) for local identification, a single /8 block reserved for loopback (127.0.0.0/8), a /8 block reserved for private use (10.0.0.0/8), and a single /8 address block intended for some specialized use in so-called "public data networks" (14.0.0.0/8). Smaller address blocks are also reserved for other special uses.

The remaining 219.914 /8 address blocks are available for use in the public IPv4 Internet. IANA holds a pool of unallocated addresses, while the remainder have already been allocated by IANA for further downstream assignment by the RIRs. The current status of the total IPv4 address space is indicated in Figure 1.

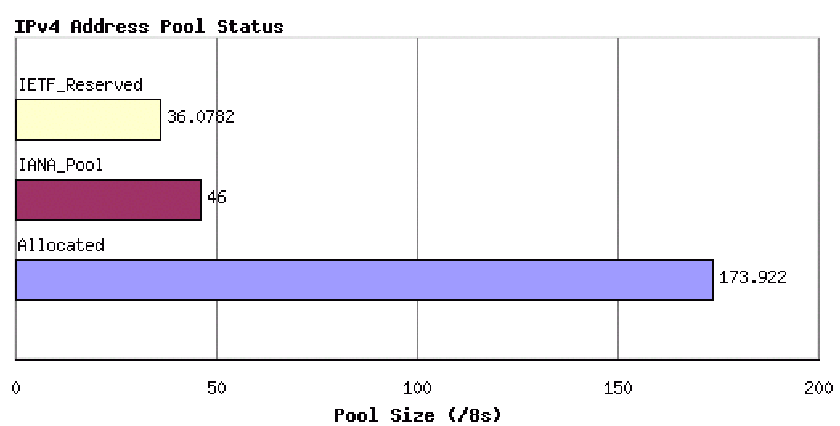

Figure 1 - Address Pool Status

This allocated number pool is managed by the Regional Internet Registries, (RIRs) and the breakdown of IANA allocated address blocks to each of the RIRs is shown in Figure 2. The address block allocated to "VARIOUS" refers to the [IANA IPv4 Address registry] where a number of /8 blocks were assigned prior to the commencement of today's RIR system, and are listed as assigned to "Various Registries". Address blocks that are assigned from these /8s are typically managed by multiple registries. The figure also includes 40 /8s listed against an IANA Registry. This refers again to the [IANA IPv4 Address registry] where, prior to the RIR system, a number of assignments were made directly by the IANA.

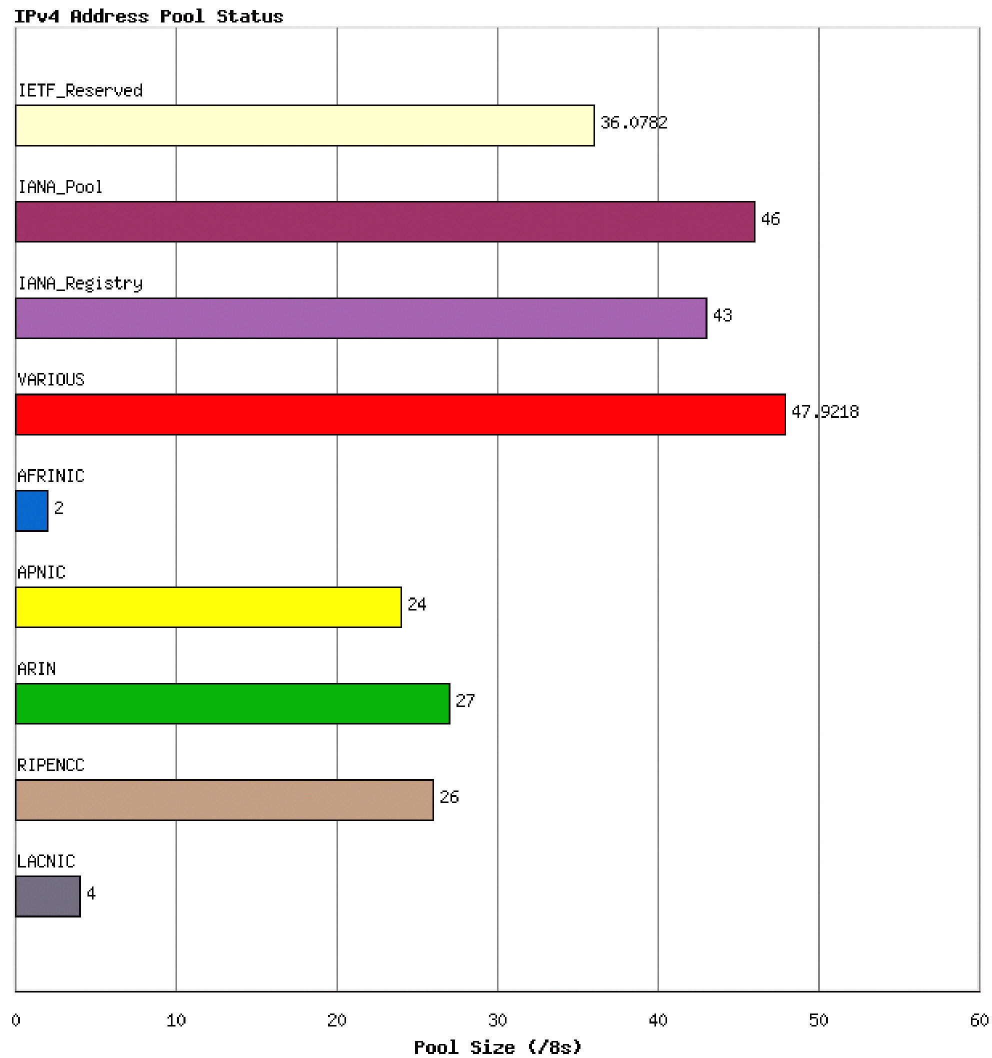

Figure 2 - Address allocations to RIRs

Any individual IPv4 address can be in any one of five states:

- reserved for special use, or
- part of the IANA unallocated address pool,
- part of the unassigned pool held by an RIR,
- assigned to an end user entity but not advertised in the routing system, or
- assigned and advertised in BGP.

The current totals of IP addresses according to this set of states is shown in Figure 3.

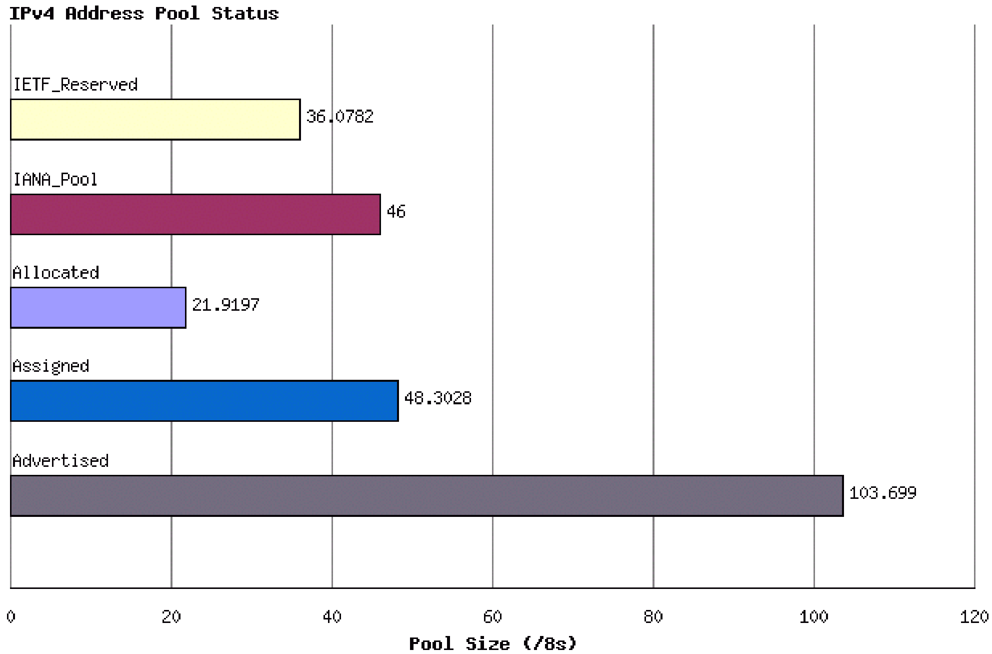

Figure 3 - Address Pools by State

This status can be further categorized per RIR, as shown in Figure 4.

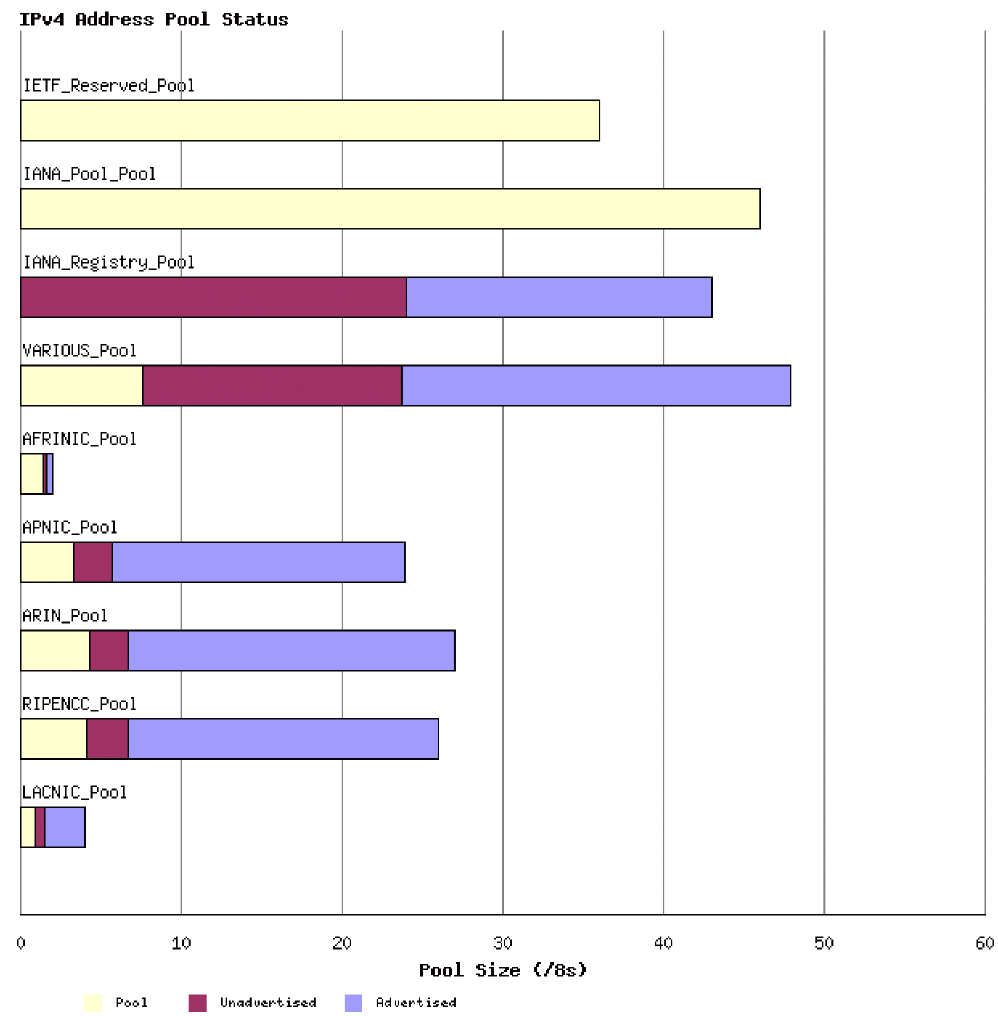

Figure 4 - Address Pools by RIR by State

Another view of the address state pools is by grouping the address space into a sequence of /8s, and looking at state sub totals within each /8 address block. The following view shows the current status of the IPv4 address space as 256 /8 columns each describing a pool of 16,777,216 addresses.

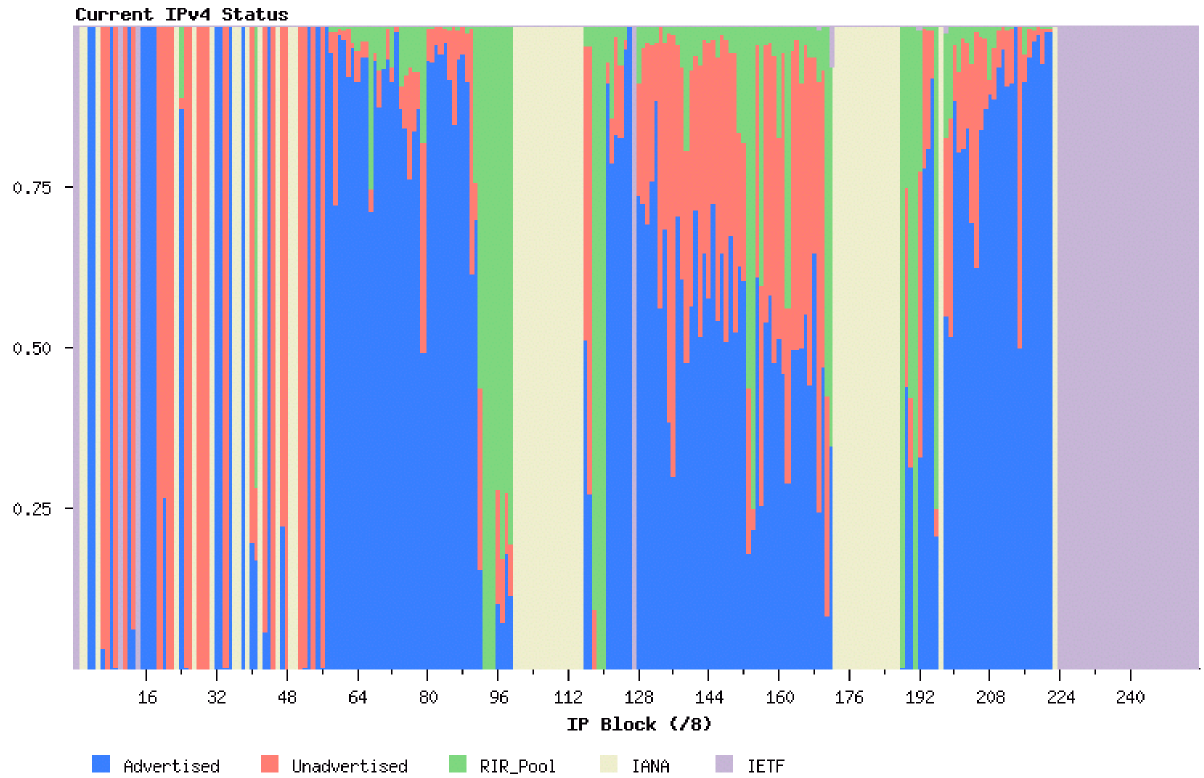

Figure 5 - IPv4 Address Status

Time Series Data

Allocations

IPv4 Address are drawn from the Unallocated Address Number Pool, administered by the IANA. These allocations are made to the Regional Internet Registries (RIRs), and the allocation unit is in units of /8s.

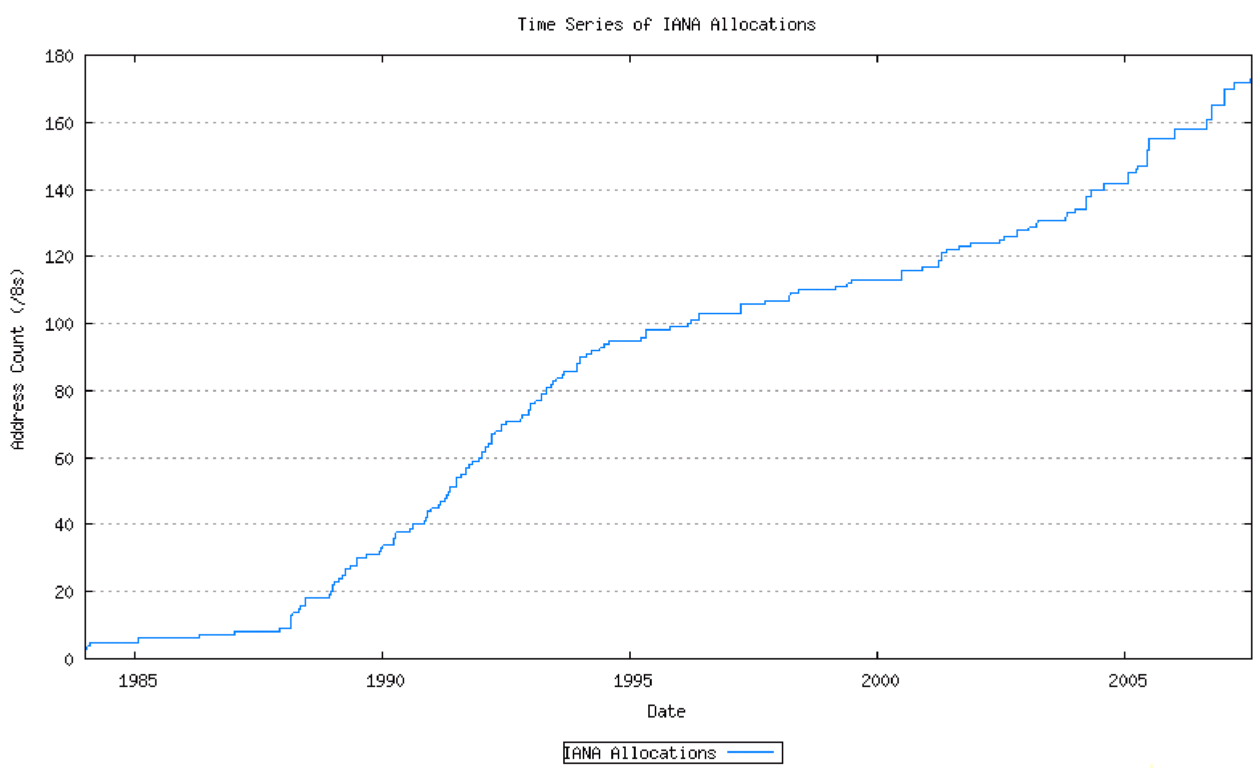

Figure 6 - Cumulative IANA Address allocations

This series can be further broken down by tracking the cumulative number of addresses that have been allocated to each of the 5 current RIRs. Also indicated here are the pre-RIR allocated blocks which are marked here as "VARIOUS". These allocations are indicated in Figure 7.

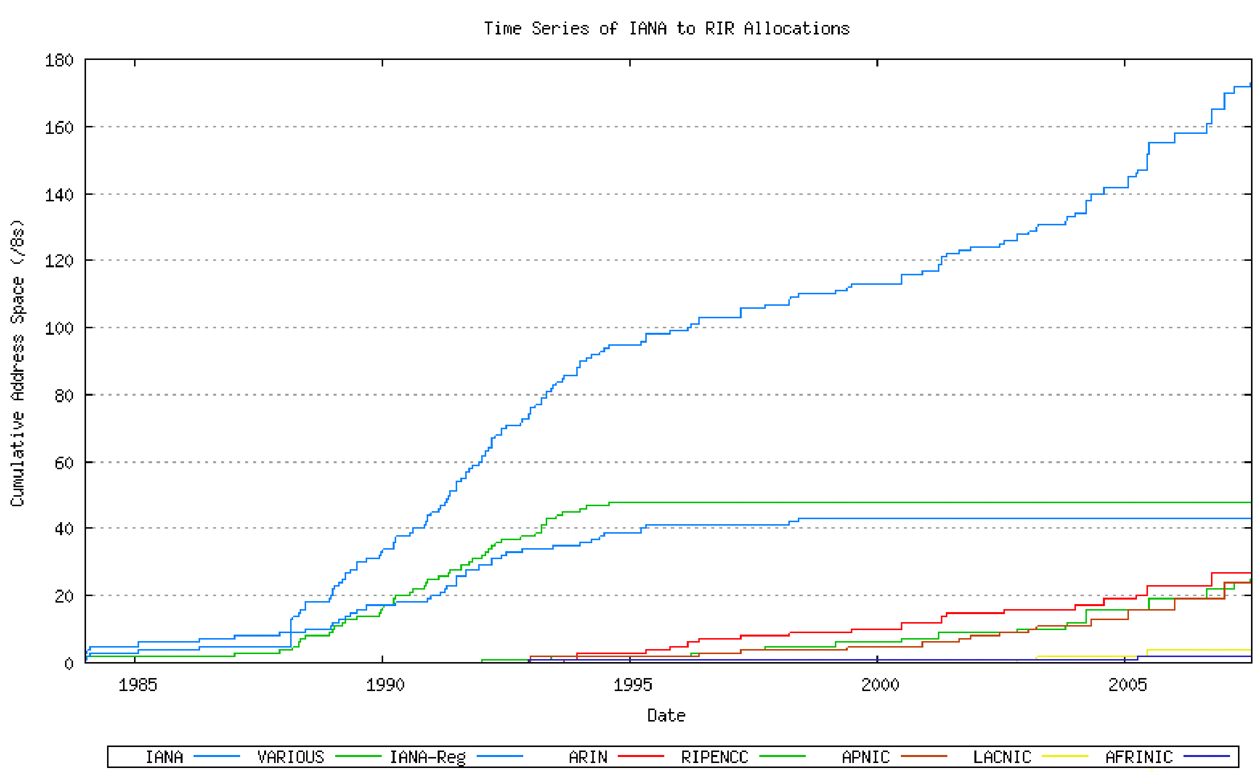

Figure 7 - Cumulative IANA Address block allocations per RIR

Assignments

RIRs perform assignments of address blocks to ISPs and local Internet registries. The cumulative number of assigned addresses over time is shown in Figure 8.

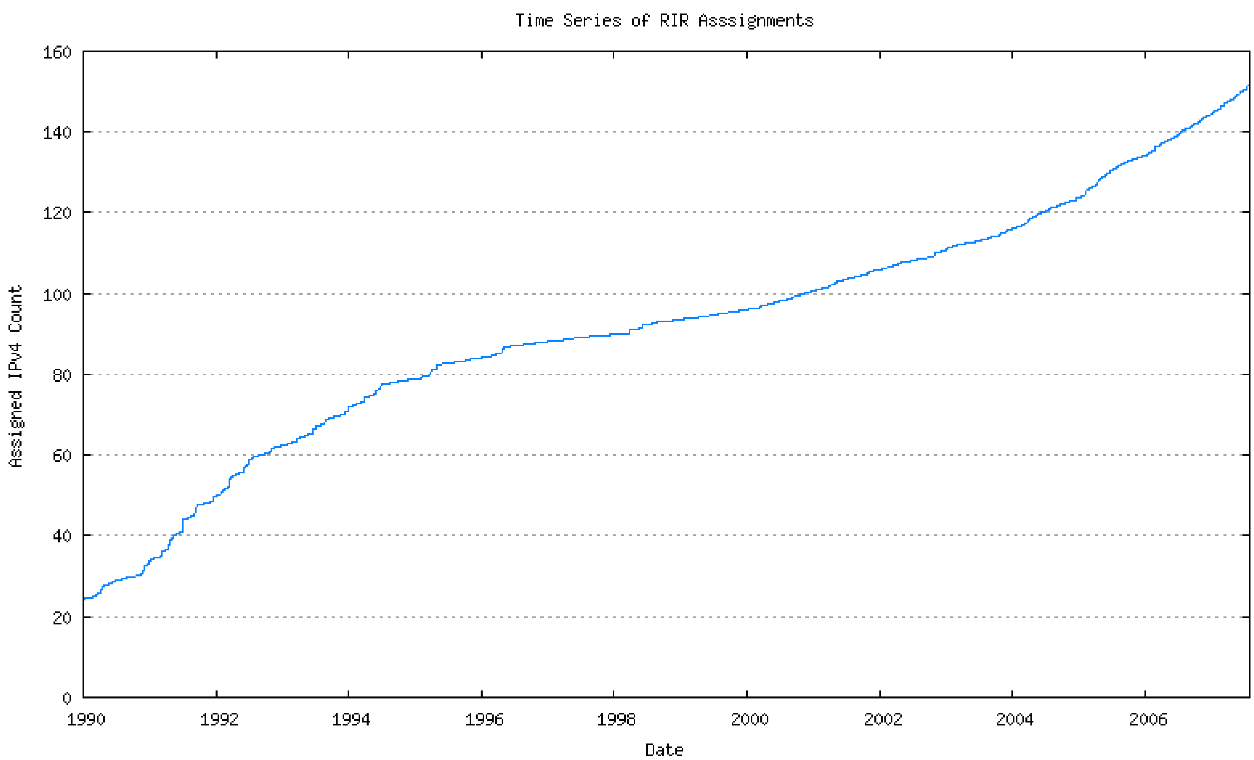

Figure 8 - Cumulative RIR Address assignments

This data can be further categorized by looking at the original allocation classification of the block from which the assignment has been performed.

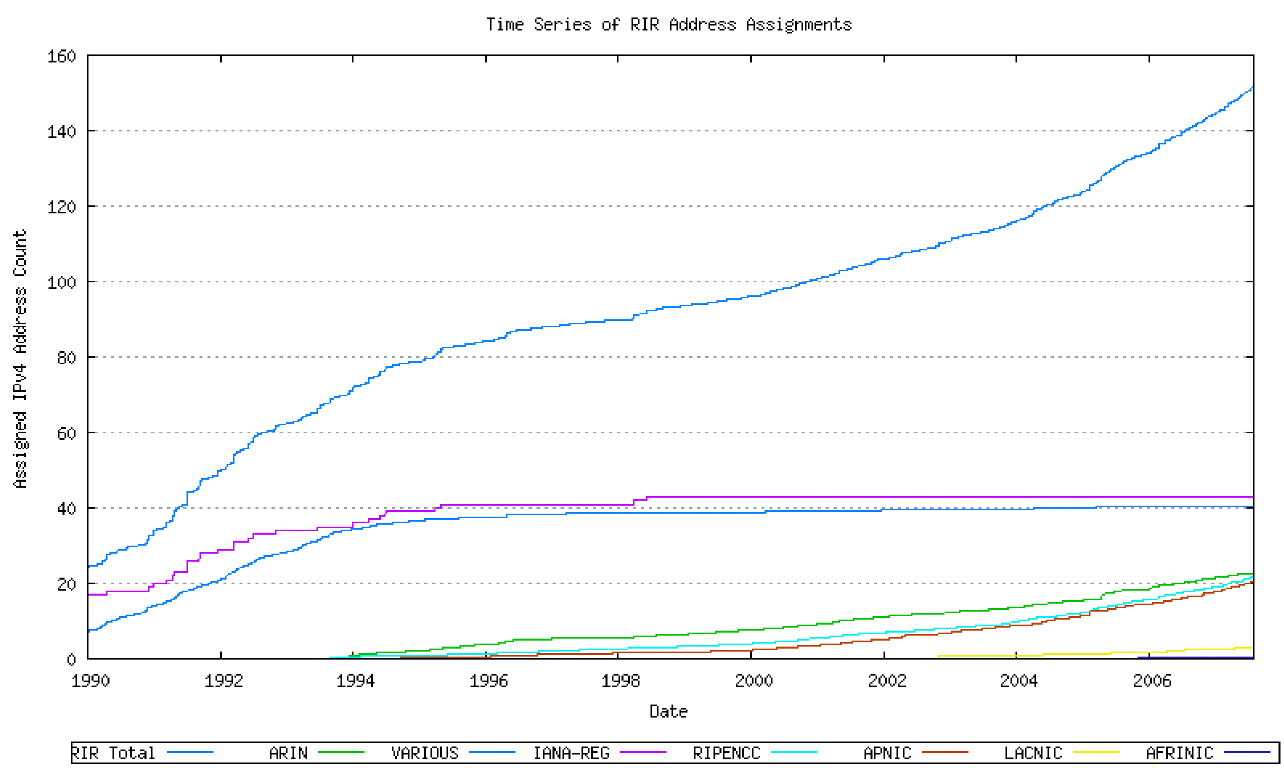

Figure 9 - Cumulative RIR address assignments, per RIR

RIR Pools

Each RIR allocates from its locally administered number pool. When the pool reaches a low threshold size a further address block is allocated by IANA to the RIR. The allocation quantity is based on the allocation activity recorded by the RIR for the 18 months prior to the allocation request, rounded to the next largest /8 address block. The pool size within each RIR over time can be derived from the allocation and assignment series data, producing the following graph. This is indicated in Figure 10.

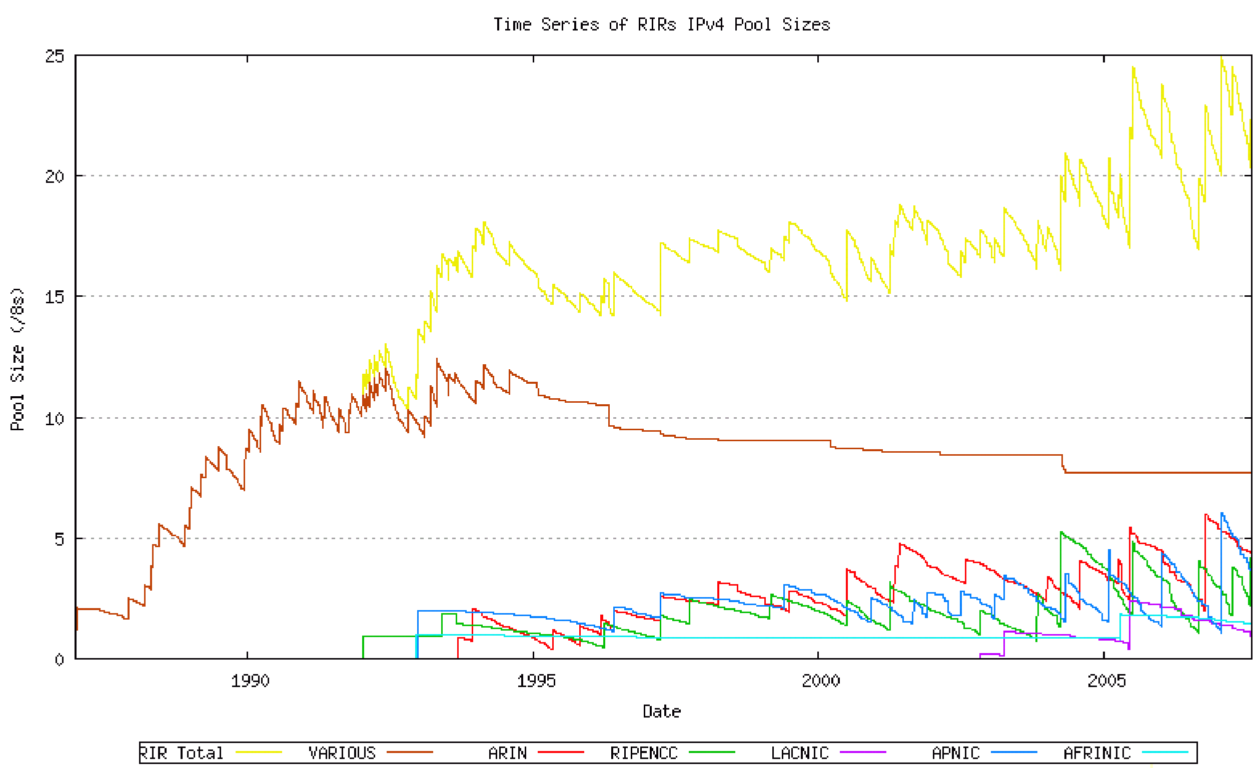

Figure 10 - RIR Address Pool size

The more recent data from this series is shown in Figure 10a.

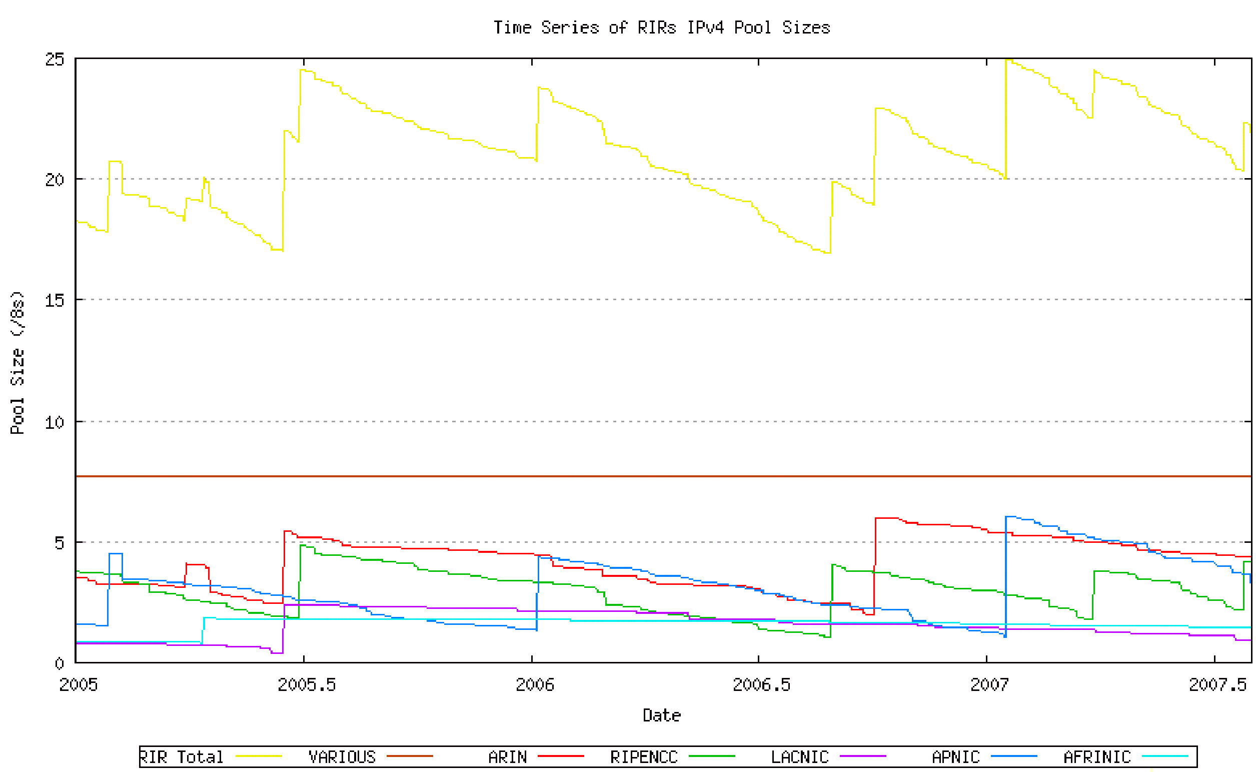

Figure 10a - RIR Address Pool size

Advertisements

The next data set is total span of address space advertised in the BGP routing table over time. The data has been collected on a 2-hourly basis since late 1999. This is shown in Figure 11.

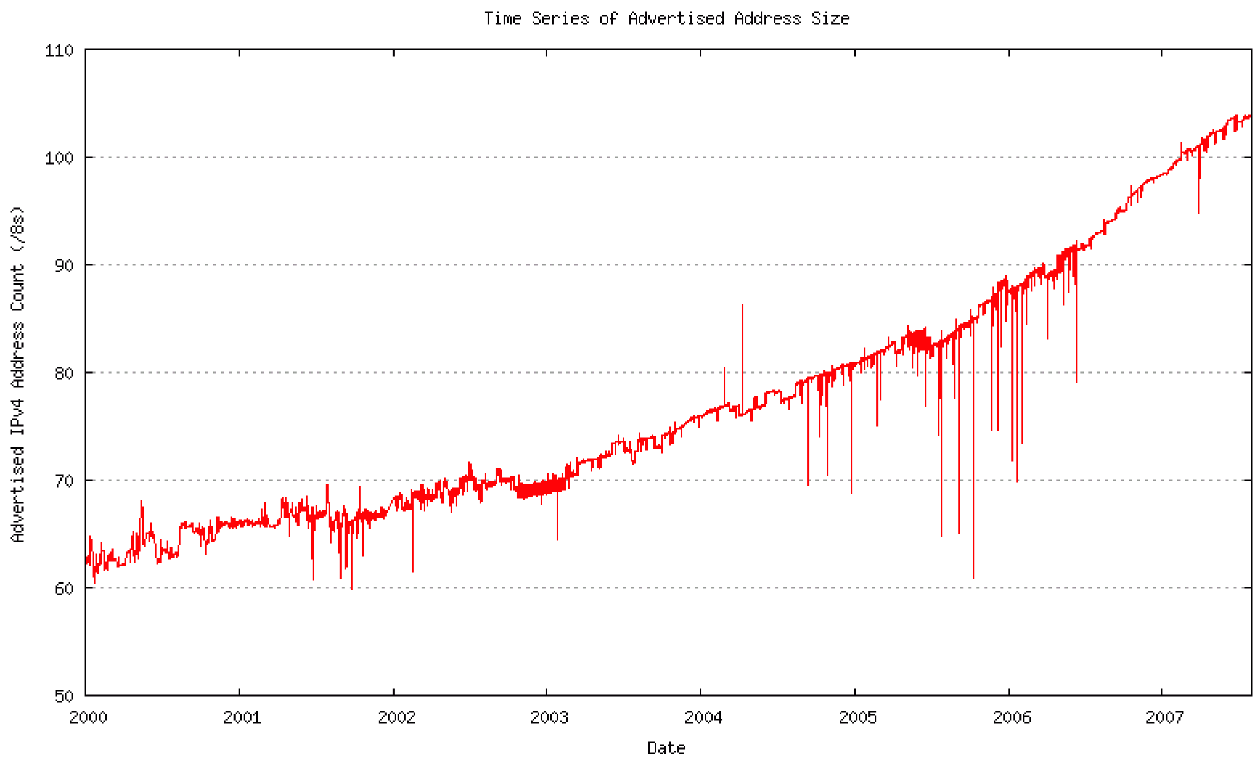

Figure 11 - Advertised Address Count

This data shown a relatively high level of noise, due to the intermittent appearance of up to 3 /8 address advertisements, with frequencies that vary from hours to a number of days. in attempting to generate a best fit sequence to this data, some effort has been made to smooth this data, as indicated in the following figures. The first pass is to generate a day-by-day sequence, where all the sample values recorded over a day are averaged into a single daily value. This is shown in Figure 11a.

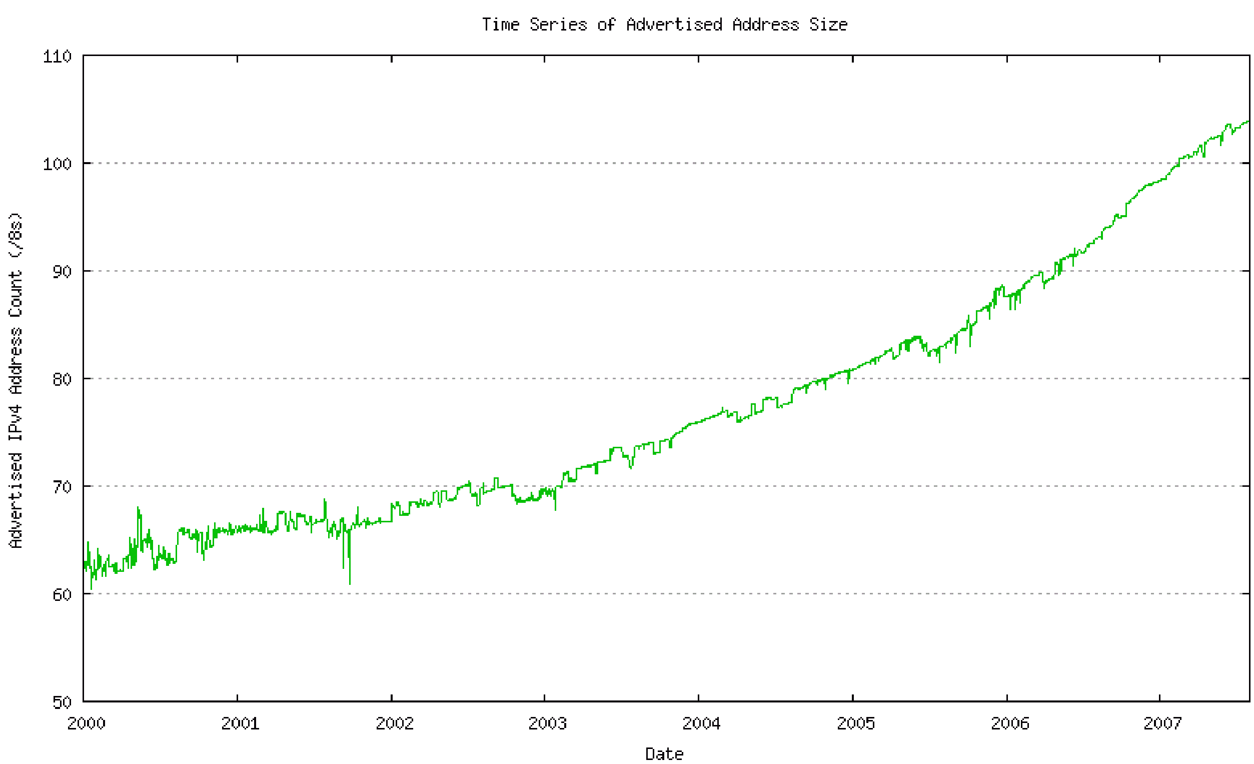

Figure 11a - Advertised Address Count - daily average

A comparison of the raw data and these daily averages is shown in Figure 11b.

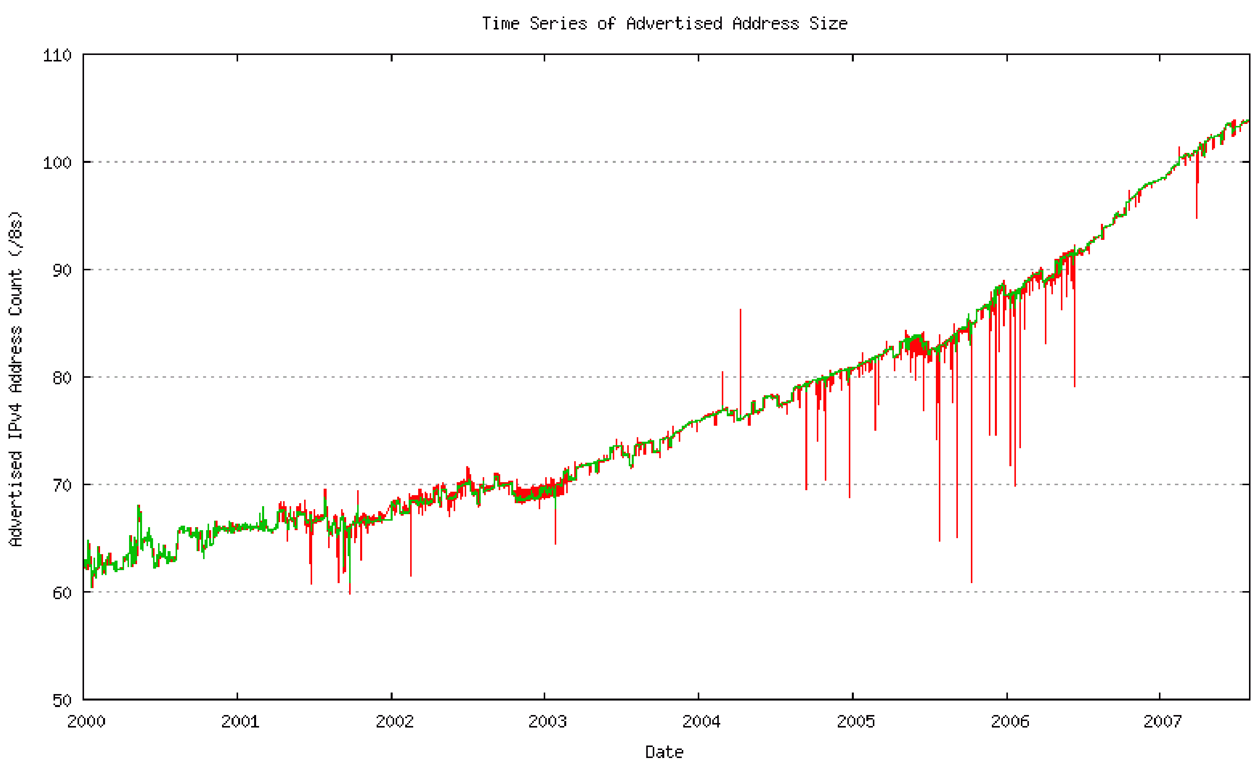

Figure 11b - Advertised Address Count - raw and daily average

This daily average sequence is smoothed by applying a sliding window average across the sequence in two passes. The size of this sliding window is 93 days (or approximately 3 months).

Figure 11c - Advertised Address Count - raw and daily average

The correlation of this smoothed sequence against the raw data and the daily average sequence is shown in Figure 11d.

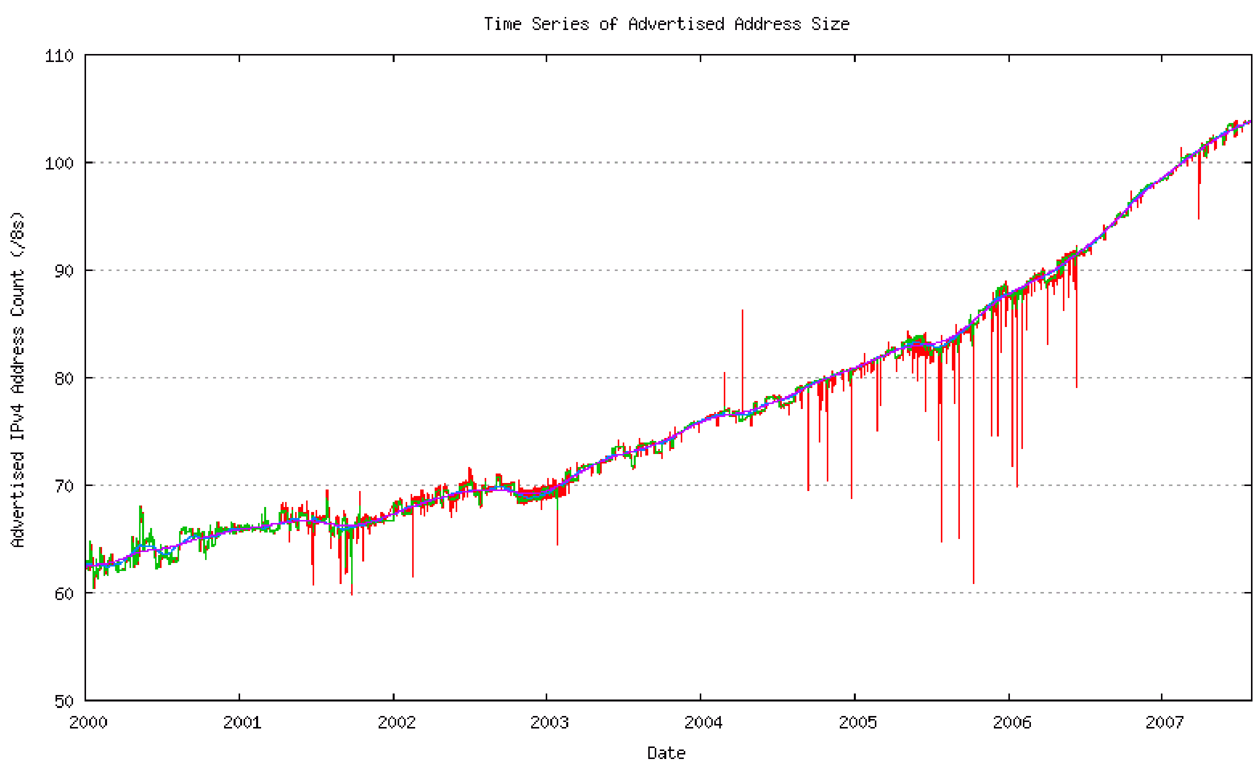

Figure 11d - Advertised Address Count - raw and daily average

Models for Address Consumption

Unadvertised Addresses

The approach used here will be based on the trend in advertised addresses. The rationale for this is that the basic policy framework used by the RIRs in distributing IPv4 addresses is that individual allocations of address space are based on demonstrated need for public addresses, most typically in the context of their intended use in the public Internet. In other words allocated addresses are allocated on the general understanding that such addresses will appear as advertised addresses in the public Internet. Some data to justify this approach is shown in Figure 14a.

However, to get to that figure it is first necessary to generate a view of the unadvertised as well as the advertised allocated address space. The difference between the daily allocated address total and the daily average of the advertised address span is the unadvertised address count for each day. Figure 12 shows the number of advertised and unadvertised addresses as a day-by-day time series.

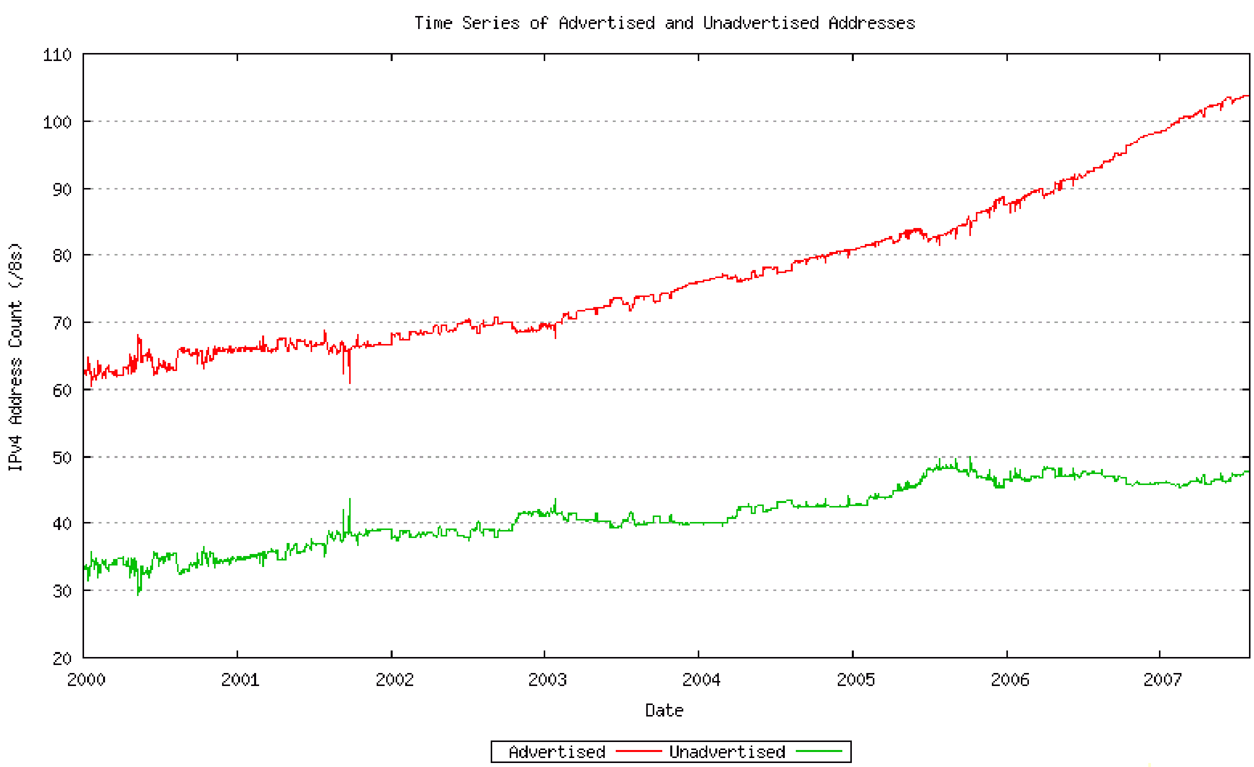

Figure 12 - Advertised and Unadvertised Addresses

The ratio of unadvertised to advertised addresses can be plotted over time. This in shown in Figure 13.

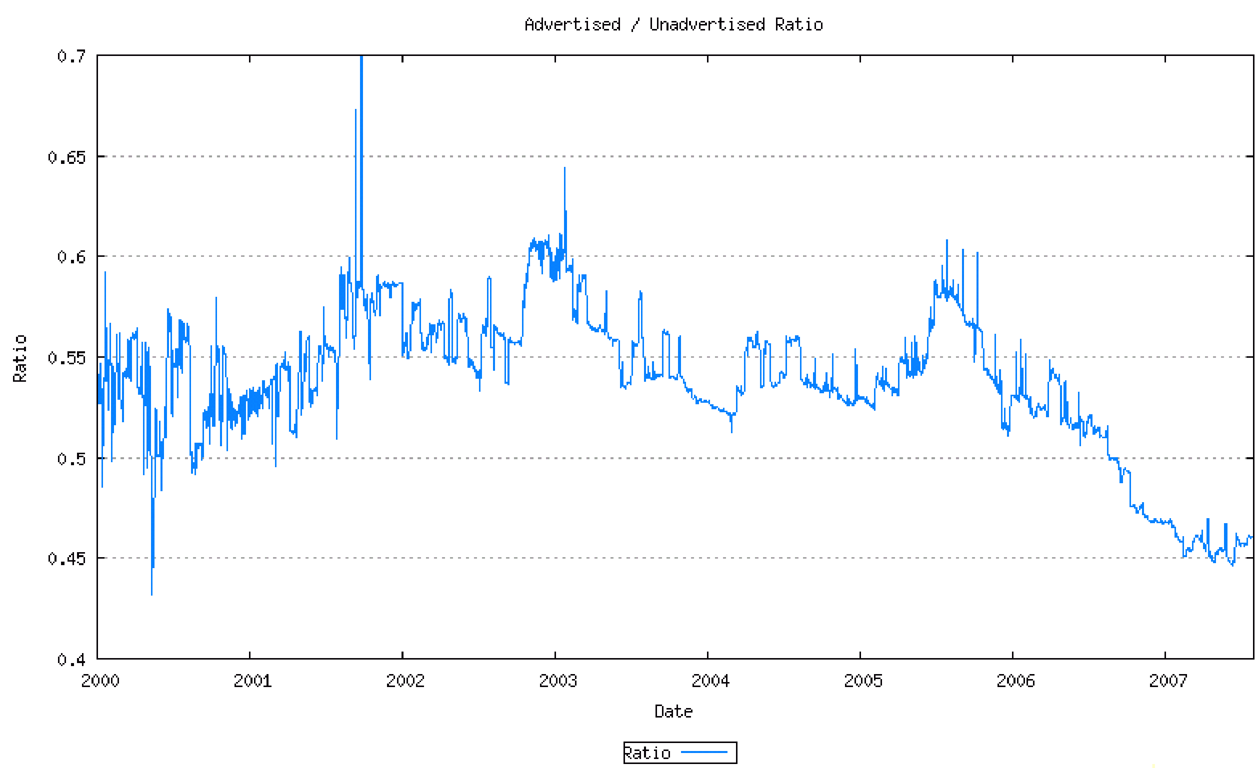

Figure 13 - Advertised / Unadvertised Addresses

Taking the most recent BGP routing table, it is possible to compare the address blocks contained in this routing table with the set of RIR allocations. This allows the construction of a view of advertised address space ordered by the data of the matching RIR allocation (or allocations). All other RIR-allocated address is effectively unadvertised address space, and, similarly, this unadvertised address space can also be ordered according to the RIR allocation date. The total address counts based on the allocation month can then be generated, and a time series of currently advertised and currently unadvertised space according to its allocation 'age' can be generated. This is indicated in Figure 14.

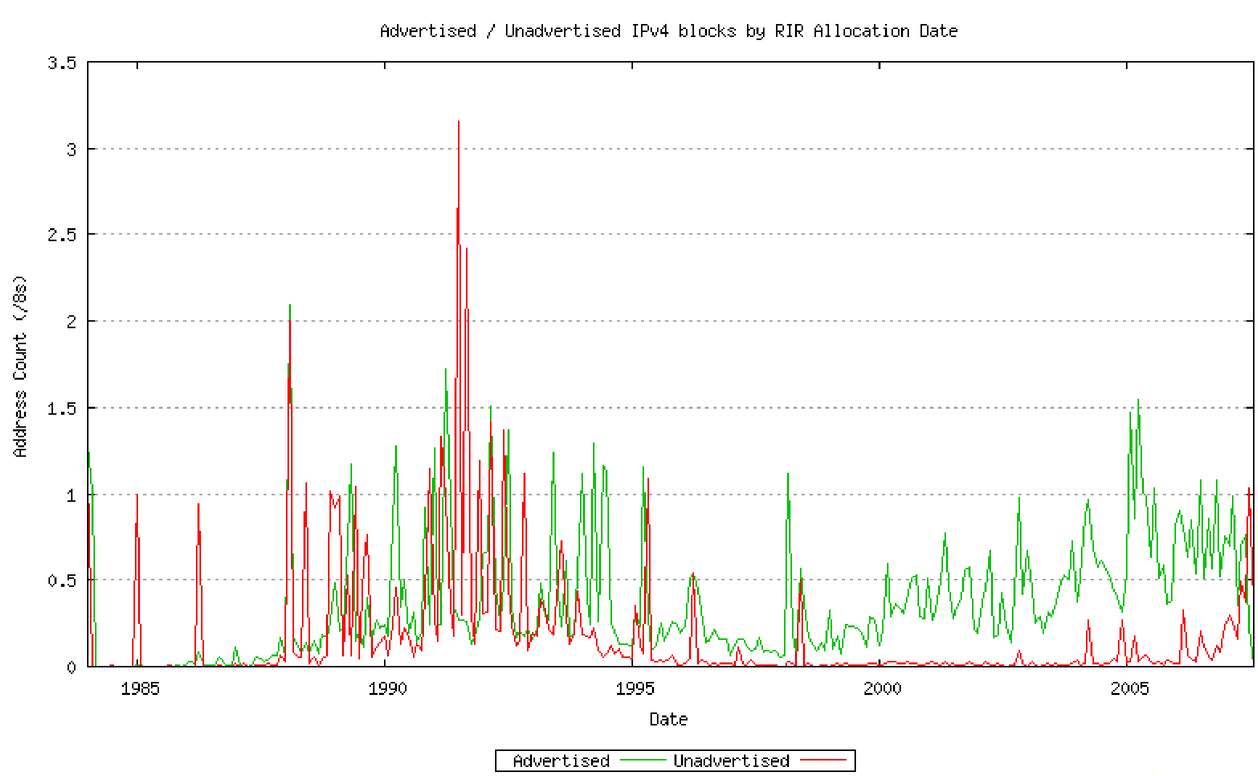

Figure 14 - Advertised / Unadvertised Assignment Series

The data since 2000 is shown in Figure 14a.

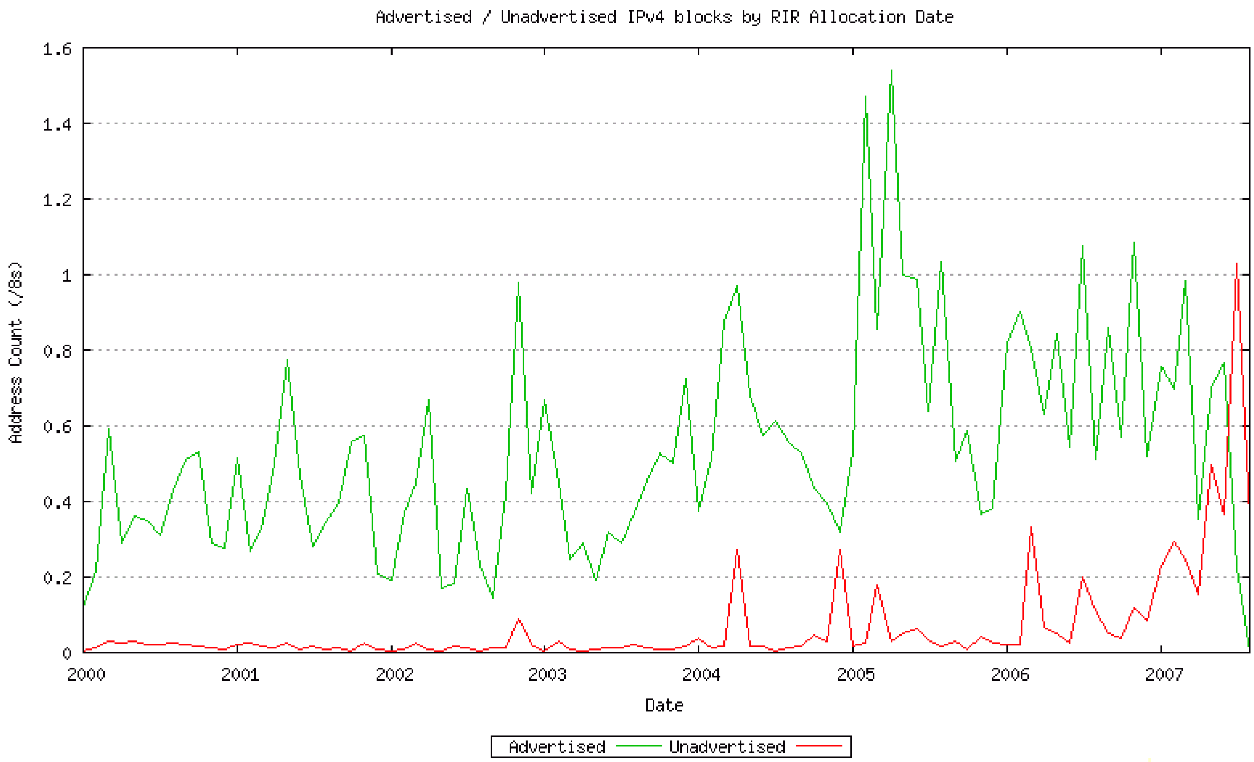

Figure 14a - Advertised / Unadvertised Assignment Series - since 2000

this has been broken for each RIR: AFRINIC (Figure 14b) , APNIC (Figure 14c), ARIN (Figure 14d), LACNIC (Figure 14f) and the RIPE NCC (Figure 14e). Also the combined unadvertised series (Figure 14g) and the combined advertised series (Figure 14h).

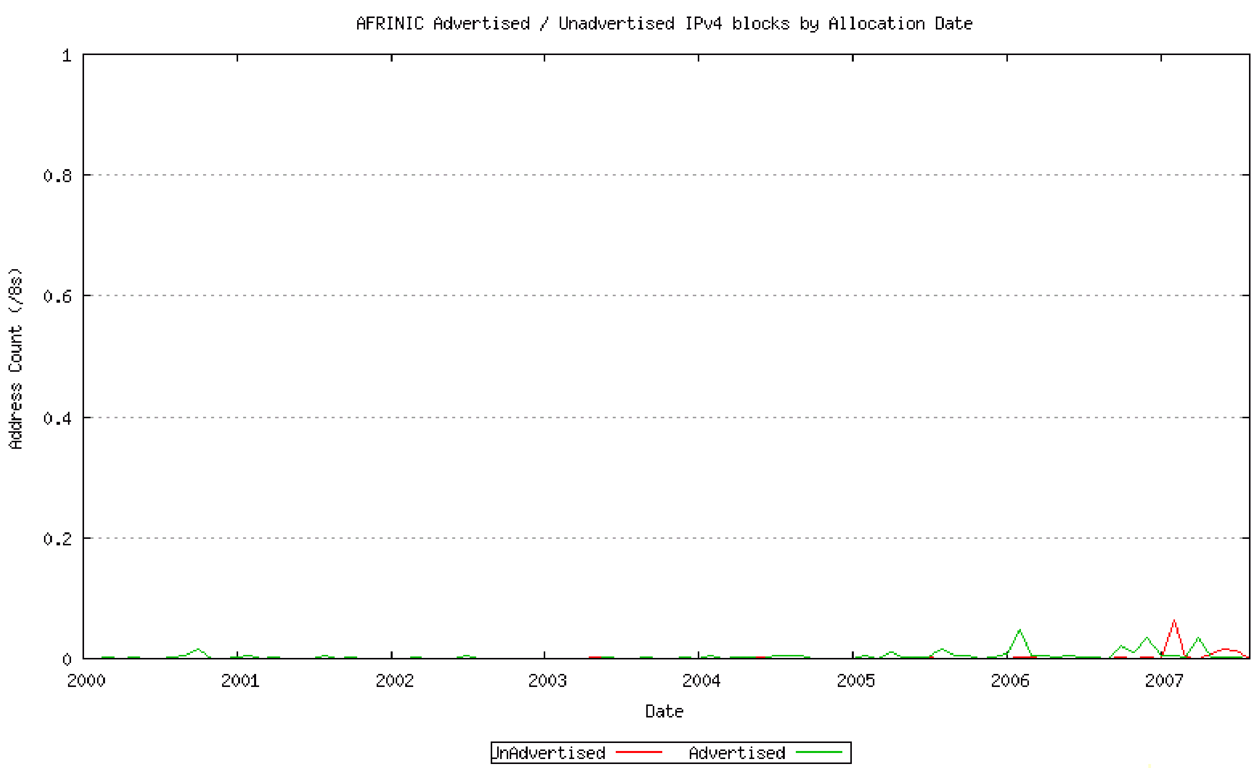

Figure 14b - AFRINIC Advertised / Unadvertised Assignment Series - since 2000

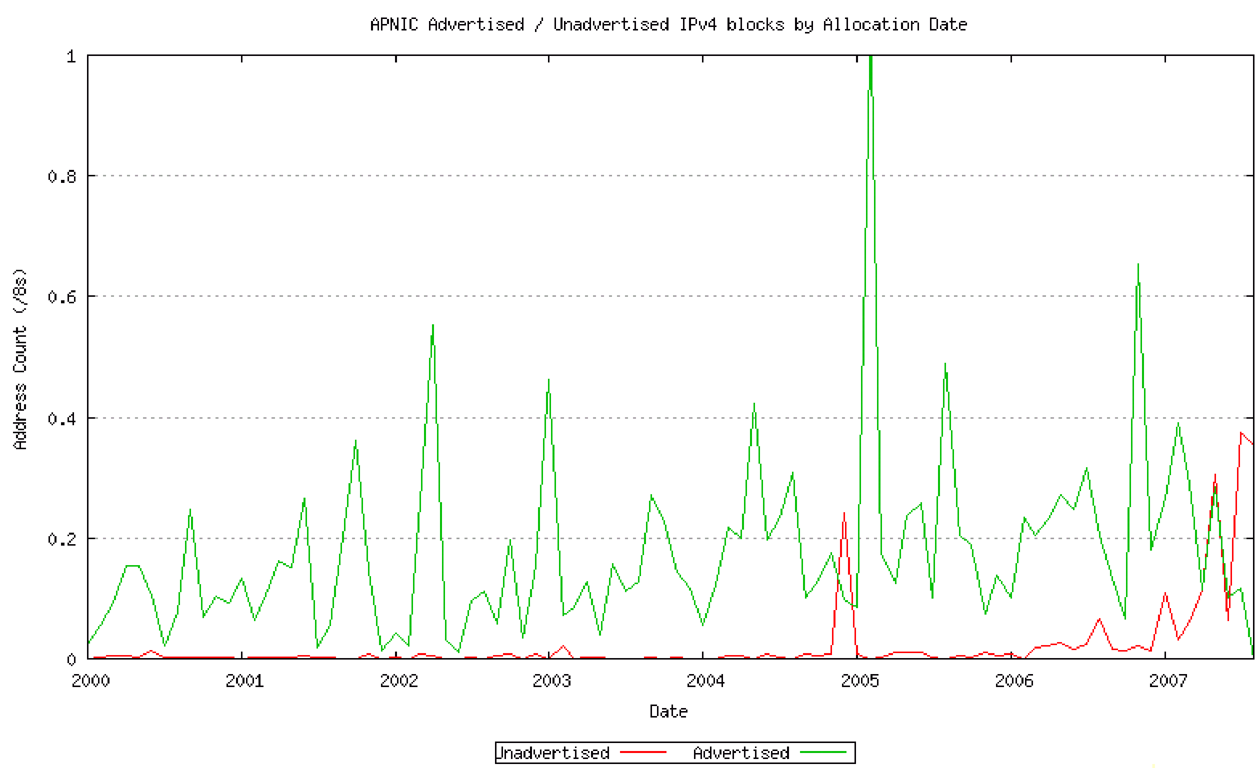

Figure 14c - APNIC Advertised / Unadvertised Assignment Series - since 2000

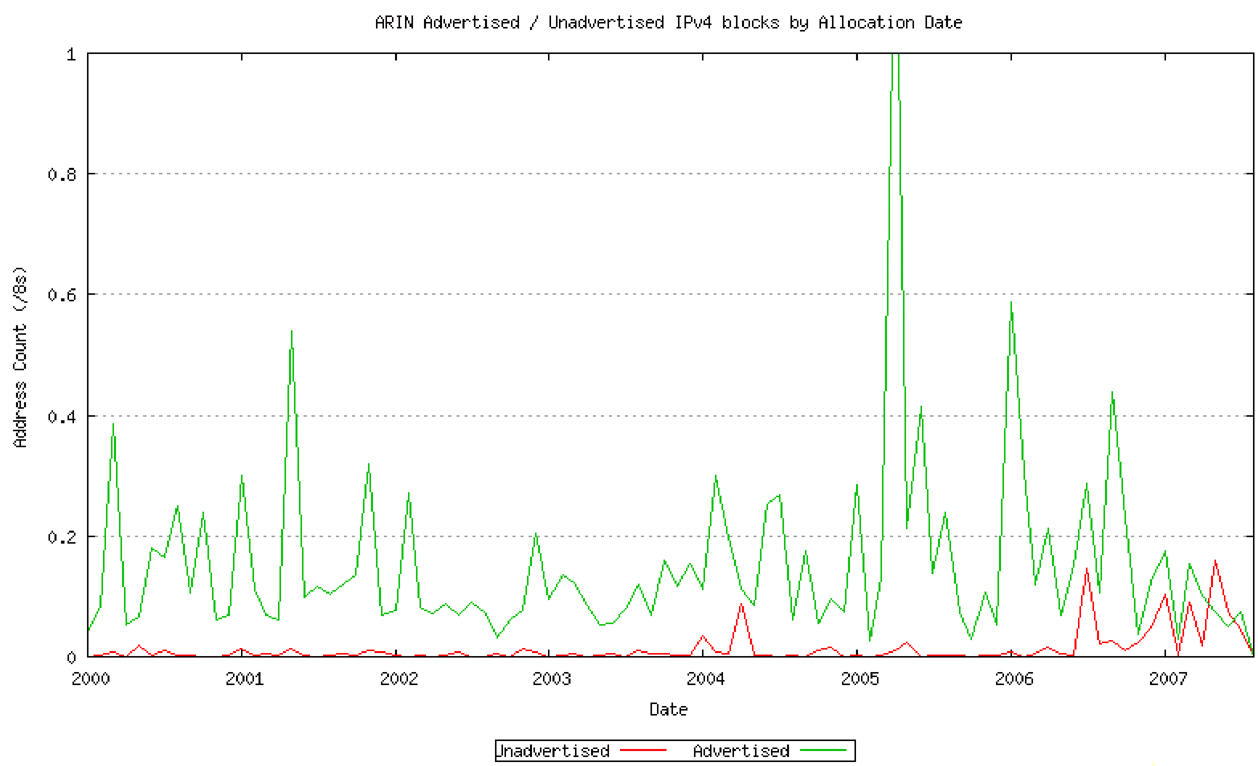

Figure 14d - ARIN Advertised / Unadvertised Assignment Series - since 2000

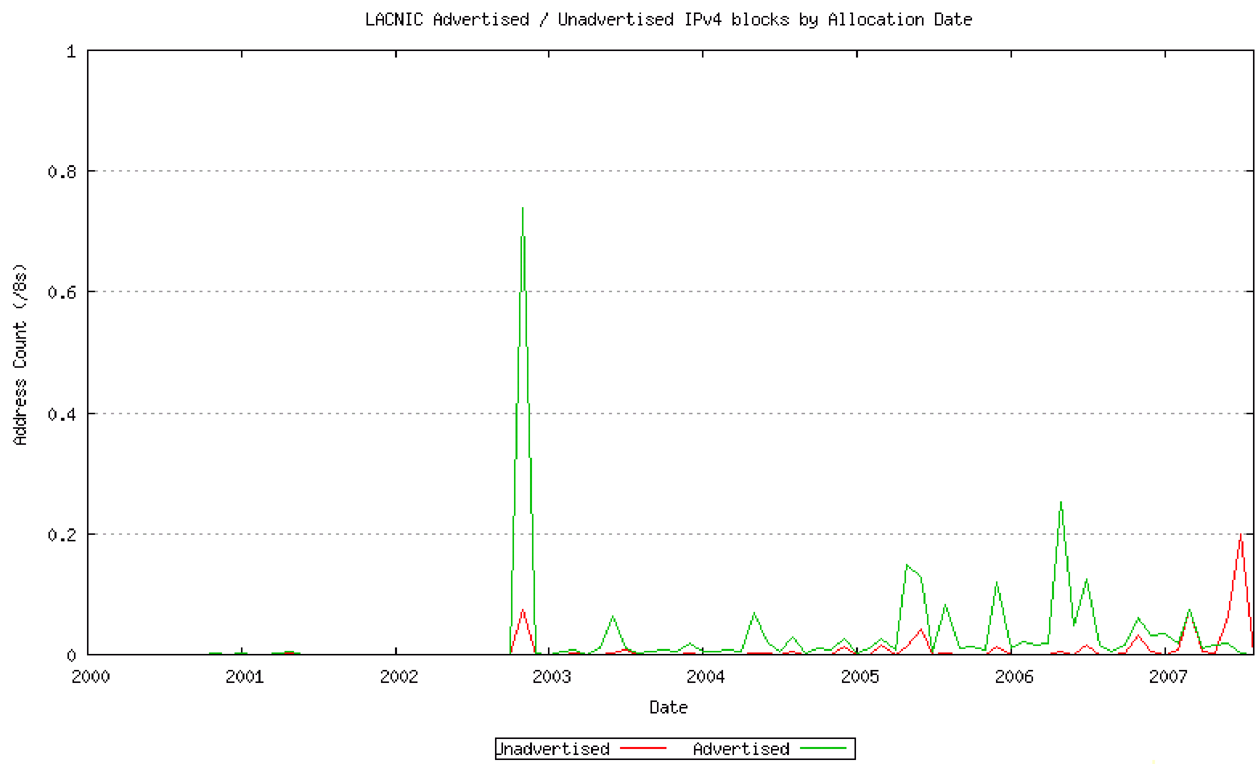

Figure 14e - LACNIC Advertised / Unadvertised Assignment Series - since 2000

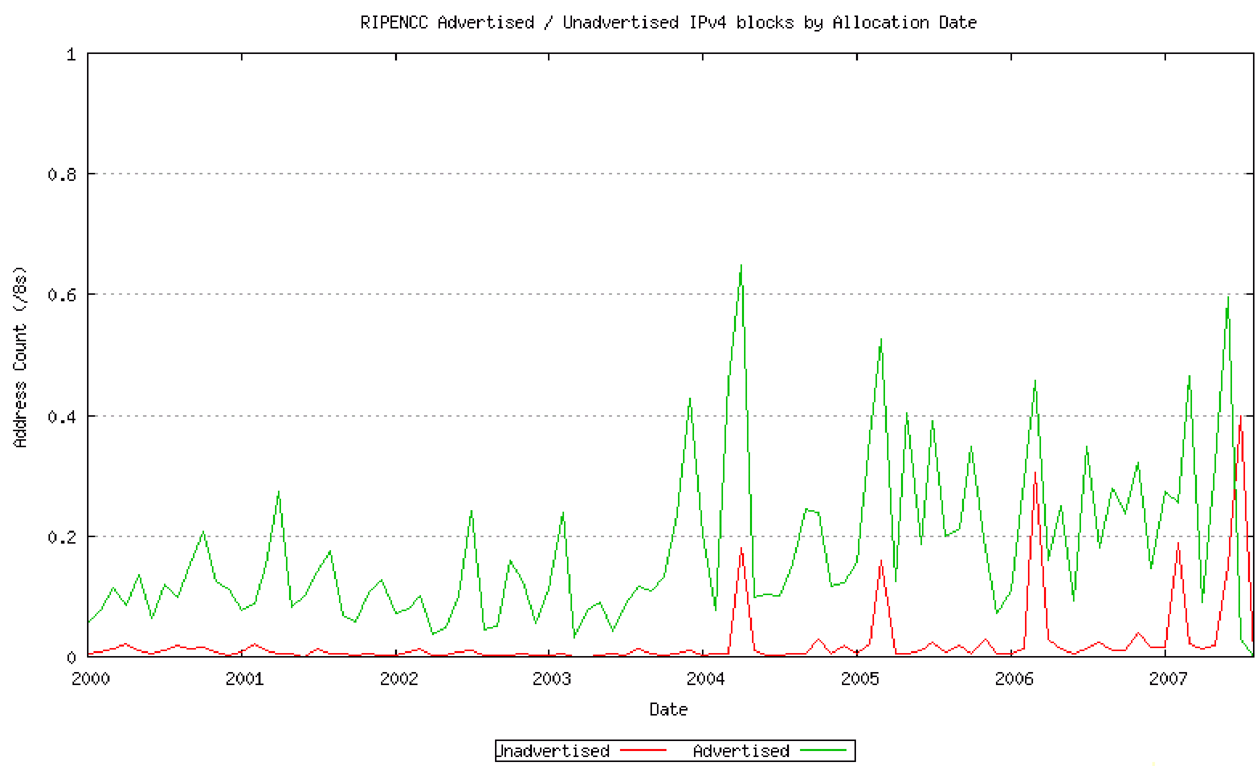

Figure 14f - RIPE NCC Advertised / Unadvertised Assignment Series - since 2000

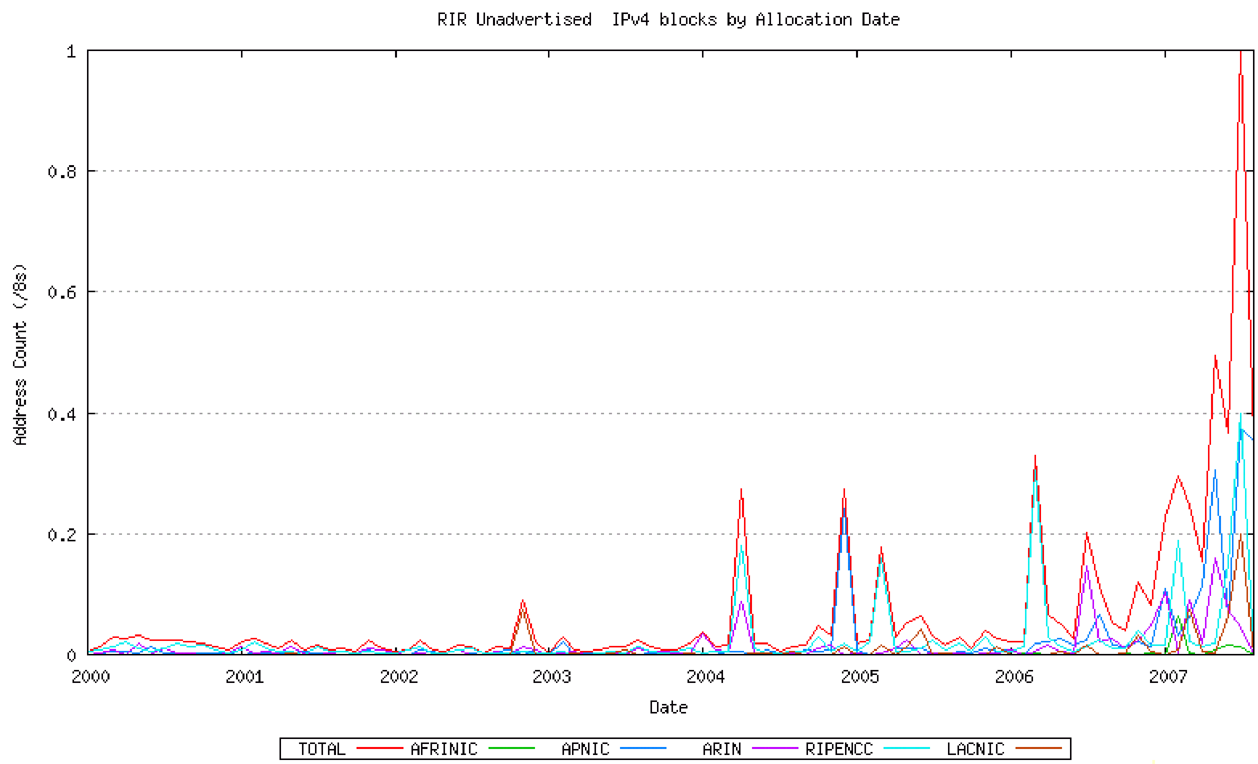

Figure 14g - Combined RIR Unadvertised Assignment Series - since 2000

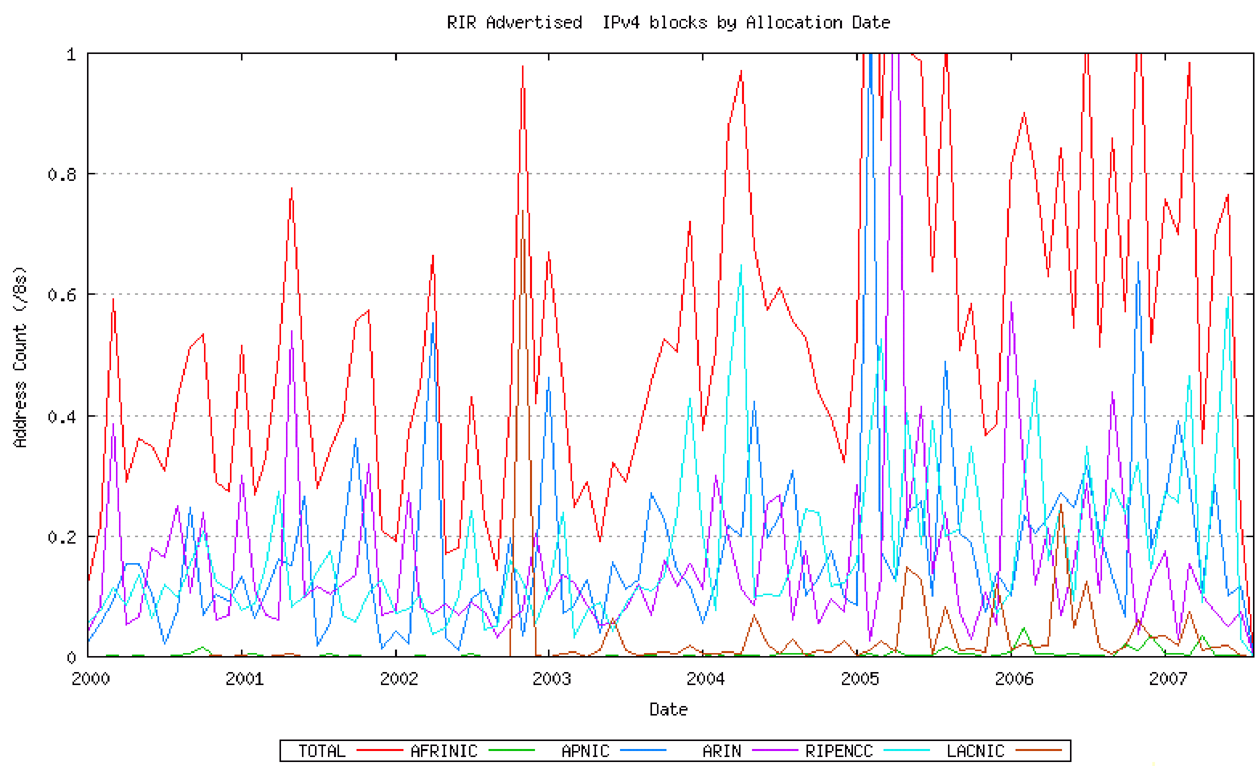

Figure 14h - Combined RIR Advertised Assignment Series - since 2000

Another way of viewing this data is to normalize the aged unadvertised address space value by looking at the aged unadvertised address space as a proportion of the advertised address space for each month. This is shown in Figure 15.

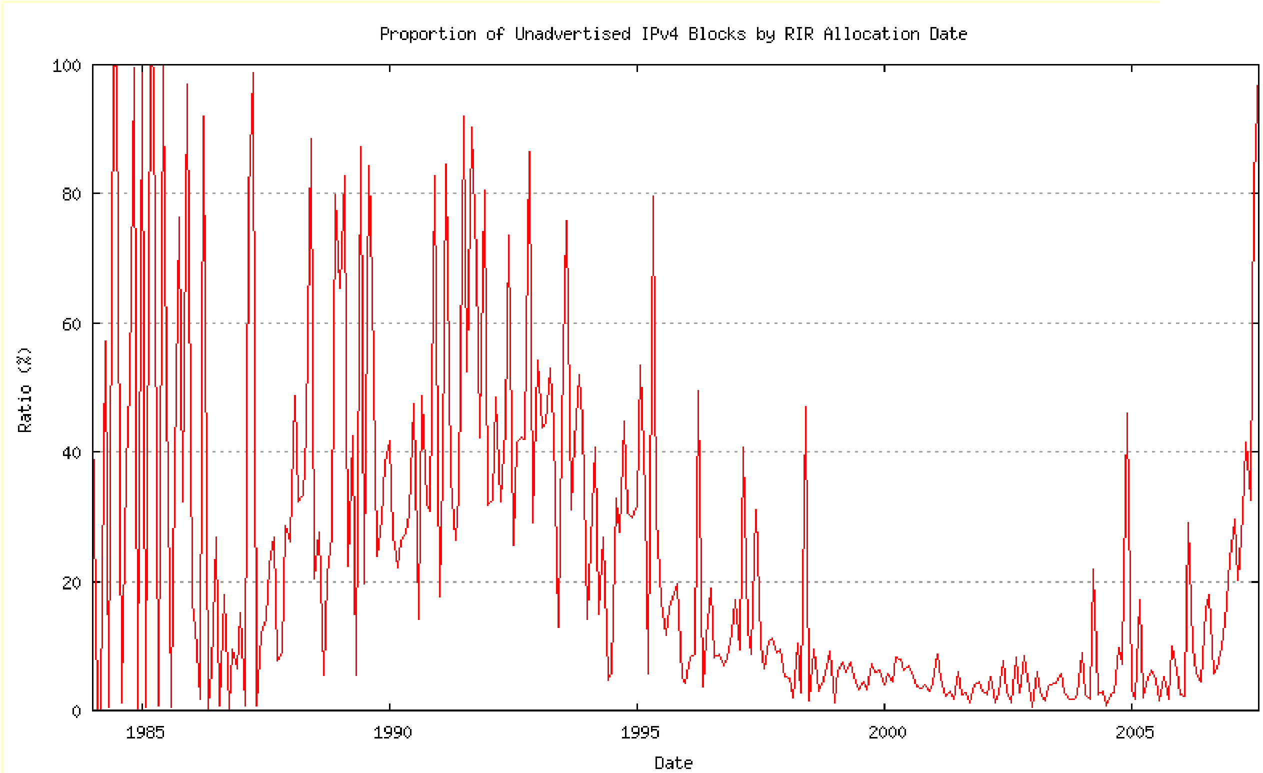

Figure 15 - Unadvertised / Advertised proportion

The data since 2000 is shown in Figure 15a.

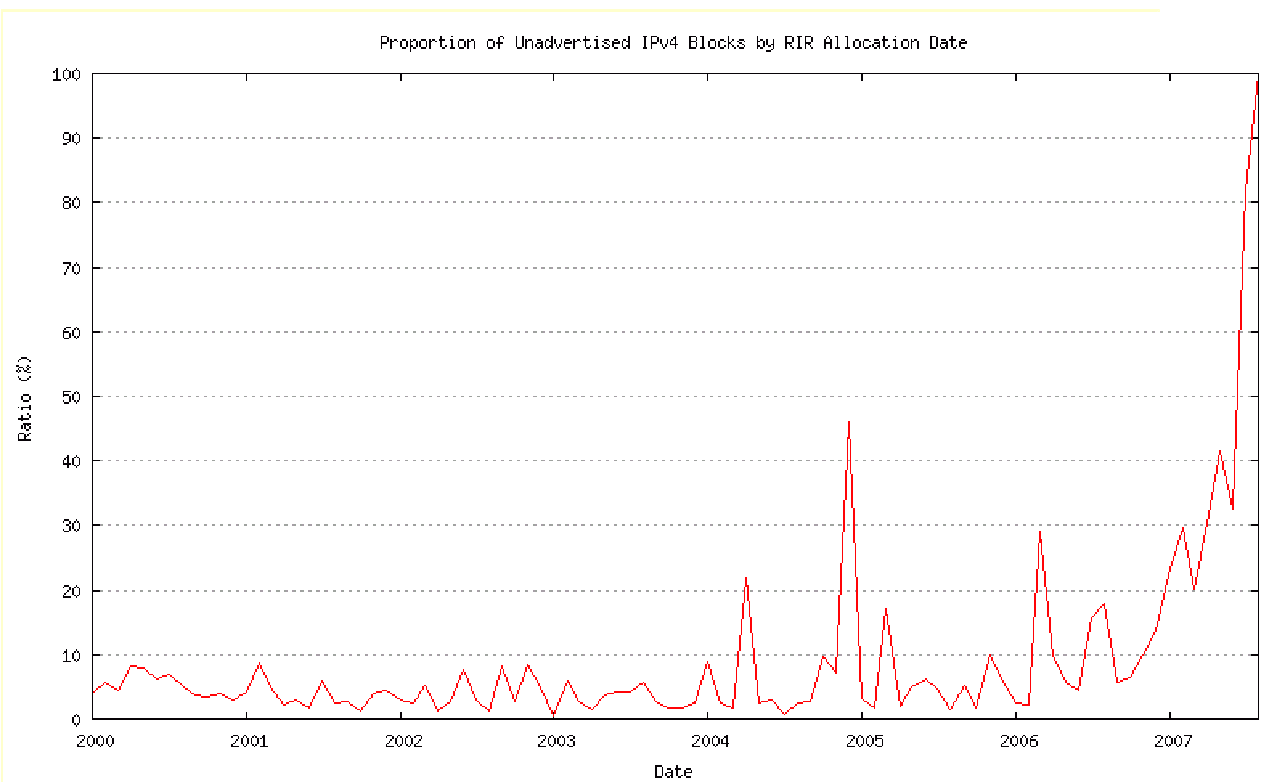

Figure 15 - Unadvertised / Advertised proportion - since 2000

The observation made here is that, with the exception of the most recent allocation intervals, some 90 to 95% of all allocated address space is currently visible in the routing table. This drops to a value of between 50% to 60% for more recently allocated address space.

This observation is used to justify the basic premise behind the predictive exercise, namely that analysis of the advertised address pool and its recent behavior can be a reliable indicator of future address consumption.

Models for Data Series

It is now possible to construct a relatively complete view of the sequences of various address pools, Figure 16 shows the total amount of space allocated by the IANA to the RIRs, the total amount of space that has been allocated by the RIRs, the total amount of space advertised in the routing table, the total amount of unadvertised space that has been allocated, and the total amount of address space that is held in the RIR's local allocation pools. This is indicated in Figure 16. The objective here is to generate a predictive model that can be used to extend these series forward in time in order to estimate a point of exhaustion of the unallocated address pool

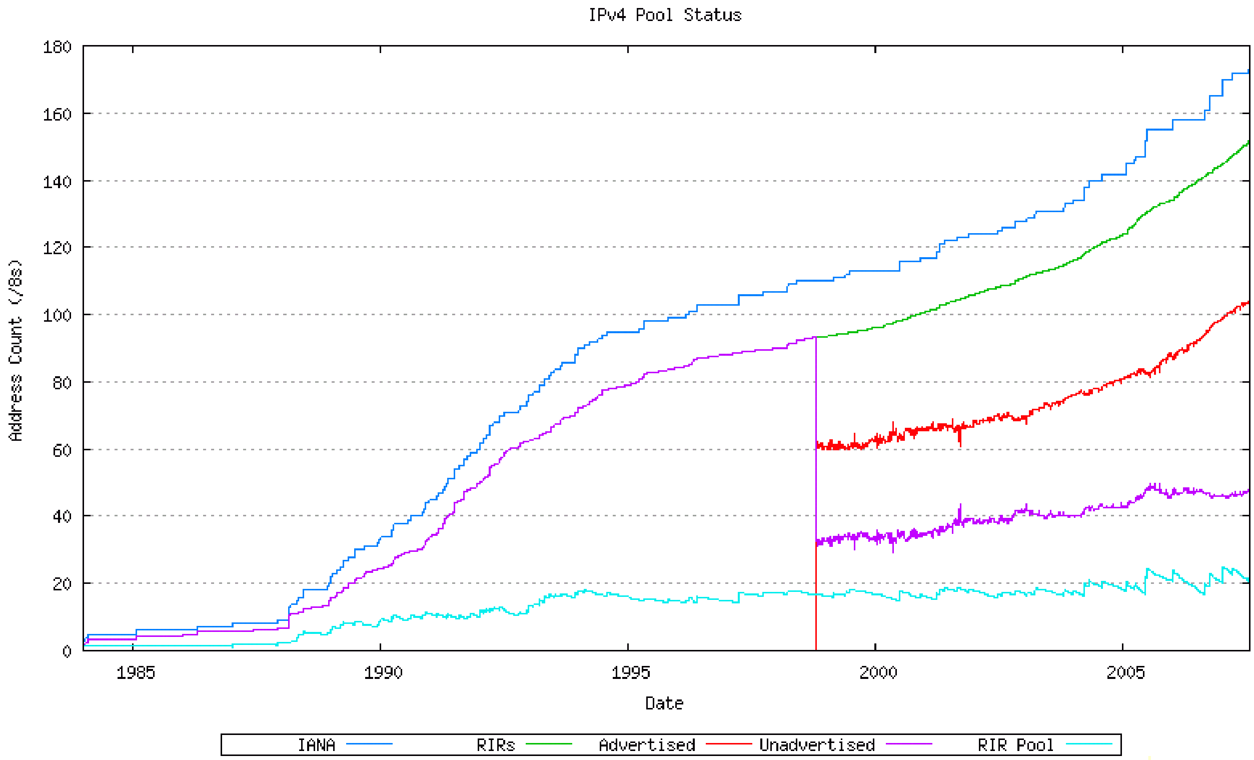

Figure 16 - IPv4 Address Pool Status

The more recent section of these series is indicated in Figure 17. The approach used here is to take a recent sequence of data as the baseline for a predictive model.

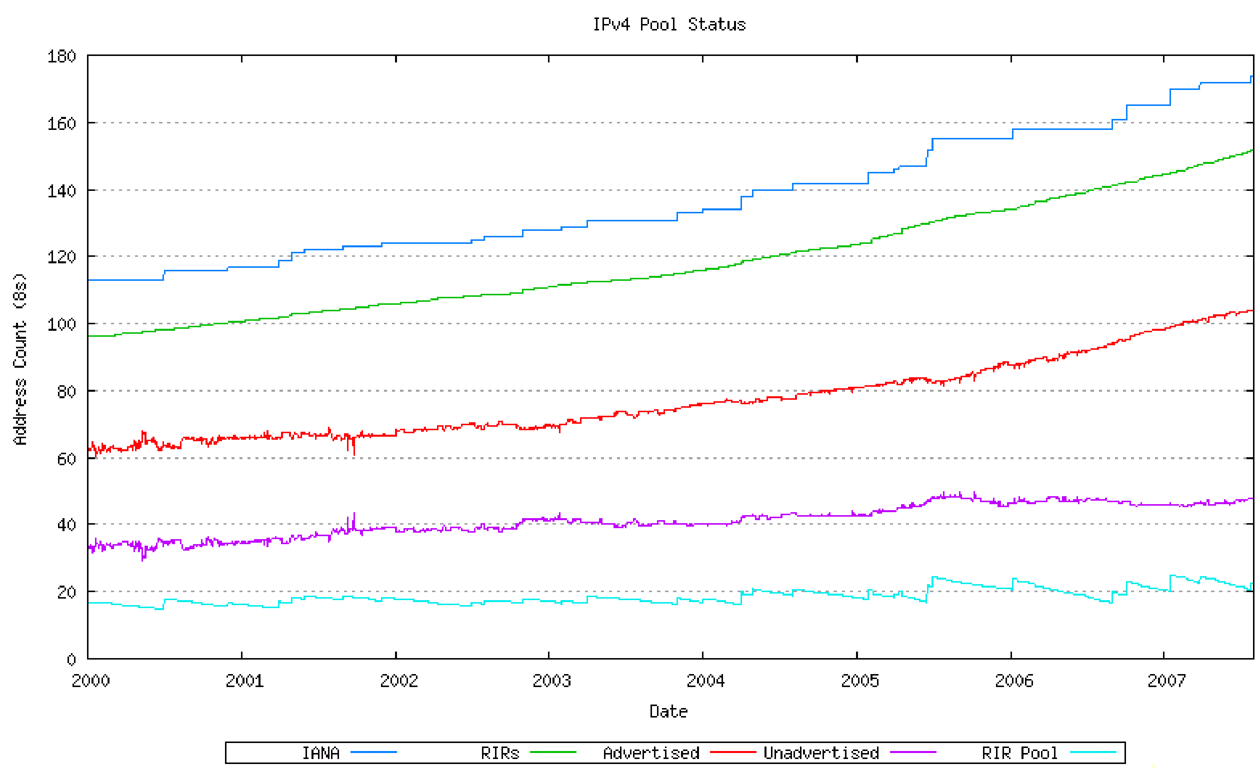

Figure 17 - IPv4 Address Pool Status - since 2000

IANA Data Series

Before looking in detail at the advertised address space, the IANA allocation data and RIR allocation data will be examined, and a relatively straightforward form of data analysis will be performed over the data series.

The IANA allocation data is indicated in Figure 18. This data is shown in both its original format, and in a smoothed format, using a sliding window smoothing algorithm, in a triple pass of the smoothing algorithm across the data.

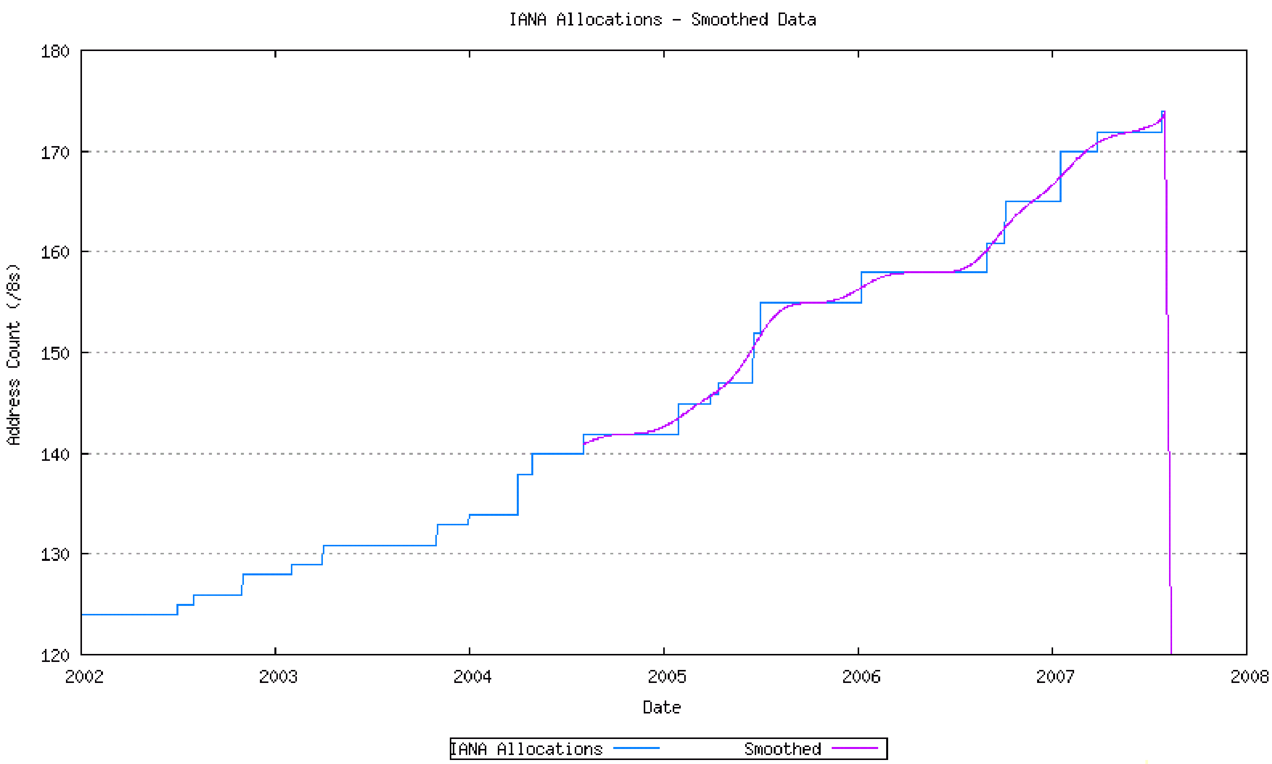

Figure 18 - IANA Allocation Series

Three least squares best fits passes have been performed over the most recent 1200 days of data: a linear best fit, an exponential best fit and a 2nd order polynomial best fit (derived from application of a linear best fit to the first order differential of the data. These are shown in Figure 18a.

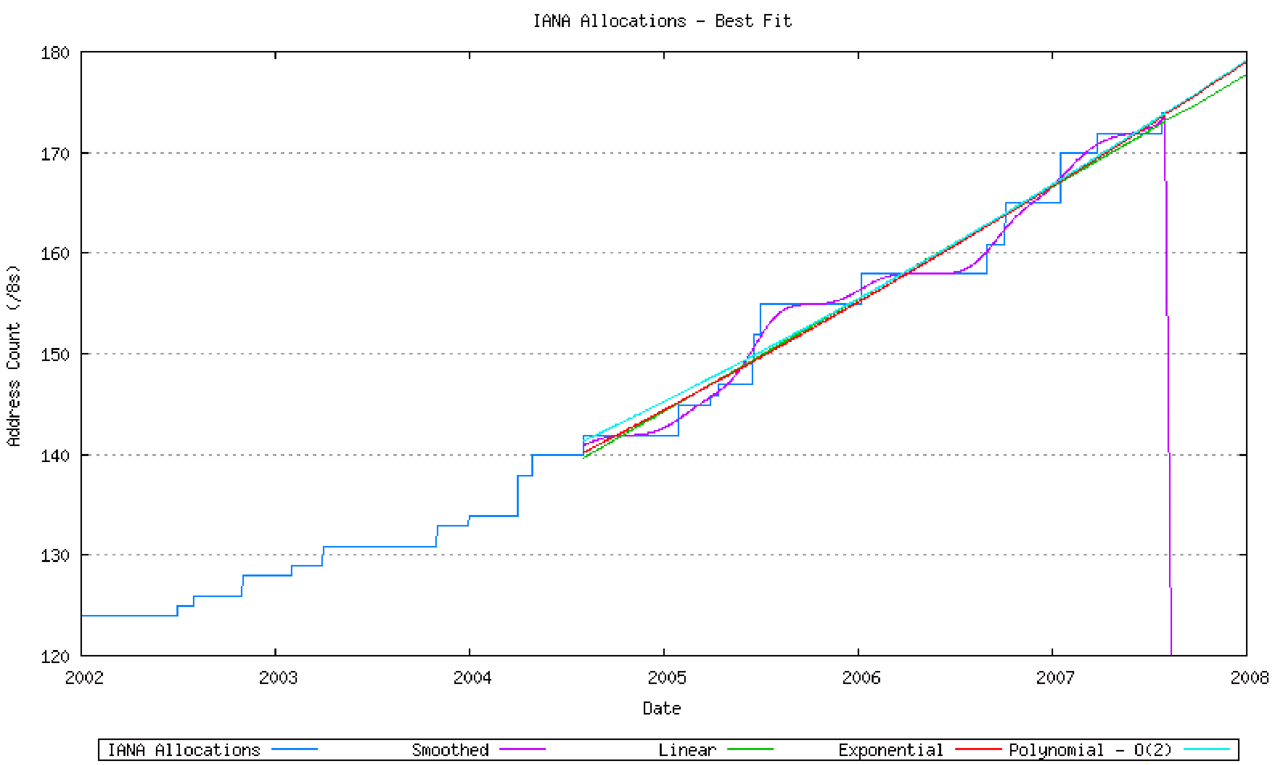

Figure 18a - IANA Allocation Series

It is then possible to take these three best fit data series, and extrapolate their data forward in time until the point where all available address space has been allocated by the IANA and no further unallocated address pool remains. This is shown in Figure 18b.

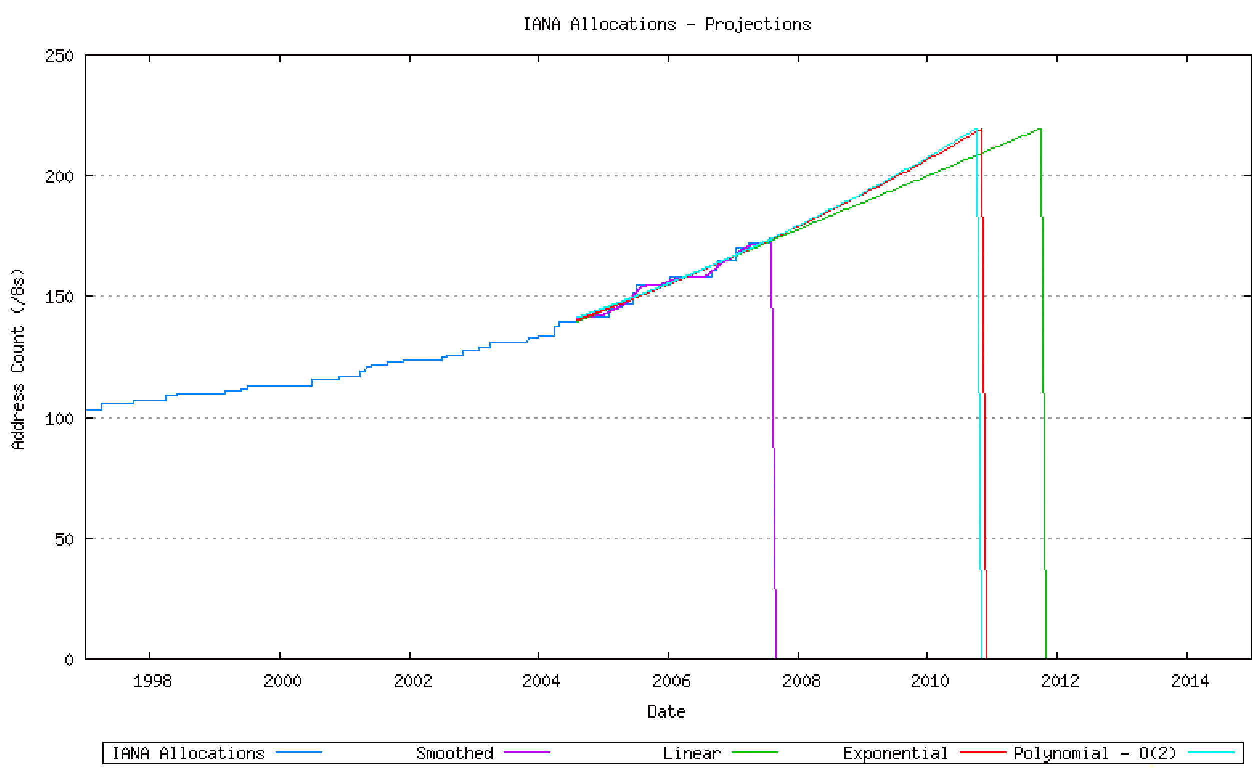

Figure 18b - IANA Allocation Series

RIR Allocations

The RIR allocation data is indicated in Figure 19. This data is shown in both its original format, and in a smoothed format, using a sliding window smoothing algorithm, in a double pass of the smoothing algorithm across the data.

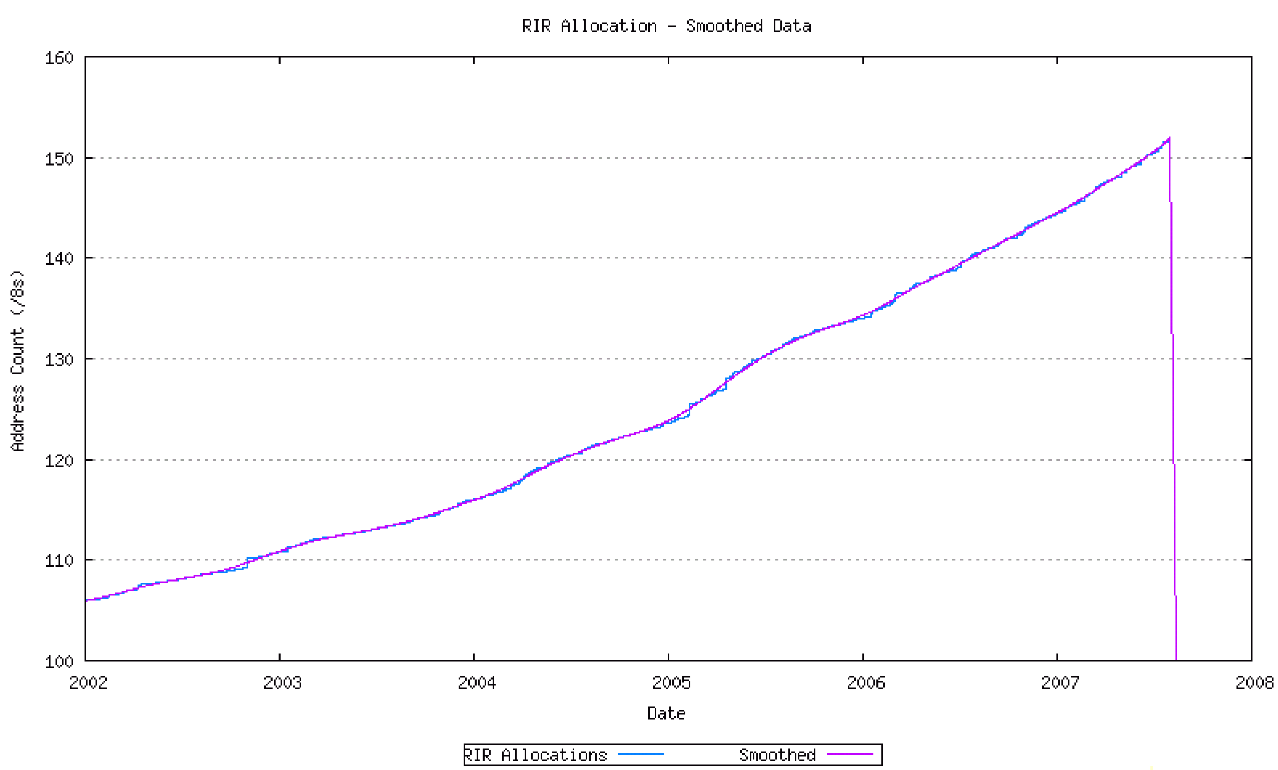

Figure 19 - RIR Allocation Series

Three least-squares best fits passes have been performed over the most recent 1200 days of data: a linear best fit, an exponential best fit and a 2nd order polynomial best fit (derived from application of a linear best fit to the first order differential of the data. These are shown in Figure 19a.

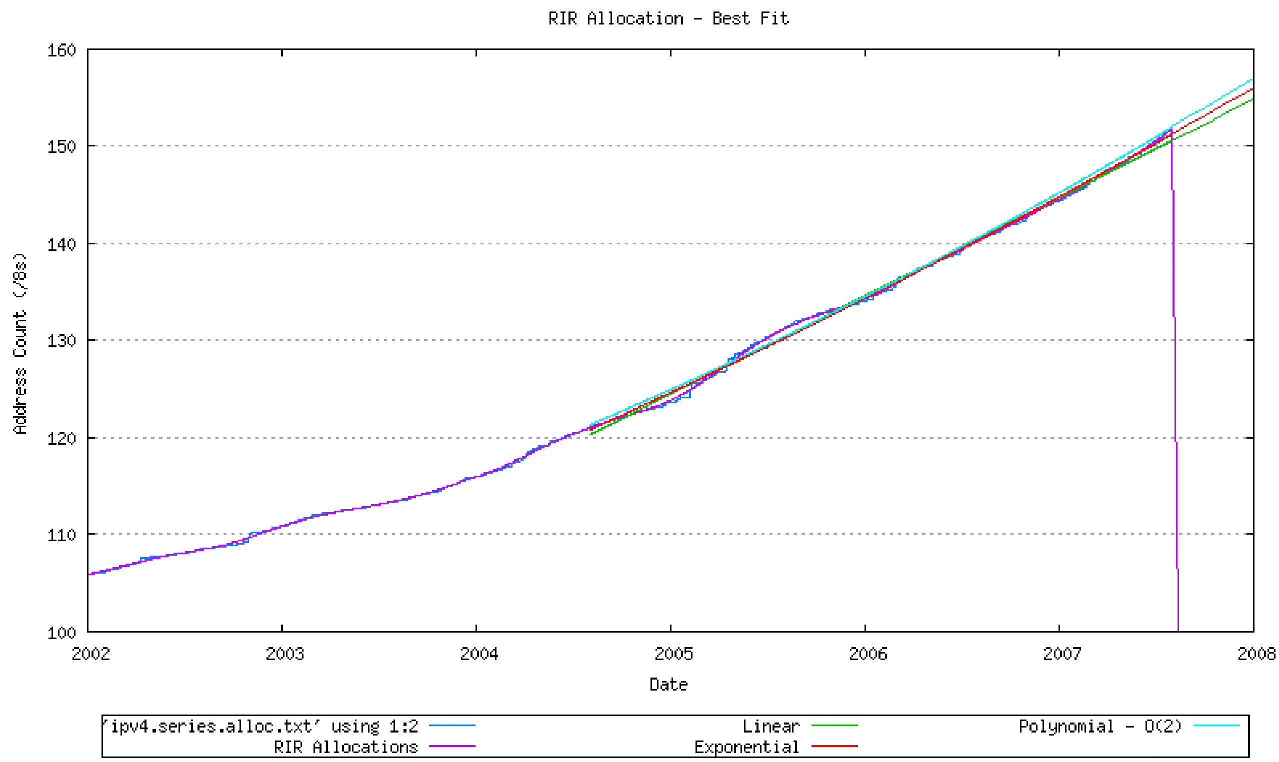

Figure 19a - RIR Allocation Series

It is then possible to take these three best fit data series, and extrapolate their data forward in time until the point where all available address space has been allocated by the RIRs and no further unallocated address pool remains. This is shown in Figure 19b.

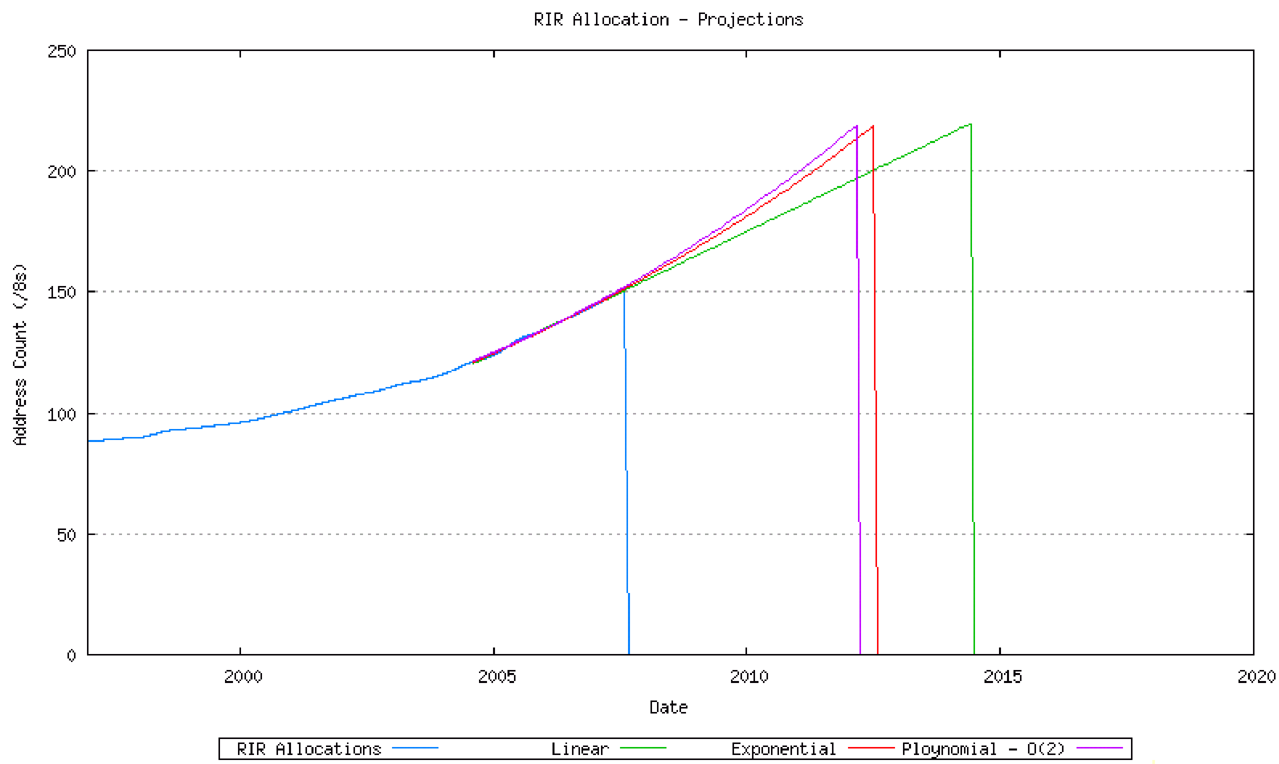

Figure 19b - RIR Allocation Series

BGP Advertised Address Range

The BGP advertised address span data is indicated in Figure 20. This data is shown in both its original format, and in a smoothed format, using a sliding window smoothing algorithm, in a triple pass of the smoothing algorithm across the data.

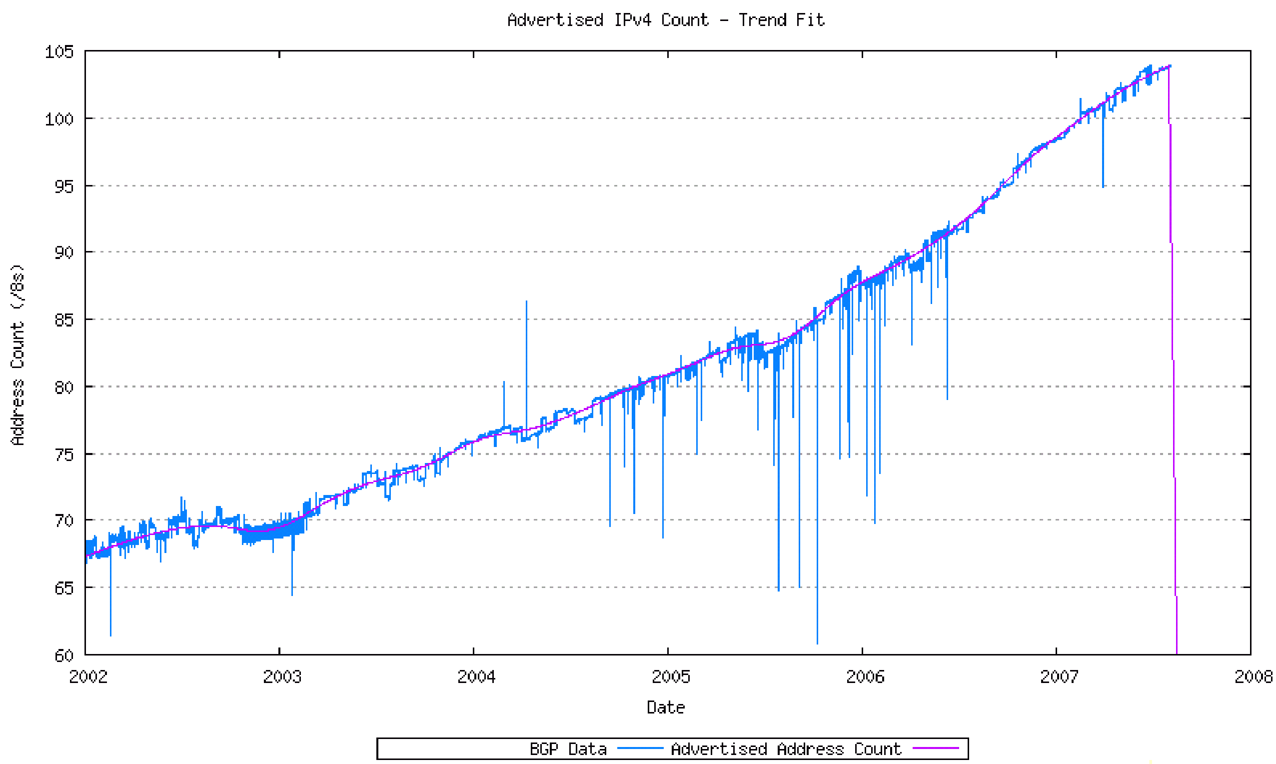

Figure 20 - BGP Advertised Series

Three least-squares best fits passes have been performed over the most recent 1200 days of data: a linear best fit, an exponential best fit and a 2nd order polynomial best fit (derived from application of a linear best fit to the first order differential of the data). These are shown in Figure 20a.

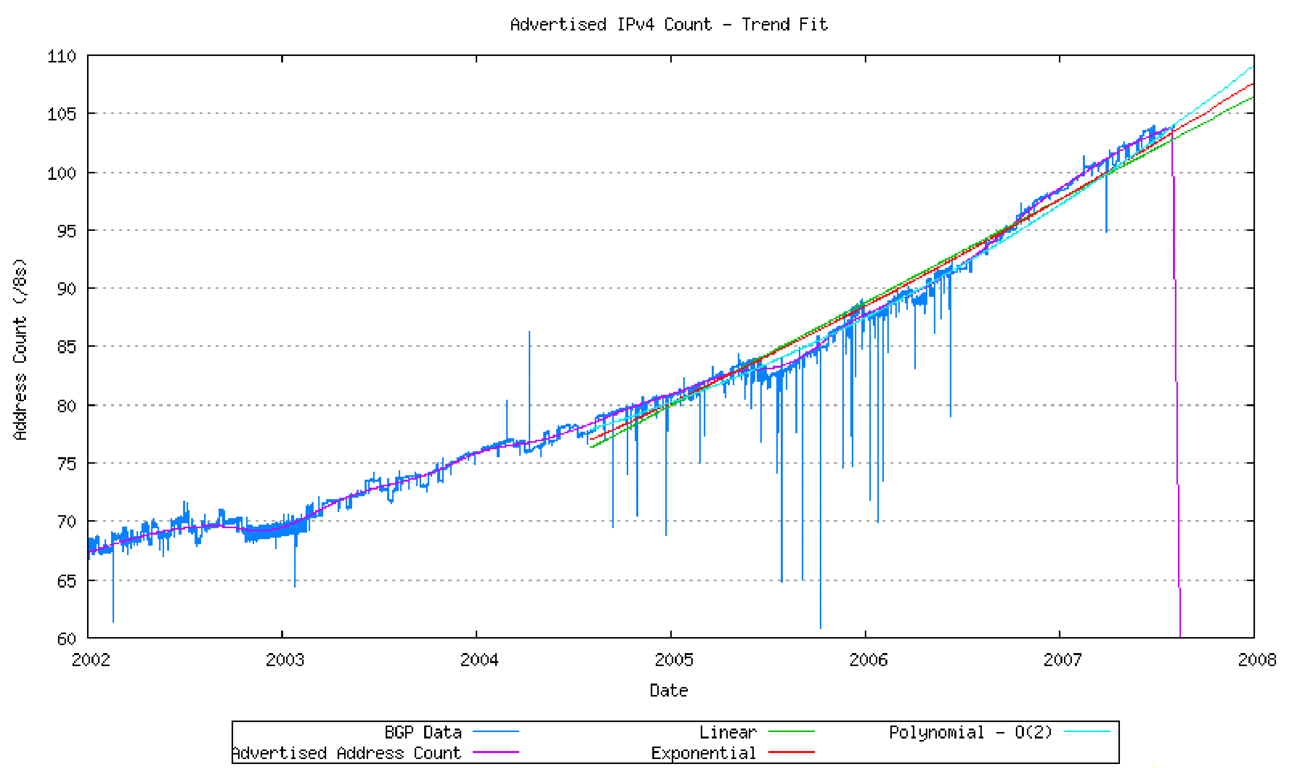

Figure 20a - BGP Advertised Series

It is then possible to take these three best fit data series, and extrapolate their data forward in time until the point where all available address space is advertised in the routing domain no further unallocated address pool remains. This is shown in Figure 20b.

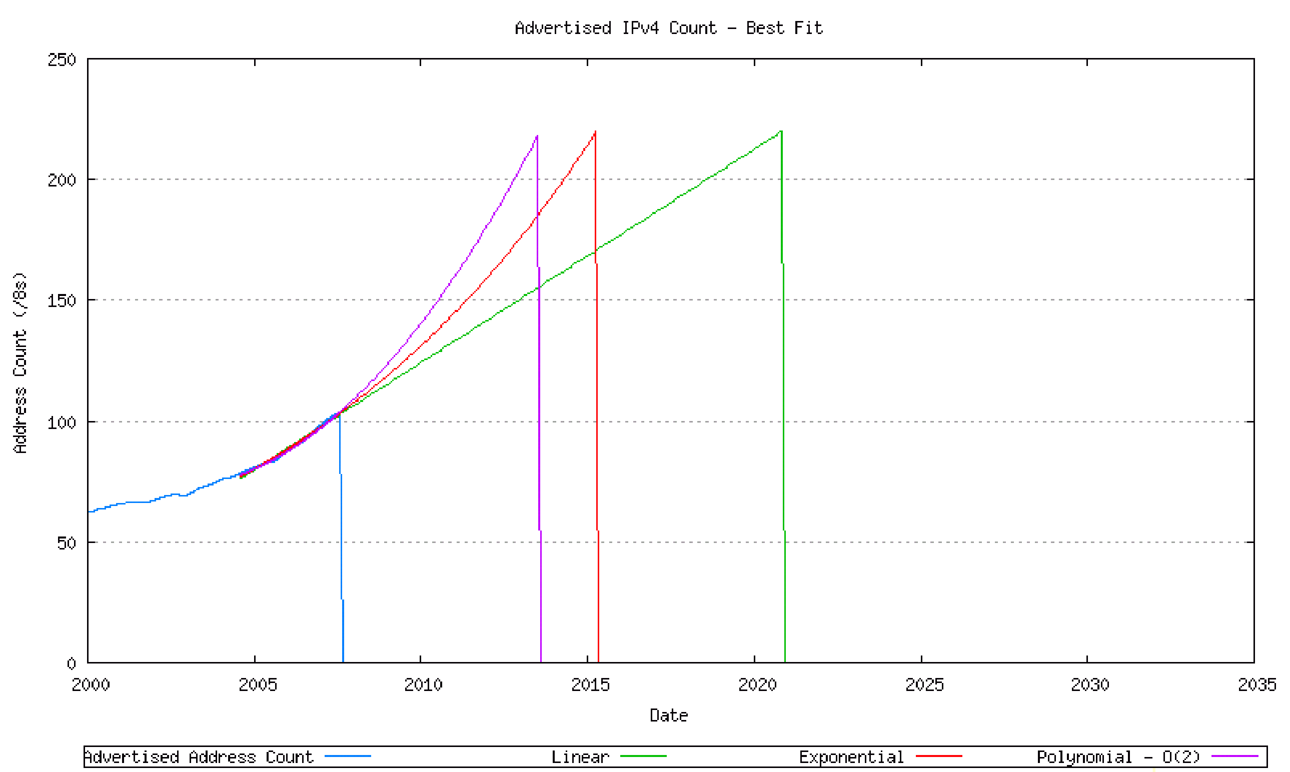

Figure 20b - BGP Advertised Series

Predicting Address Pool Exhaustion

The final step is to generate a model for address consumption. The model used here is to project forward the number of addresses found in the Internet's BGP table (advertised addresses), and also model the best fit projection of the ratio of unadvertised to advertised addresses. These two series will allow the projection of the total assigned address pool. Together with a model of the behavior of the RIR address pool, a complete address consumption model can be generated.

Modelling Advertised Addresses

The decision to use the advertised address data series as the baseline for the consumption model is based on the observation that the majority (some 95% on average) of recently allocated addresses are advertised in the Internet's routing system (as indicated in Figure 15).

The next step is to model the advertised address count. The first step is to take the daily average advertised address span and apply a sliding window smoothing function The next step is to apply a number of potential data models to the smoothed data. This is shown in Figure 21, using a linear model (y = ax= + b), an exponential model (y = $e^{ax + b}$) and an order-2 polynomial model (y = ax^2 + bx + c)

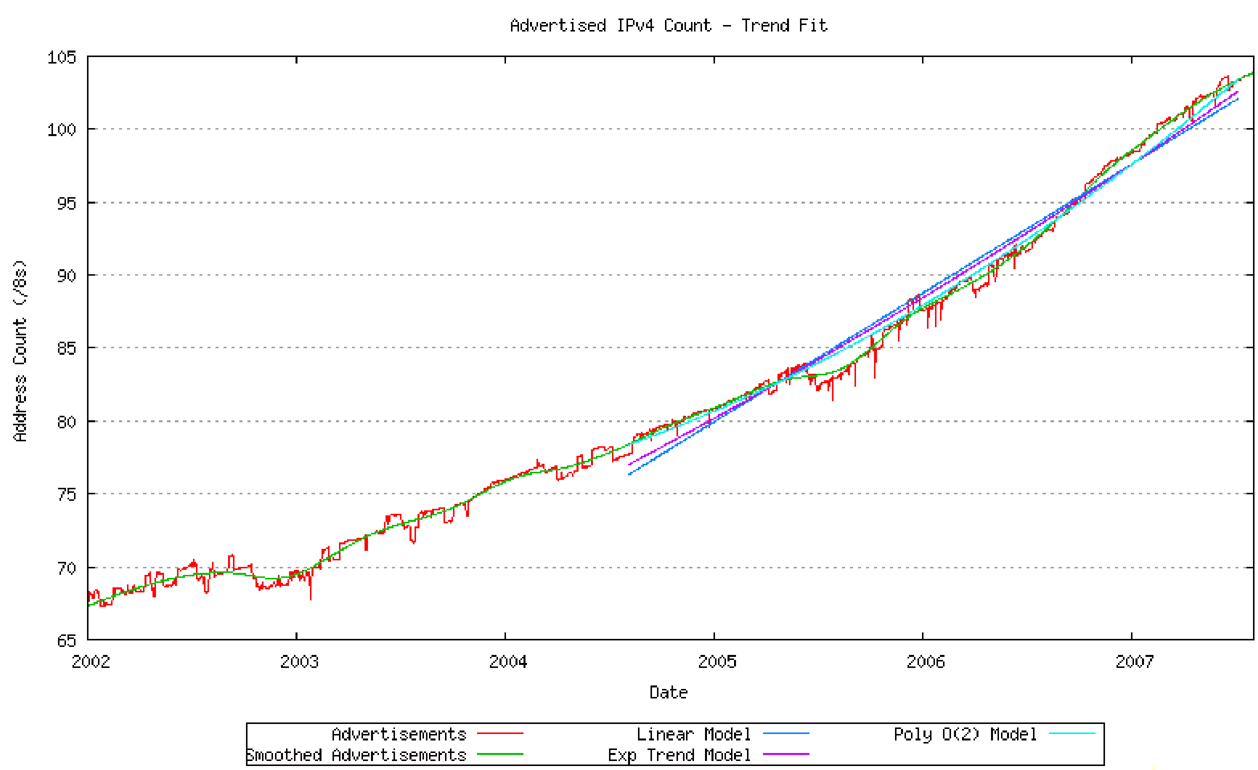

Figure 21 - Advertised Address Series - Fit to Data

The correlation of each of these models to the smoothed data is shown in Figure 22.

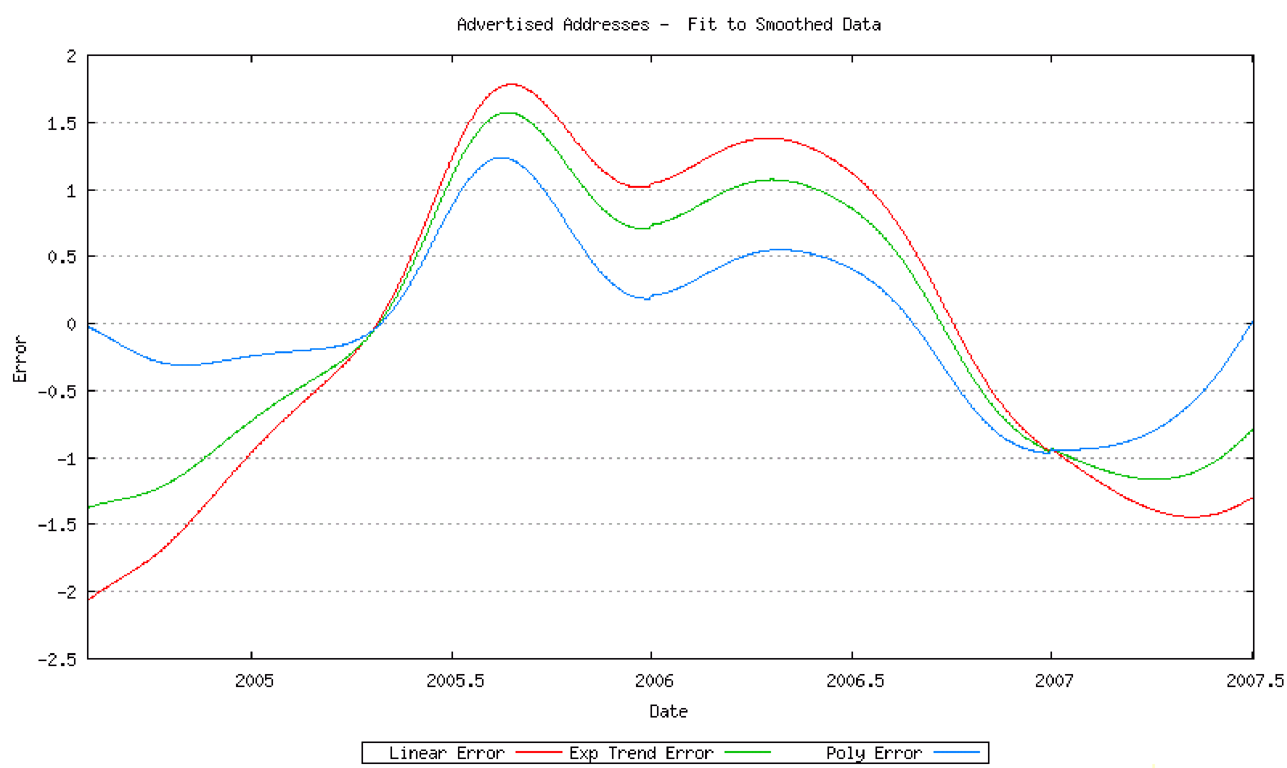

Figure 22 - Error of Best Fit models to smoothed data

The correlation of each of these models to the unsmoothed data is shown in Figure 23.

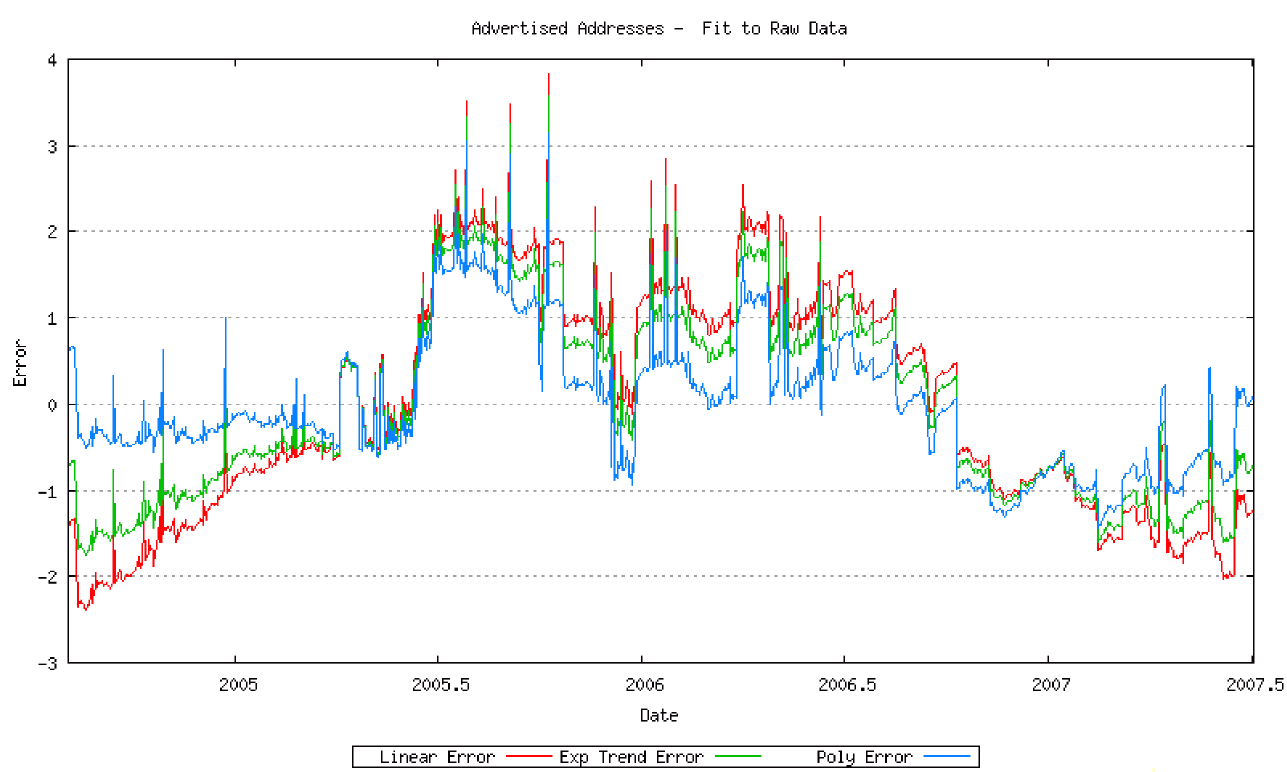

Figure 23 - Error of Best Fit models to raw data

The choice of a lowest error model can be illustrated by examining the first order differential of the advertised address space. This first order differential, and the associated least squares linear best fit, is shown in Figure 24.

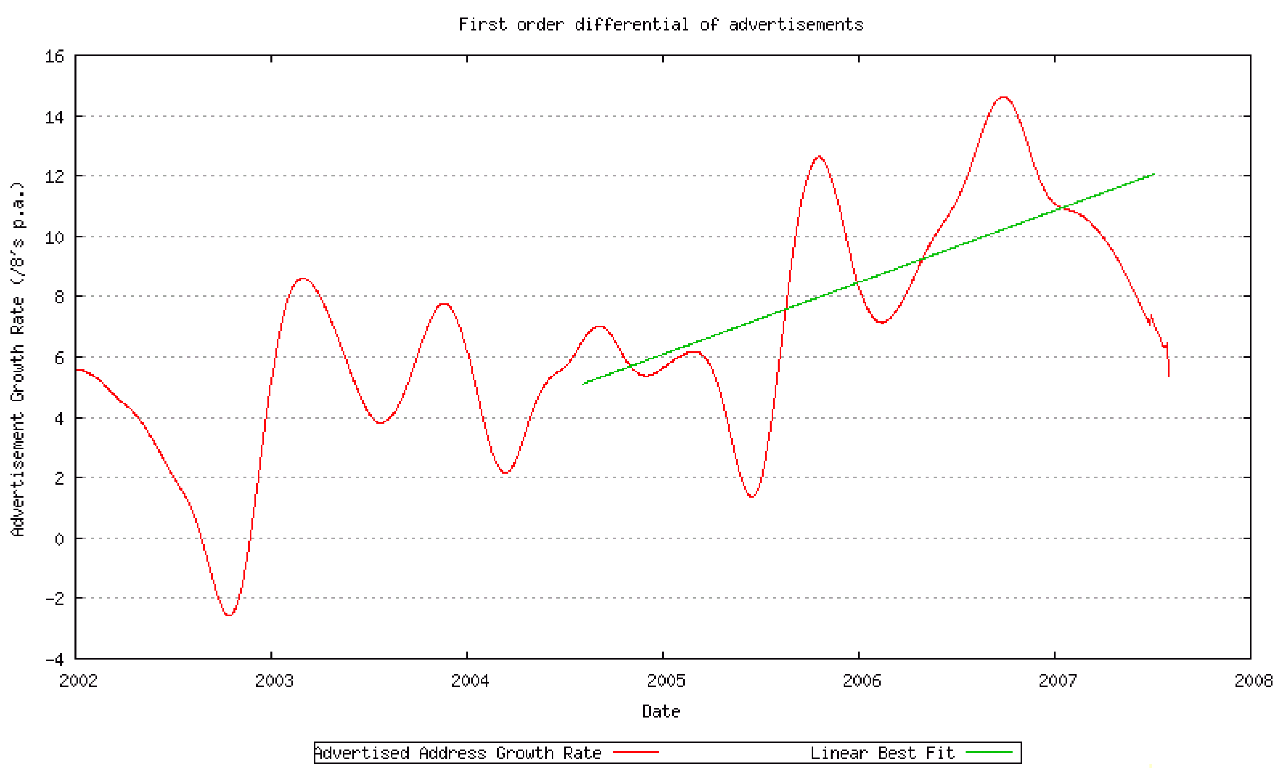

Figure 24 - First order differential of advertised address span

The rate of growth is increasing, which suggests that a linear trend model is not a good fit to the data, and possibly an 2nd order polynomial would be a better fit to the data (if d(f(x))/dx = ax + b then f(x) = a/2 * x^2 + bx + c). This corresponds to a linear increase in rate of growth over time.

Another possibility is an exponential fit to the data, suggesting that the rate of growth is a geometric progression. In this case the first order differential of the log of the data will provide the exponential function. This is shown in Figure 25. If the best fit model of the first order differential were very close to constant, it would suggest that the best fit exponential model of f(x) = $e^{ax + b}$ would be appropriate.

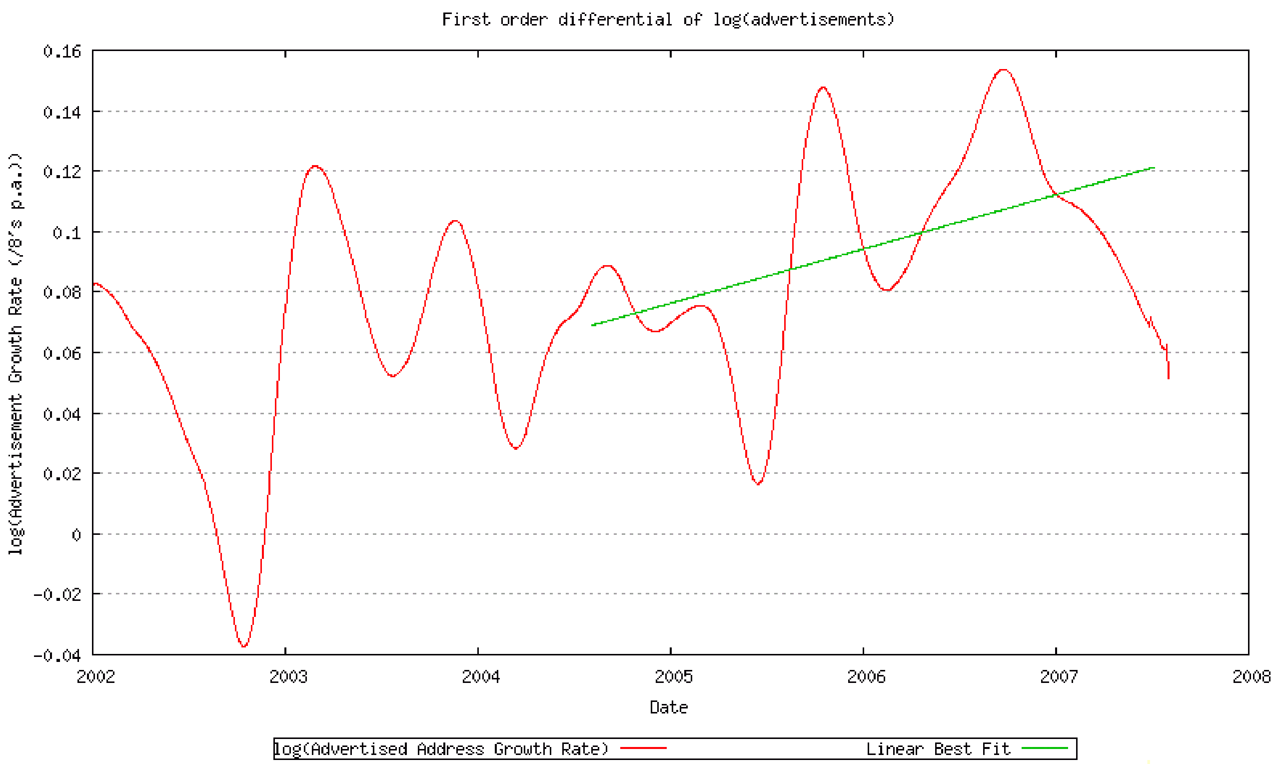

Figure 25 - First order differential of the log of advertised address span

The current best fit appears to be an order 2 polynomial function, and this quadratic projection of the advertised address count wil be used for the projections.

Unadvertised Addresses

The approach taken here is to model the size of the unadvertised address pool as a proportion of the advertised address pool size. Figure 26 shows the three steps of this process; namely generating the sequence of the ratio of the size of the unadvertised address pool to the size of the advertised address pool, then applying a sliding window average function to smooth the data, and then generating a model for this ratio that is derived from application of a least squares linear best fit to the data. The negative trend of this best fit provides a model that the unadvertised address pool is growing at a slower rate than the advertised address pool.

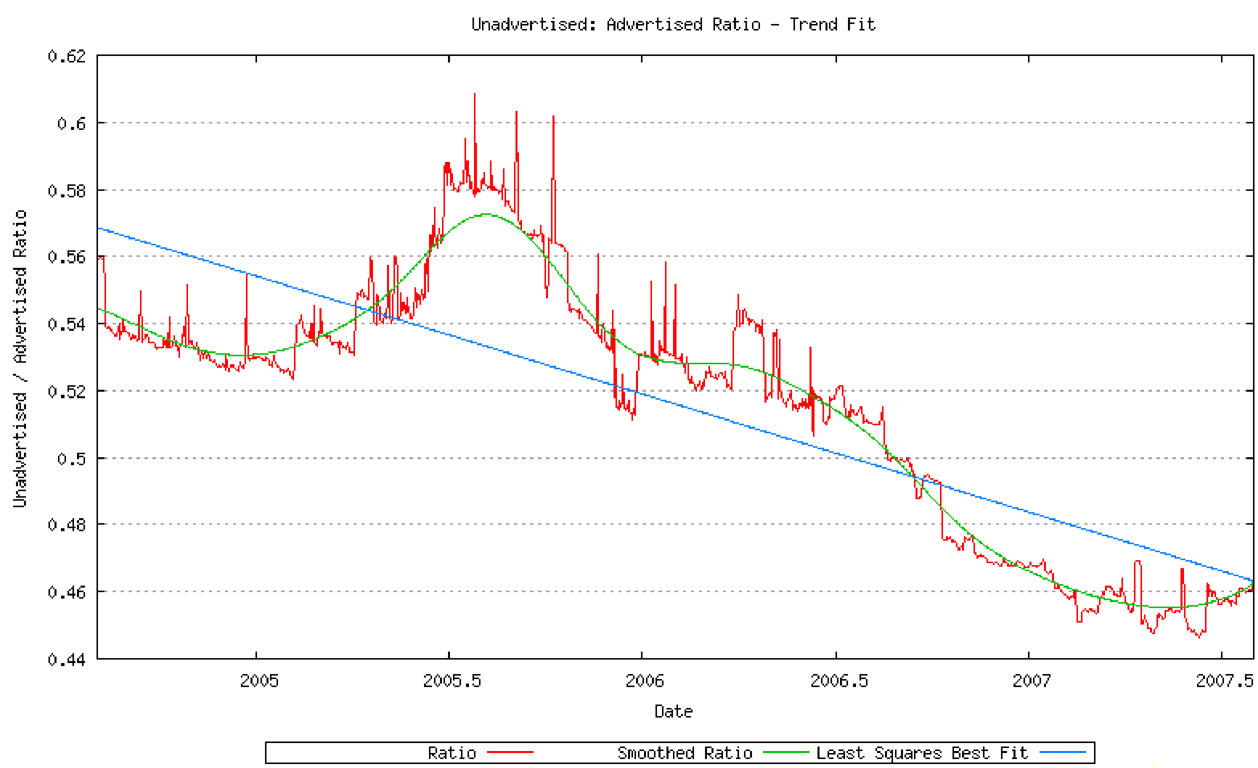

Figure 26 - Unadvertised Ratio Series

Modelling RIR behavior

The next step in this exercise is to model the relative rate of allocations from each of the RIRs in order to predict both the time when the last IANA allocation would be made, and the time when an RIR unallocated address pool will be exhausted.

Given that we have now defined models for the advertised and unadvertised address spaces, then the RIR allocation rate is the first order differential of the sum of these two address pools. However while the total RIR allocation rate can be derived in this way, the model also requires modelling of the relative rate of allocation for each RIR. In order to model this the first step is to extract the historical RIR allocations over time. (It should be noted that over time the number of regional Internet registries has grown, and older allocations that were made into the region where a RIR was subsequently established have been transferred to the relevant RIR, with the original dates intact. The data contains allocations made in the APNIC, LACNIC and AFRINIC regions prior to the establishment of these RIRs.) This allocation data series is shown in Figure 27.

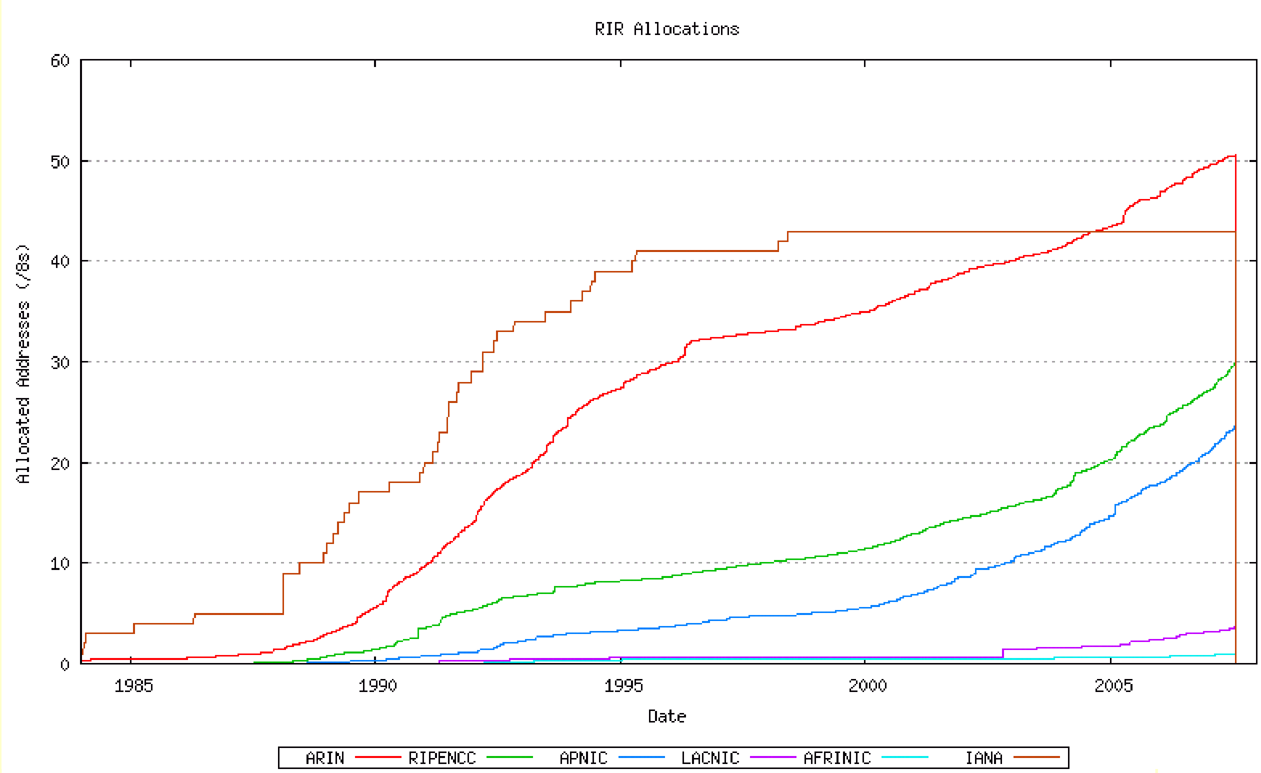

Figure 27 - RIR Allocations

The technique here is firstly look at the first order differential of the smoothed data, and then to apply an appropriate smoothing function to each RIR data series, apply a best fit using an exponential function, and then projecting this forward. The first order differentials for this allocation data is indicated for AFRINIC (Figure 27a), APNIC (Figure 27b) ARIN (Figure 27c), LACNIC (Figure 27d) and the RIPE NCC (Figure 27e), and the combined view (Figure 27f).

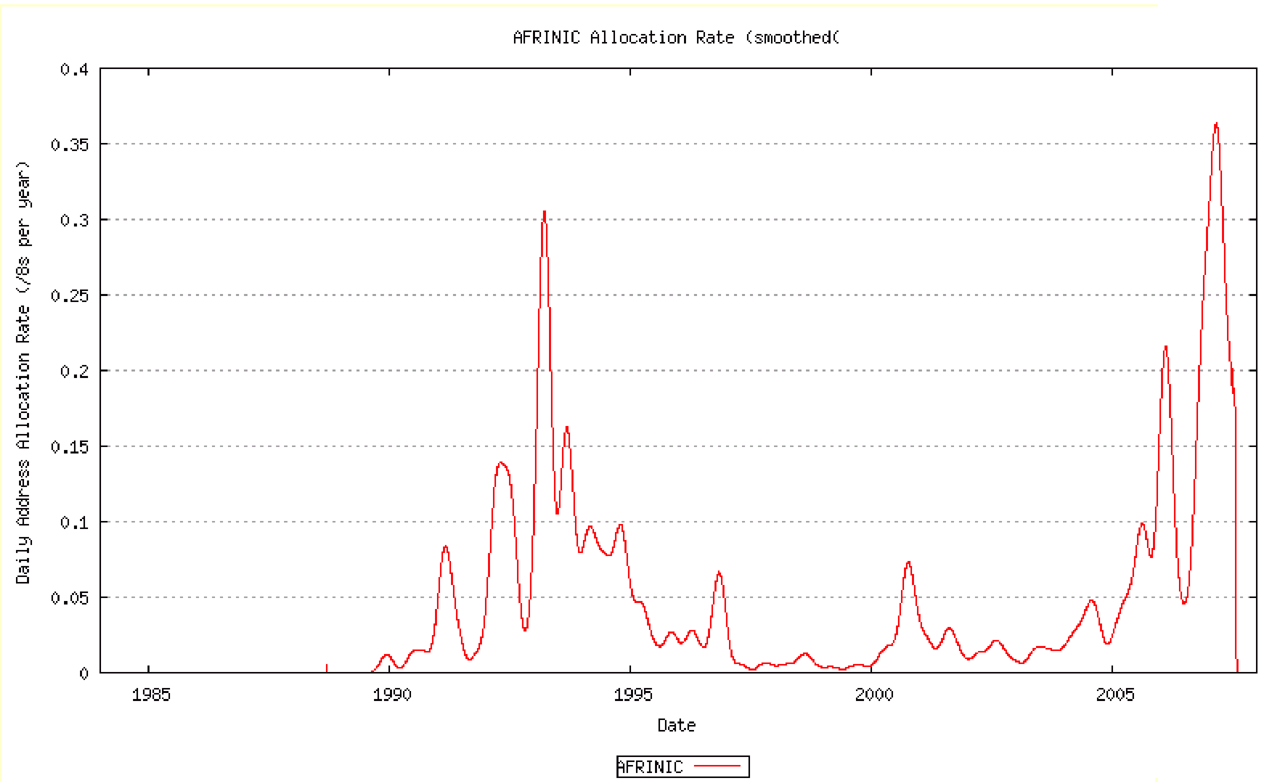

Figure 27a - AFRINIC Address Allocation Rate

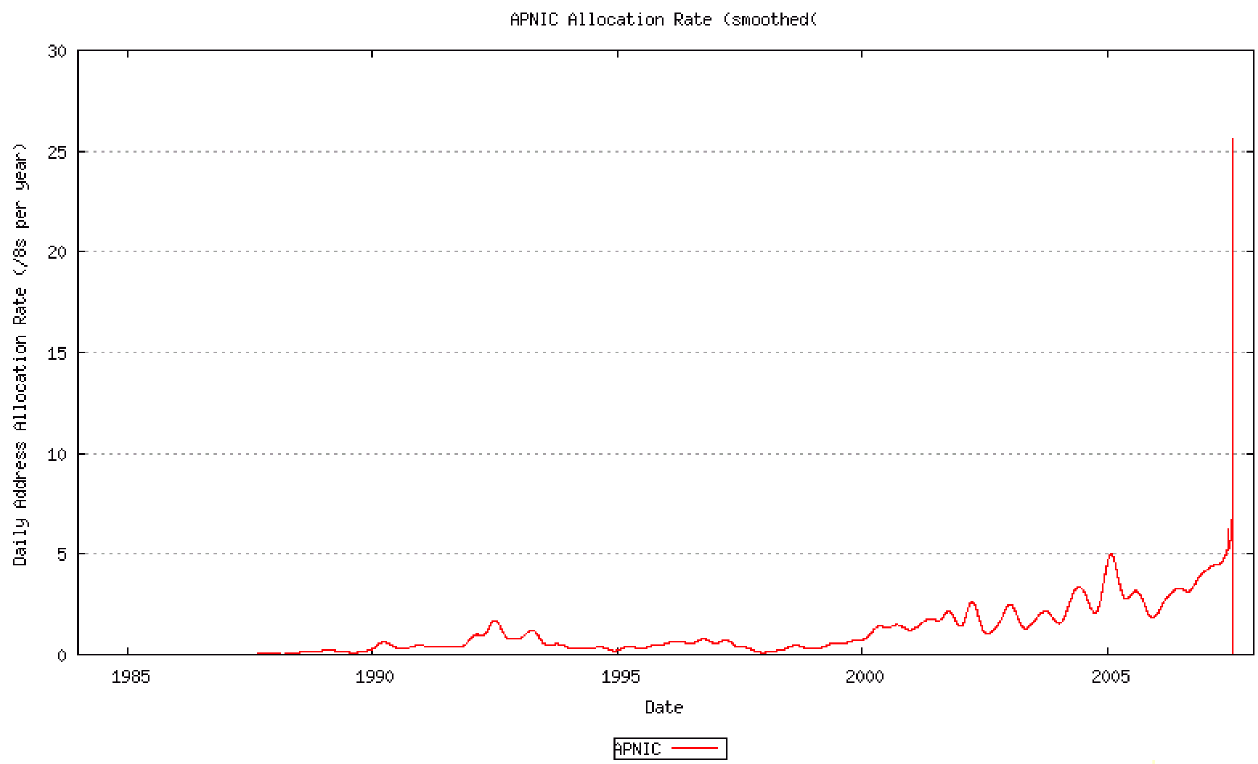

Figure 27b - APNIC Address Allocation Rate

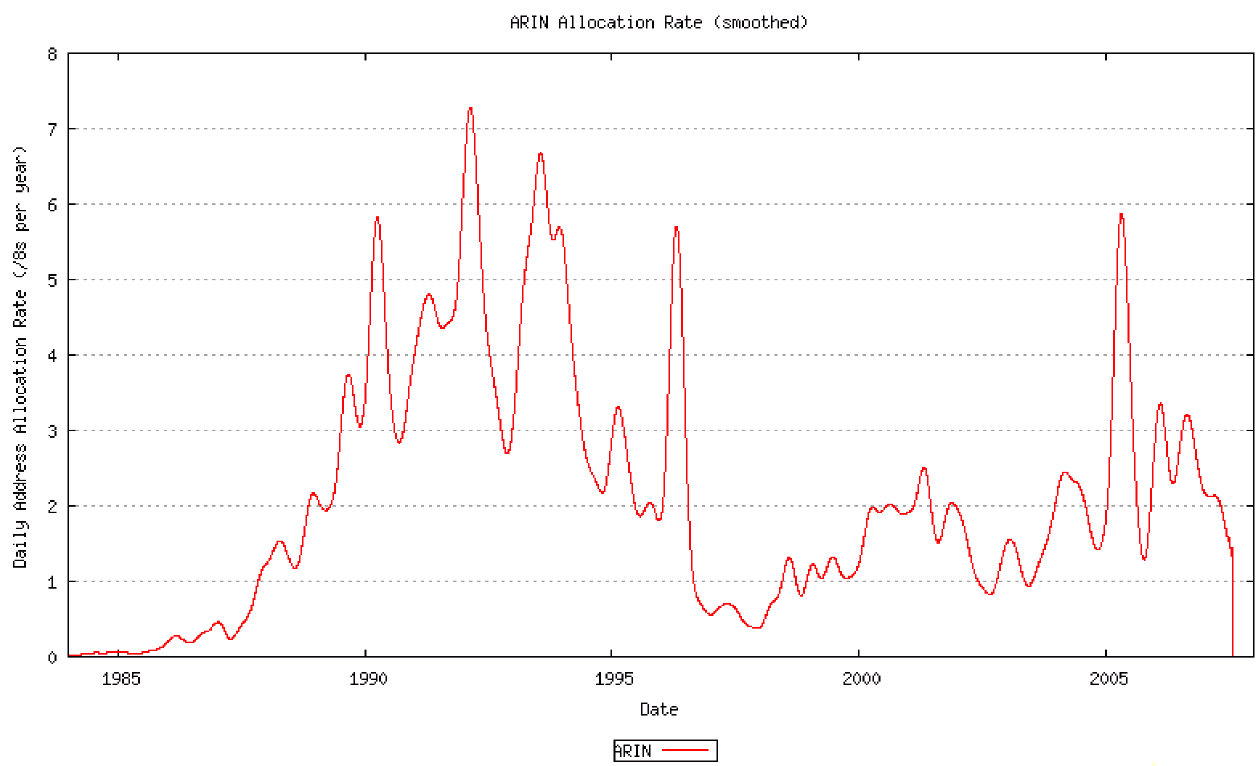

Figure 27c - ARIN Address Allocation Rate

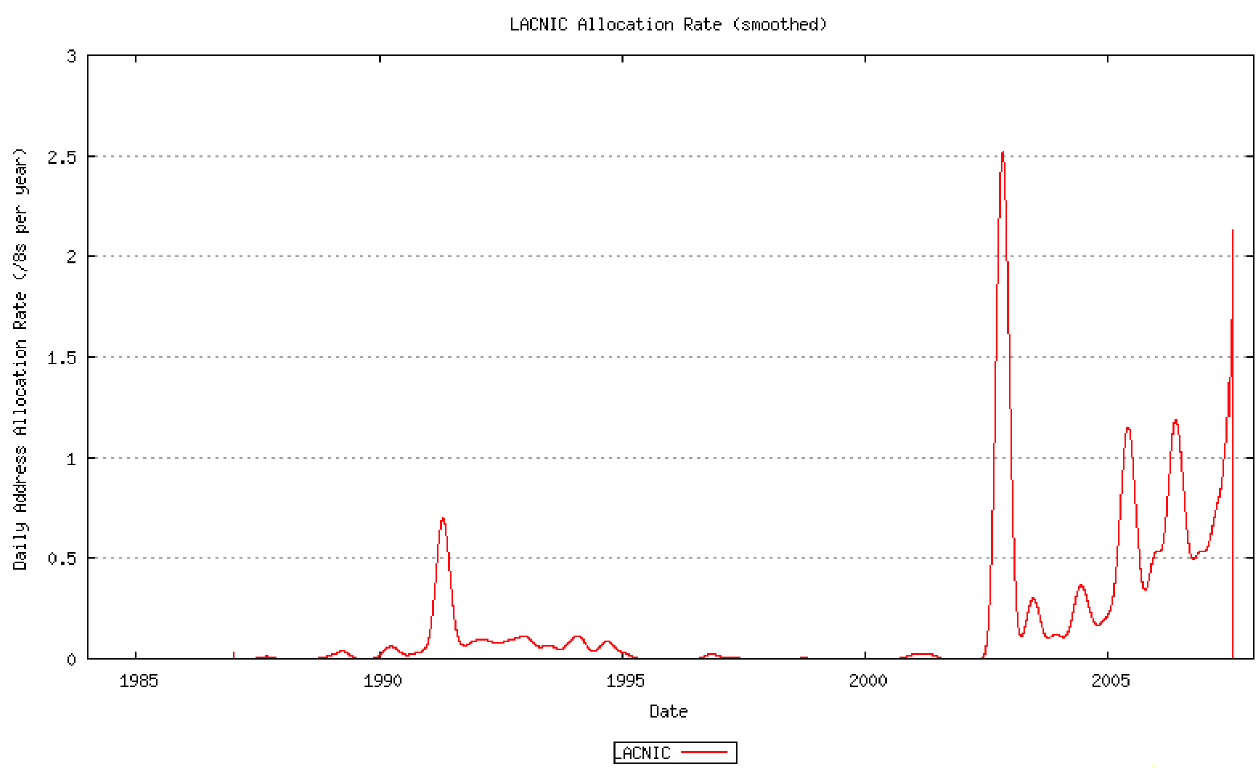

Figure 27d - LACNIC Address Allocation Rate

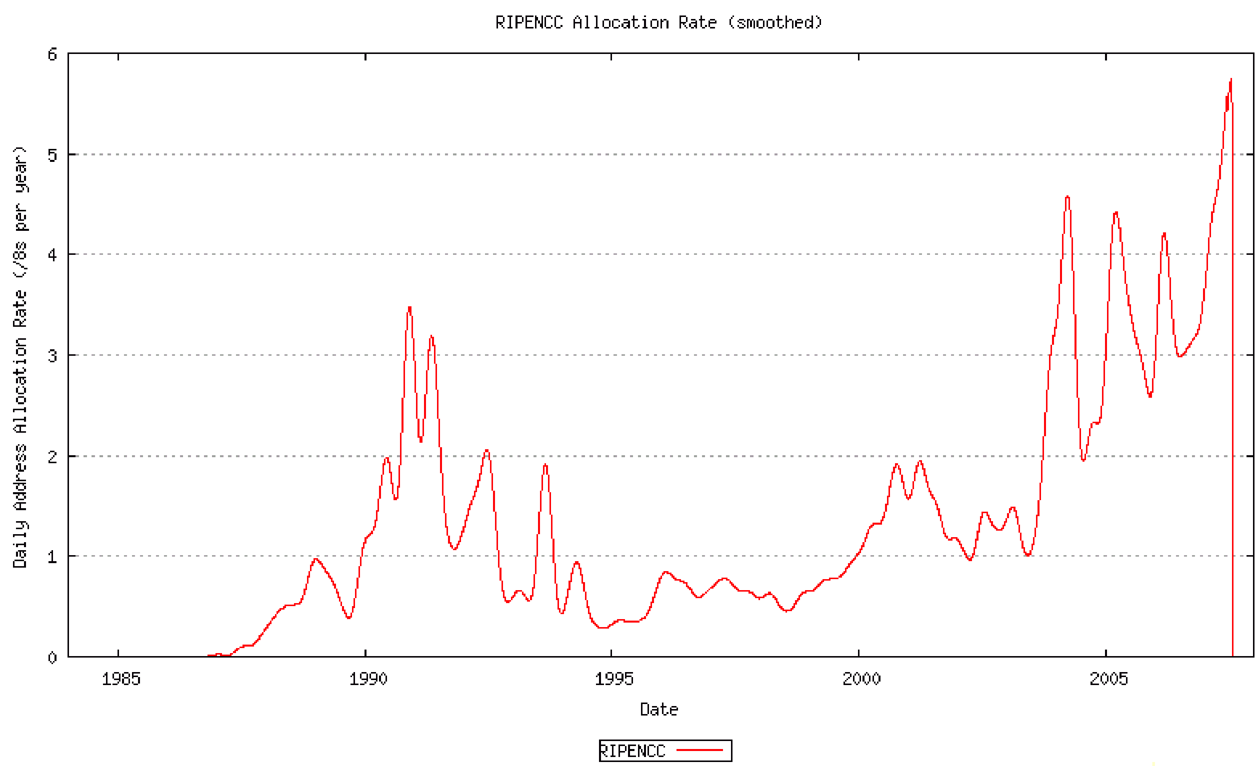

Figure 27e - RIPE NCC Address Allocation Rate

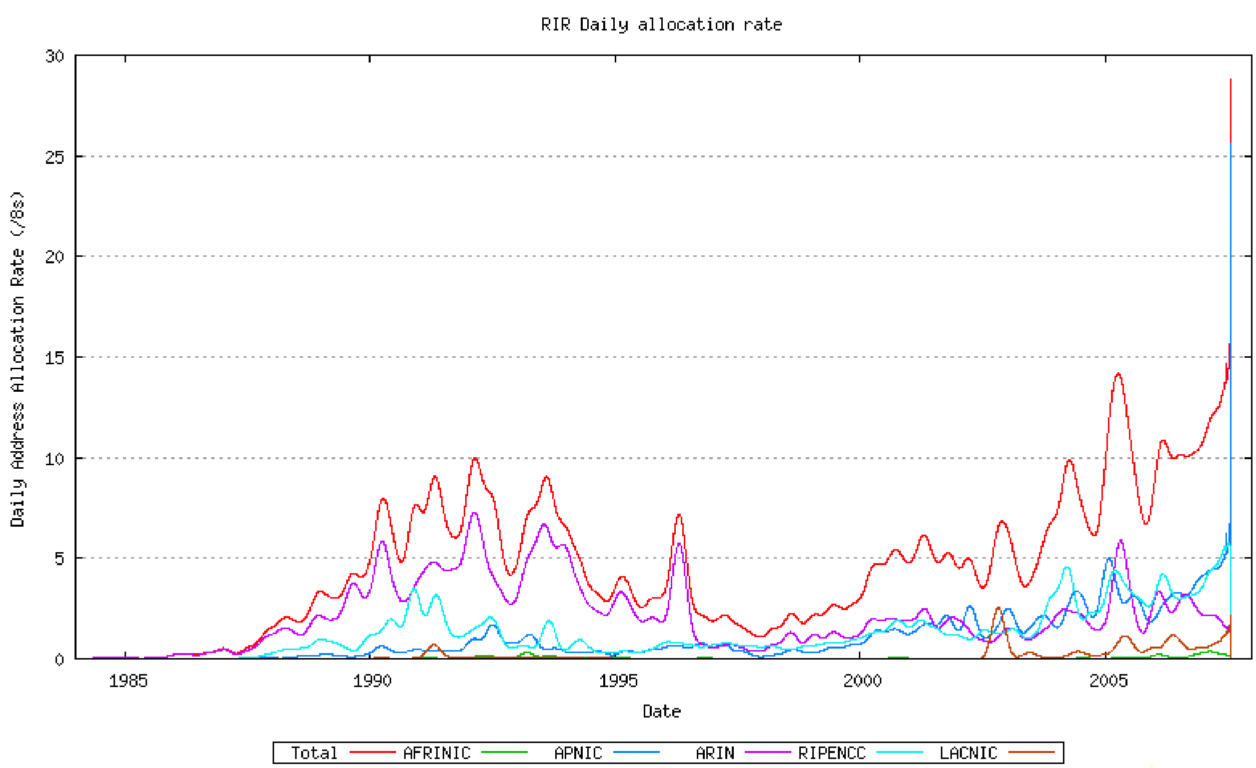

Figure 27f - Combined Address Allocation Rate

None of these allocation rate sequences, either individually for each RIR, appears to be a uniform linear rate. While there are considerable variations in this data, both historically over the extended two decade period and over the recent 3 years, it appears that some form of non-linear growth model is appropriate. The best fit model used in this exercise to model relative RIR allocation rates is that of an exponential growth model based on a linear best fit to the logarithm of the sequence data. This is shown for AFRINIC (Figure 27a), APNIC (Figure 27b) ARIN (Figure 27c), LACNIC (Figure 27d) and the RIPE NCC (Figure 27e), and the combined view (Figure 27f).

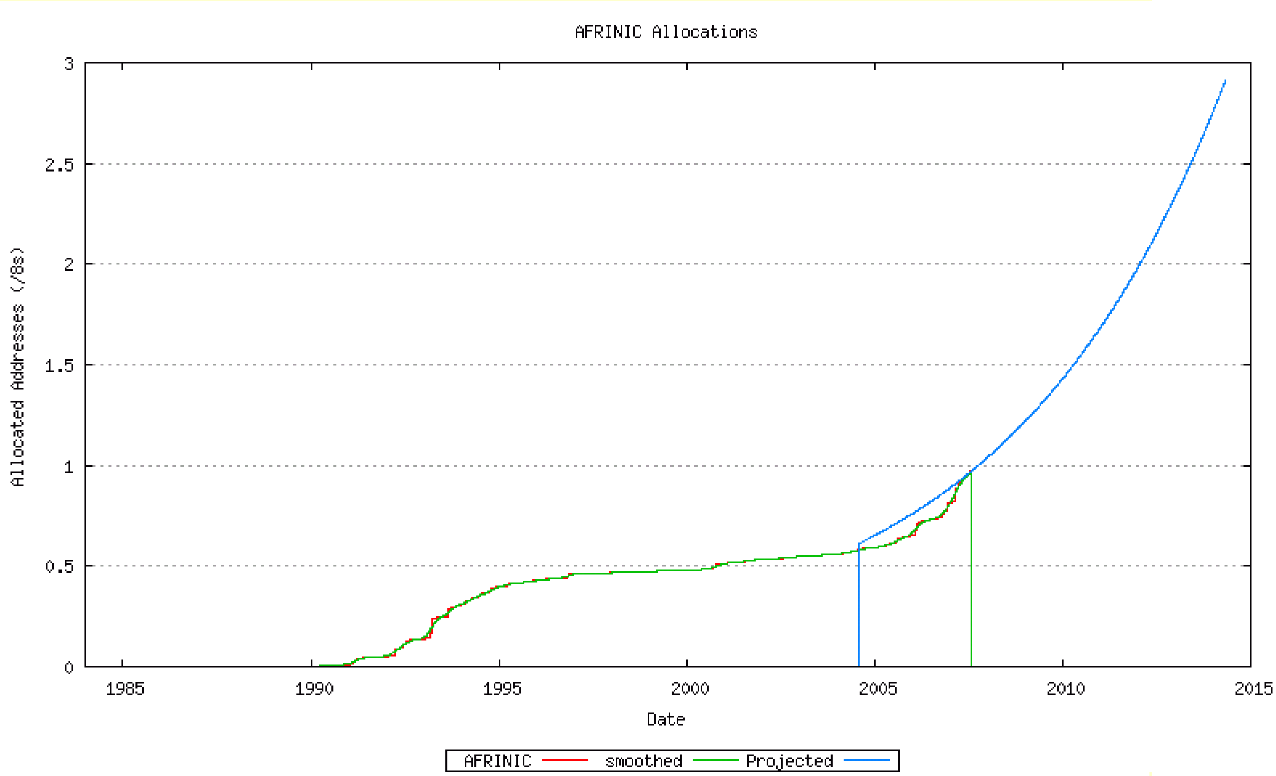

Figure 27g - AFRINIC Address Allocations

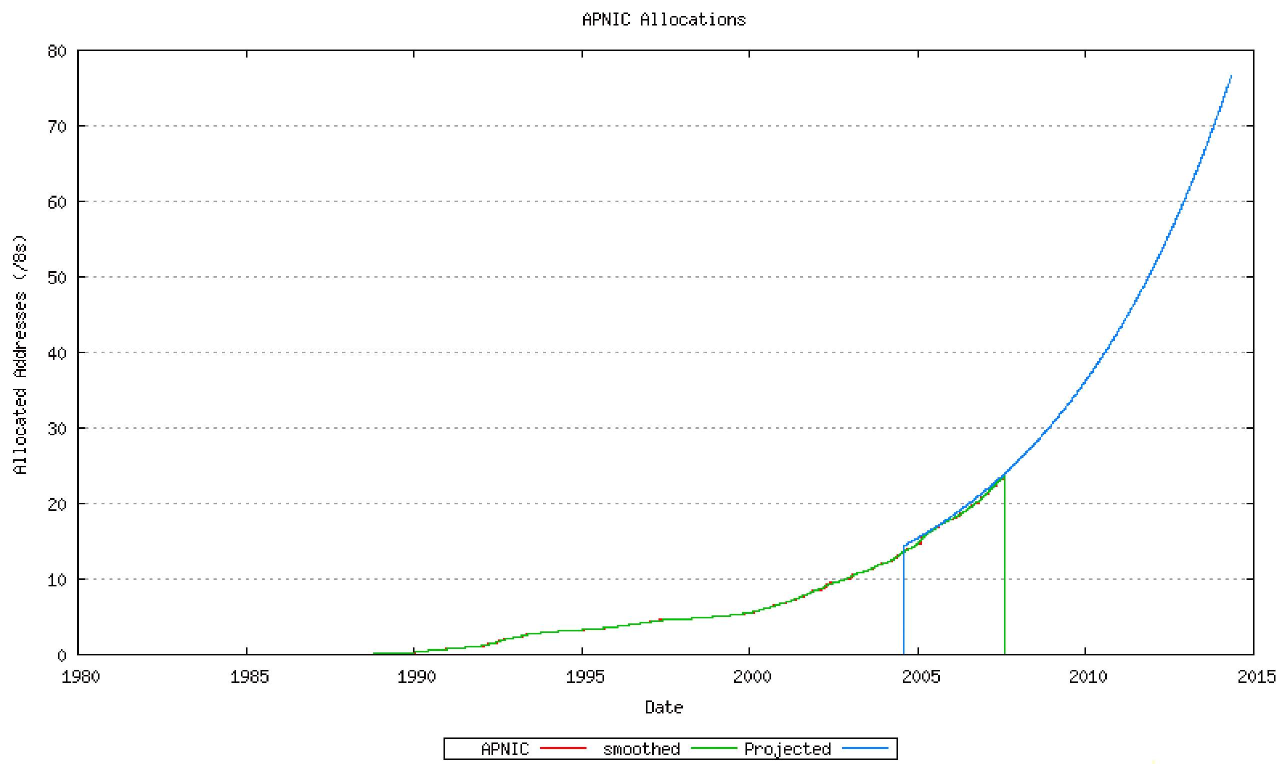

Figure 27h - APNIC Address Allocations

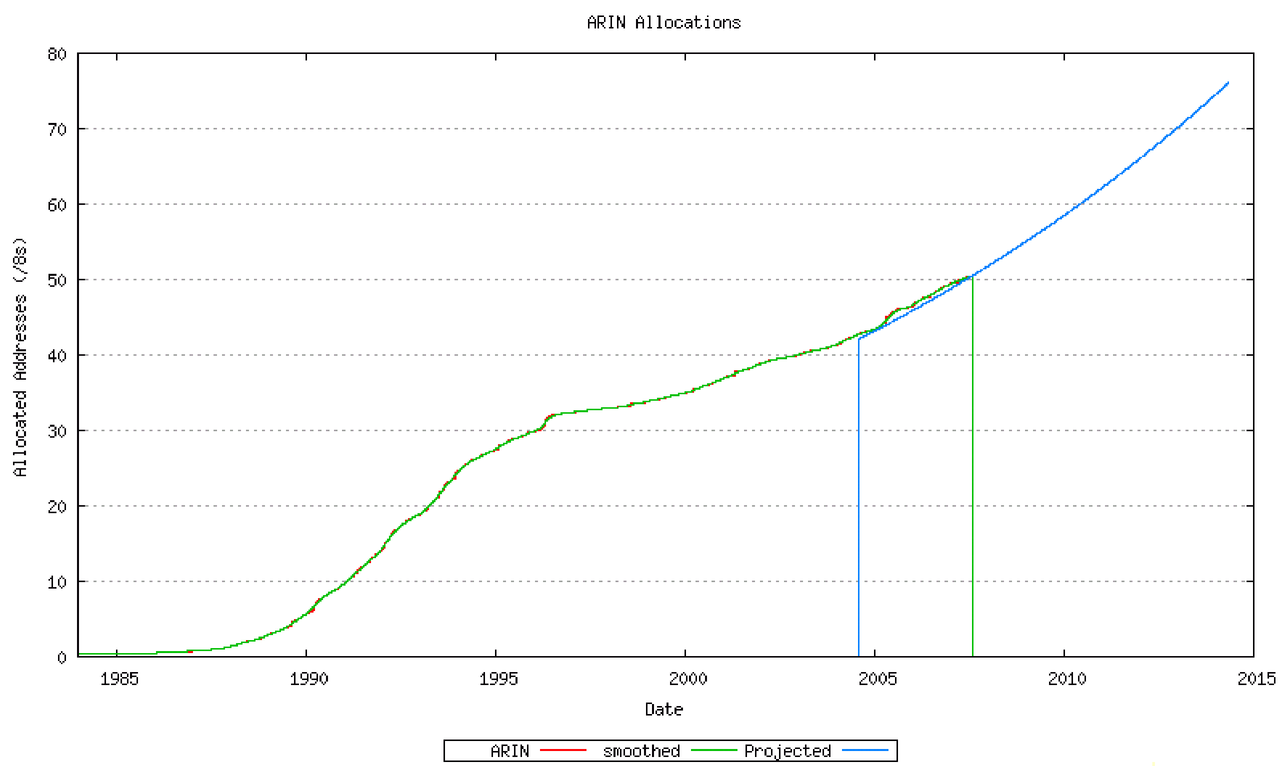

Figure 27i - ARIN Address Allocations

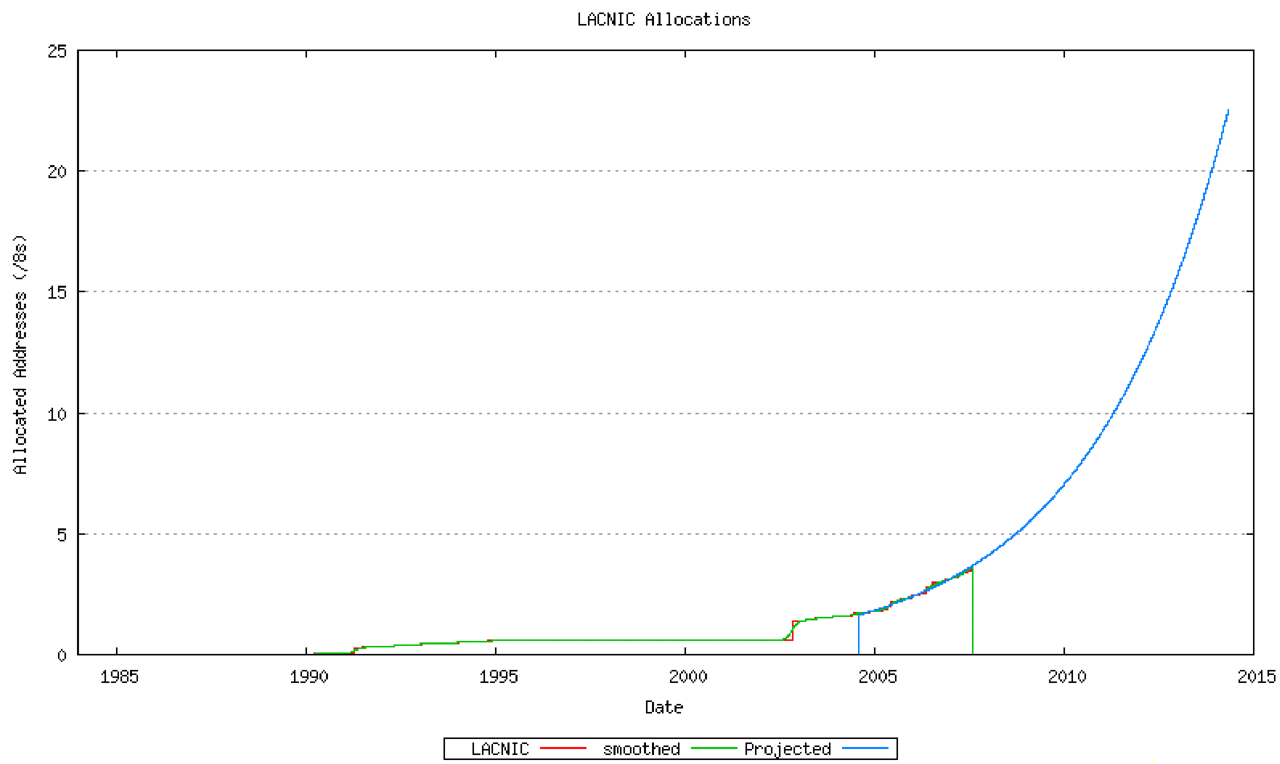

Figure 27j - LACNIC Address Allocations

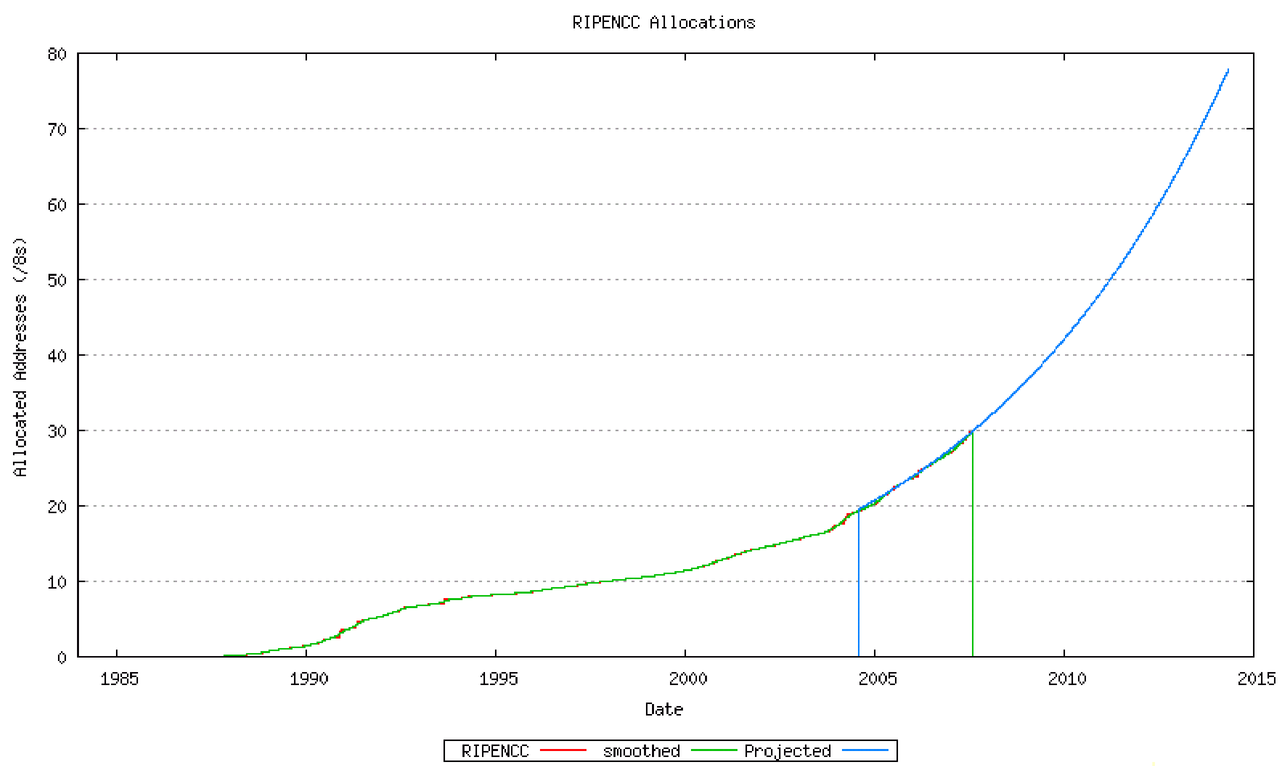

Figure 27k - RIPE NCC Address Allocations

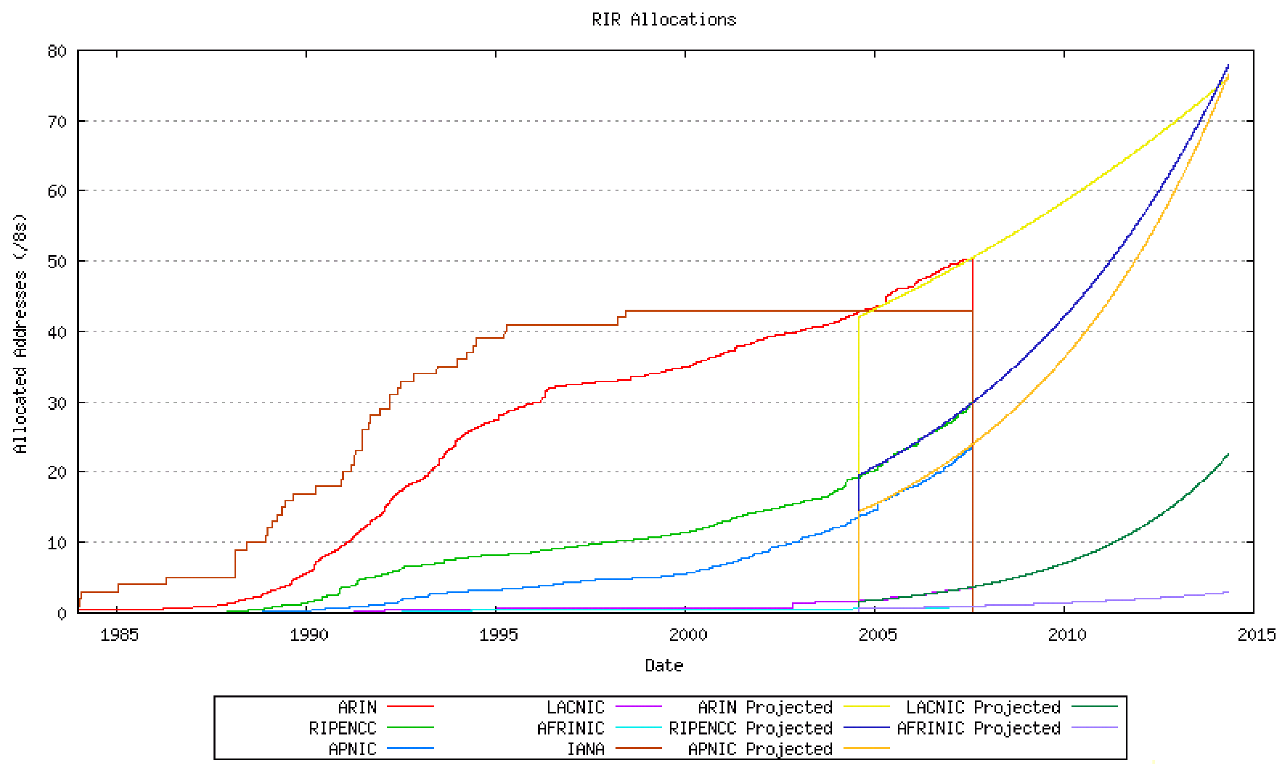

Figure 27l - Combined Address Allocations

The slope of these projections can be compared to each other, and a relative allocation proportion can be derived for each RIR. From this is it now possible to divide up the total address demand from the growth in advertised and unadvertised address pools across each RIR, and apportion this to each RIR according to the relative allocation rates shown in Figure 28. In other words, if a certain address span was allocated by the RIRs in a given month then how much of that span would be allocated by AFRINIC, APNIC, etc?. The relative allocation rates are shown for all the RIRs in Figure 28, and for AFRINIC (Figure 28a), APNIC (Figure 28b) ARIN (Figure 28c), LACNIC (Figure 28d) and the RIPE NCC (Figure 28e)

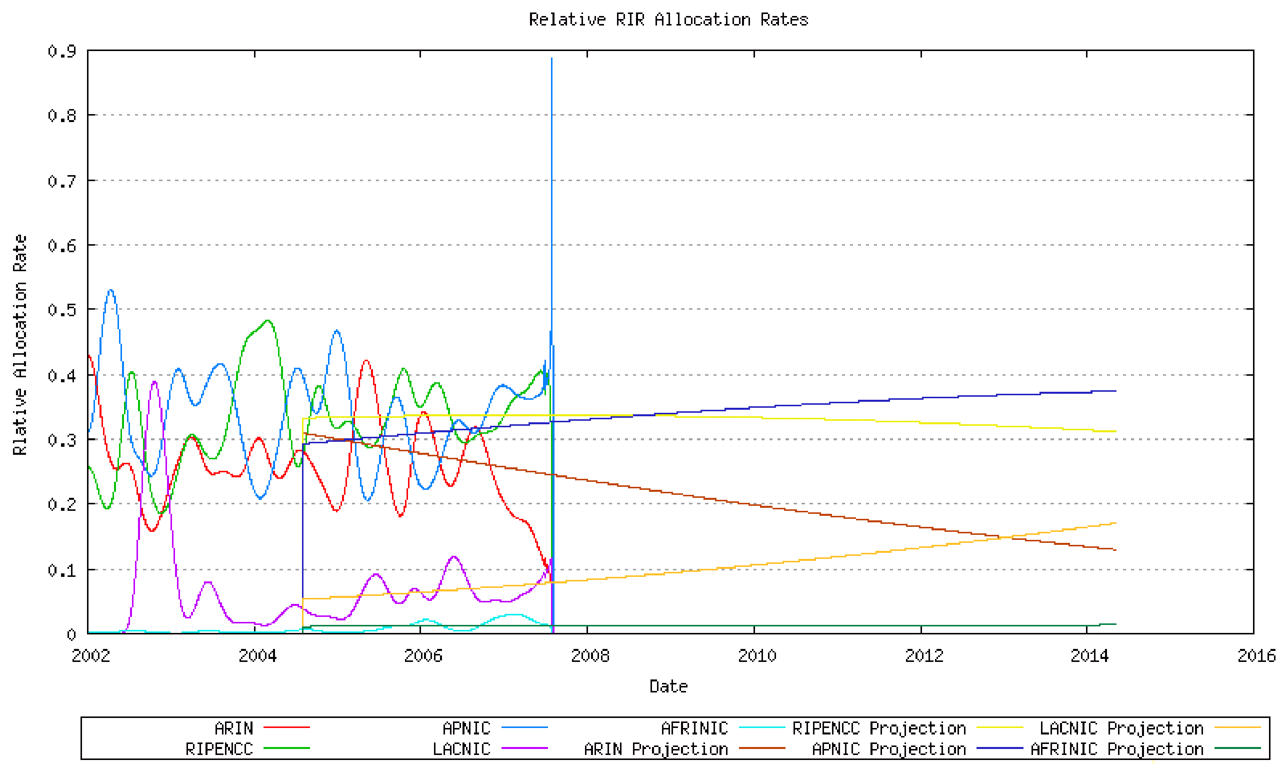

Figure 28 - Relative RIR Allocation rates

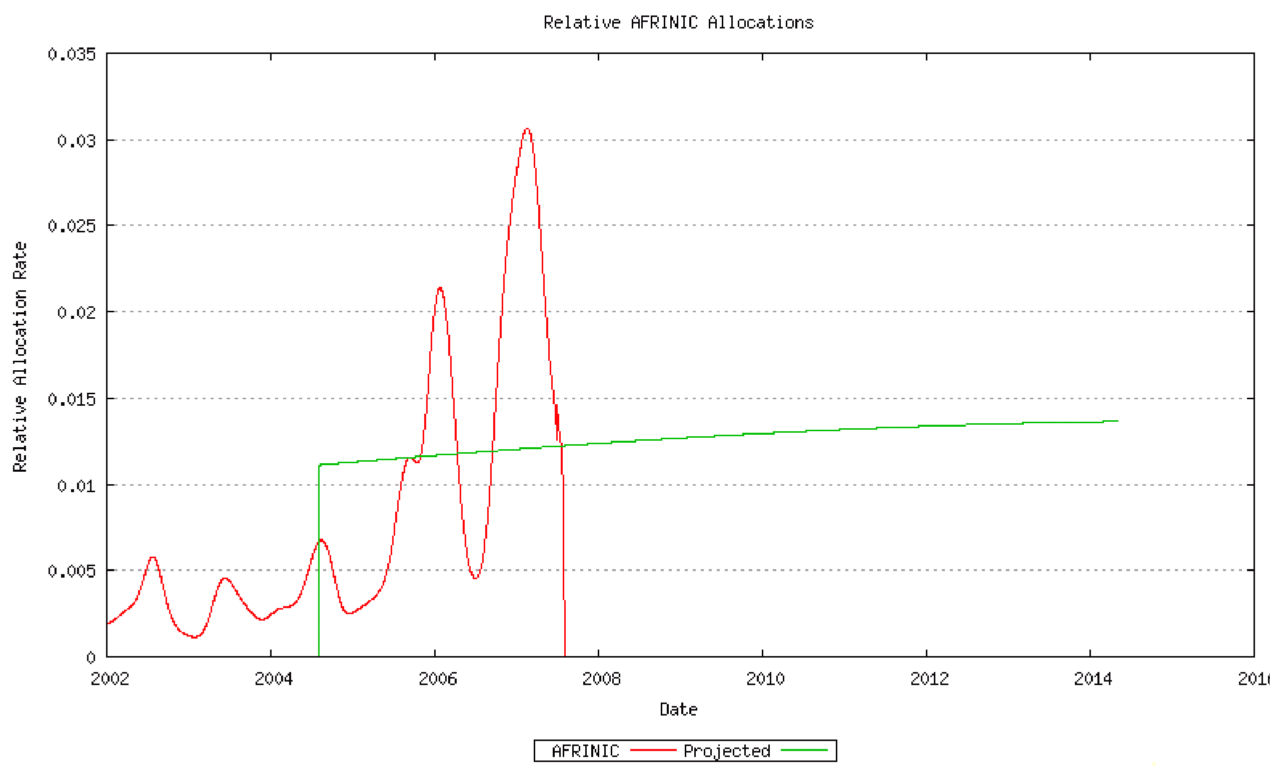

Figure 28a - AFRINIC Relative Address Allocation Rate

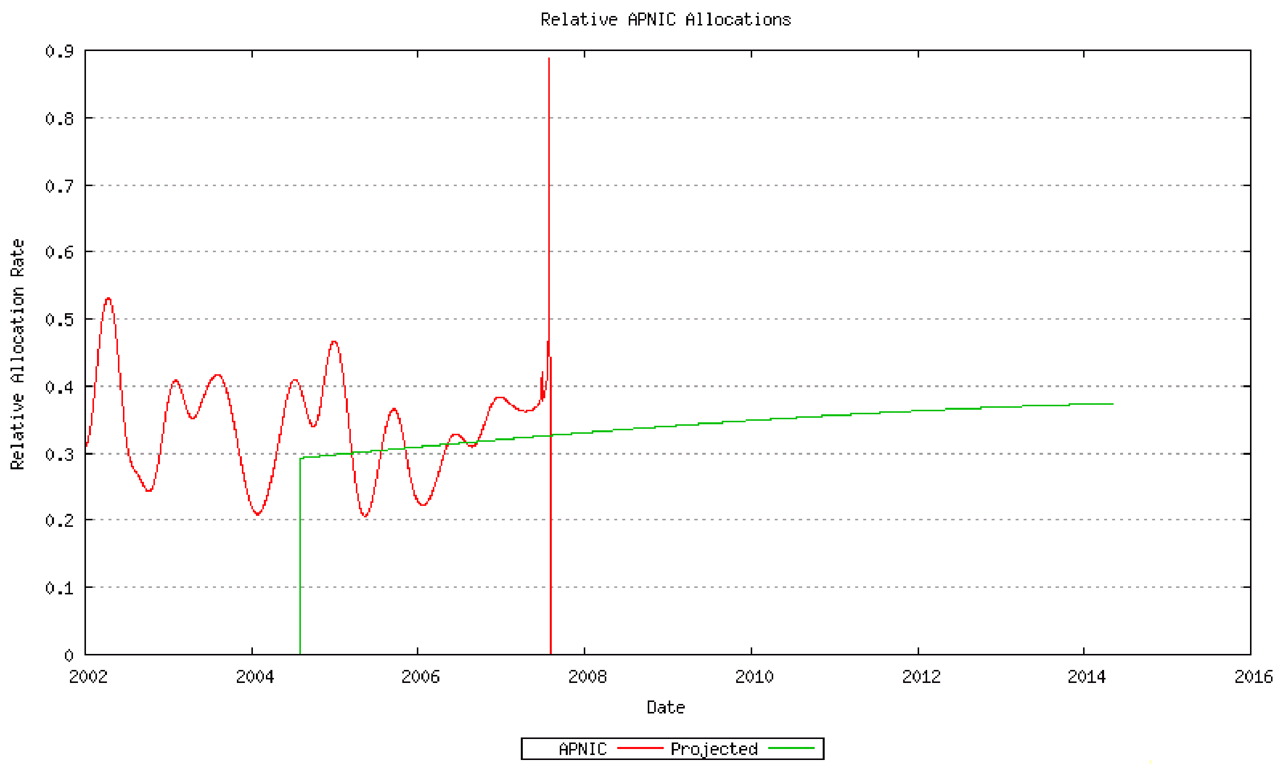

Figure 28b - APNIC Relative Address Allocation Rate

Figure 28c - ARIN Relative Address Allocation Rate

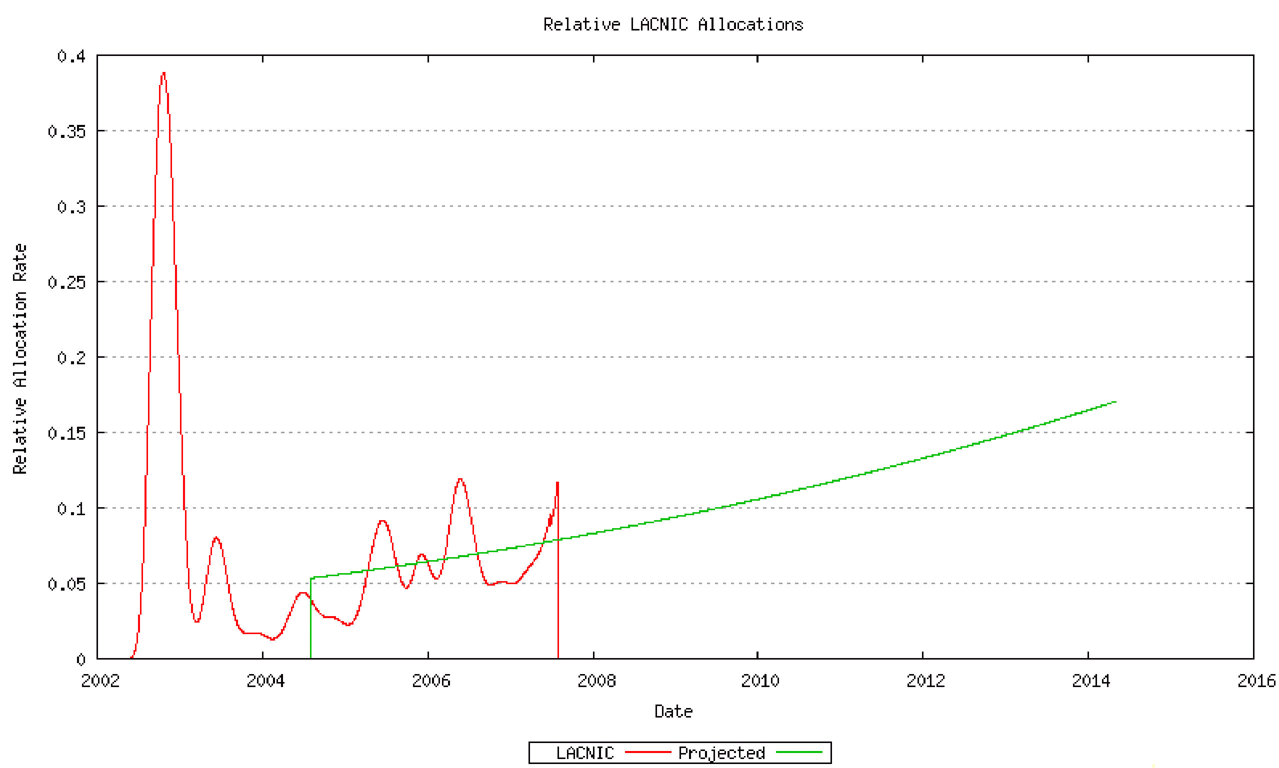

Figure 28d - LACNIC Relative Address Allocation Rate

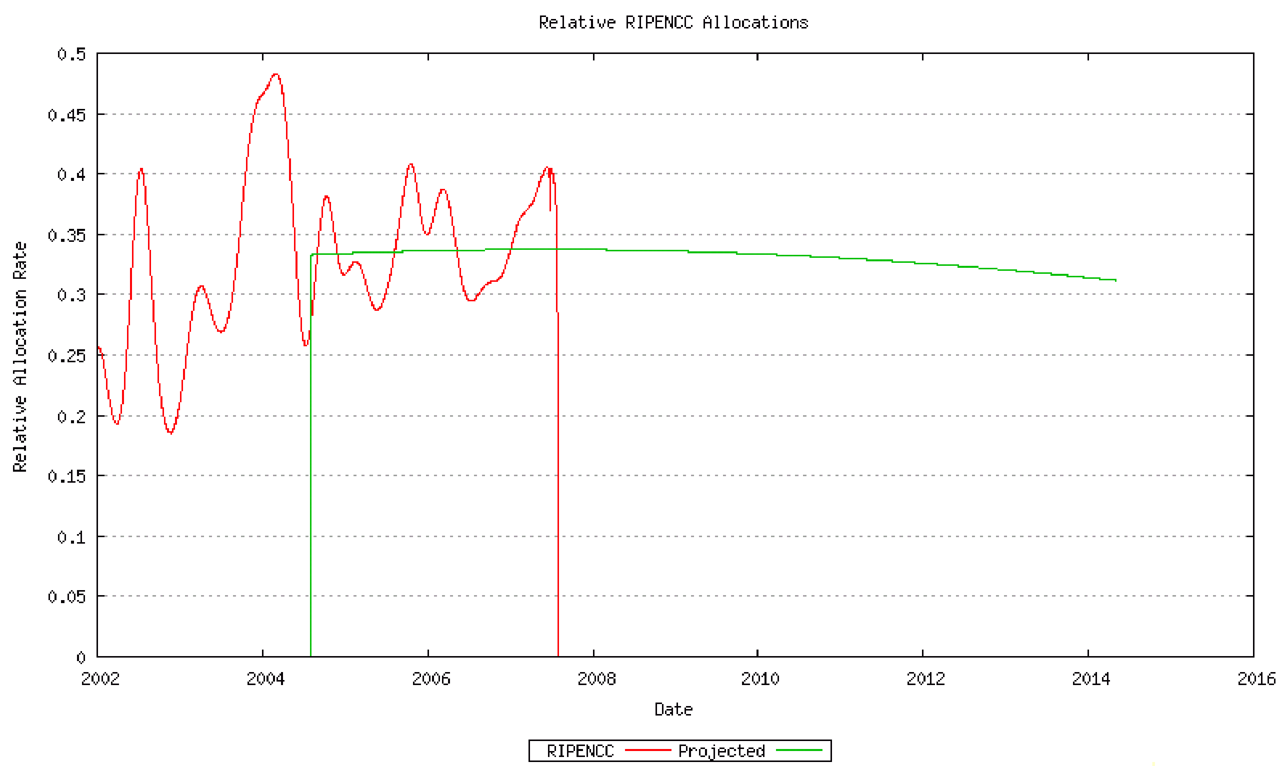

Figure 28e - RIPE NCC Relative Address Allocation Rate

By looking at historical data is also possible to model for each RIR a "low threshold" point for the RIR's unallocated address pool. When the RIR's unallocated address pool falls to this level it will request a further allocation of address blocks from IANA. The amount requested in this model is the lesser of 3 /8 address blocks and the cumulative sum of the RIR's address allocations over the previous 18 months. The model also assumes that the remainder of the address pool currently marked by the IANA as "Various" will not be used for further allocations until the IANA unallocated pool is exhausted. This overall model is indicated in Figure 29. This is also shown for

AFRINIC (Figure 29a), APNIC (Figure 29b) ARIN (Figure 29c), LACNIC (Figure 29d), the RIPE NCC (Figure 29e), and the "Various" address pool (Figure 29f).

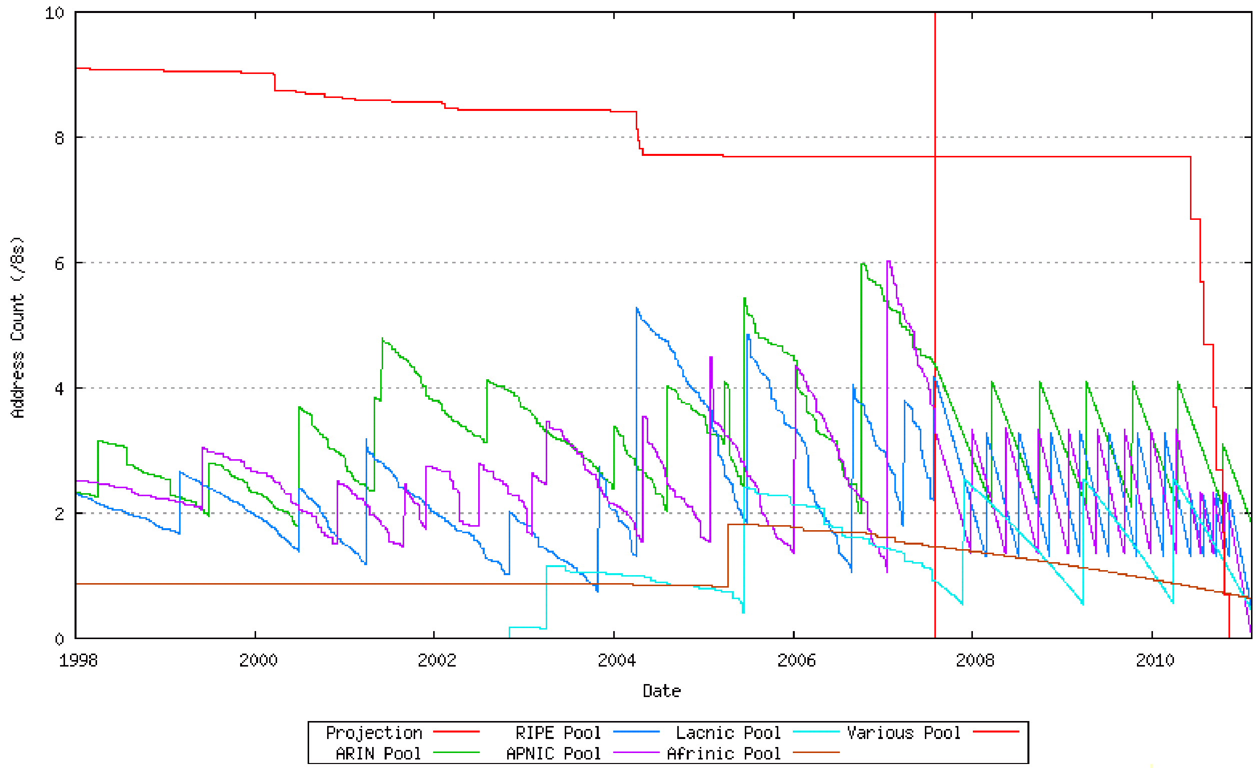

Figure 29 - Projected Address Allocations

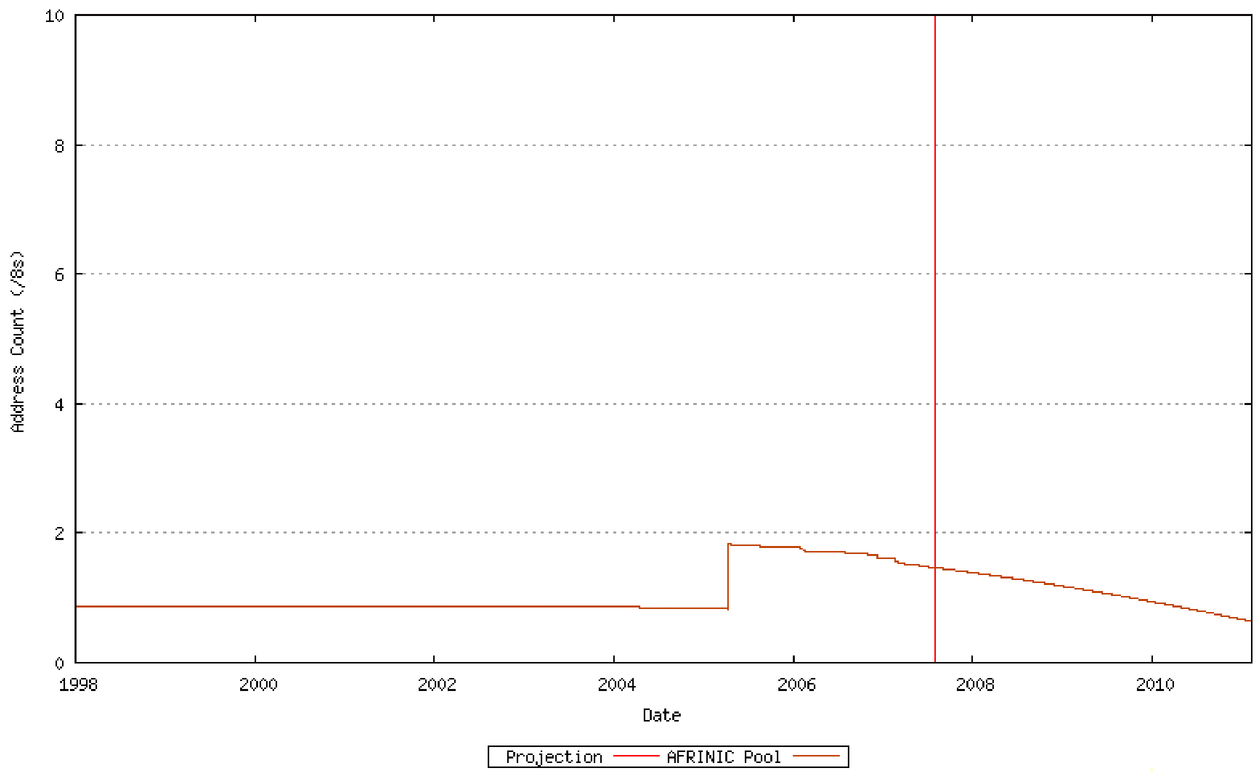

Figure 29a - AFRINIC Projected Address Allocations

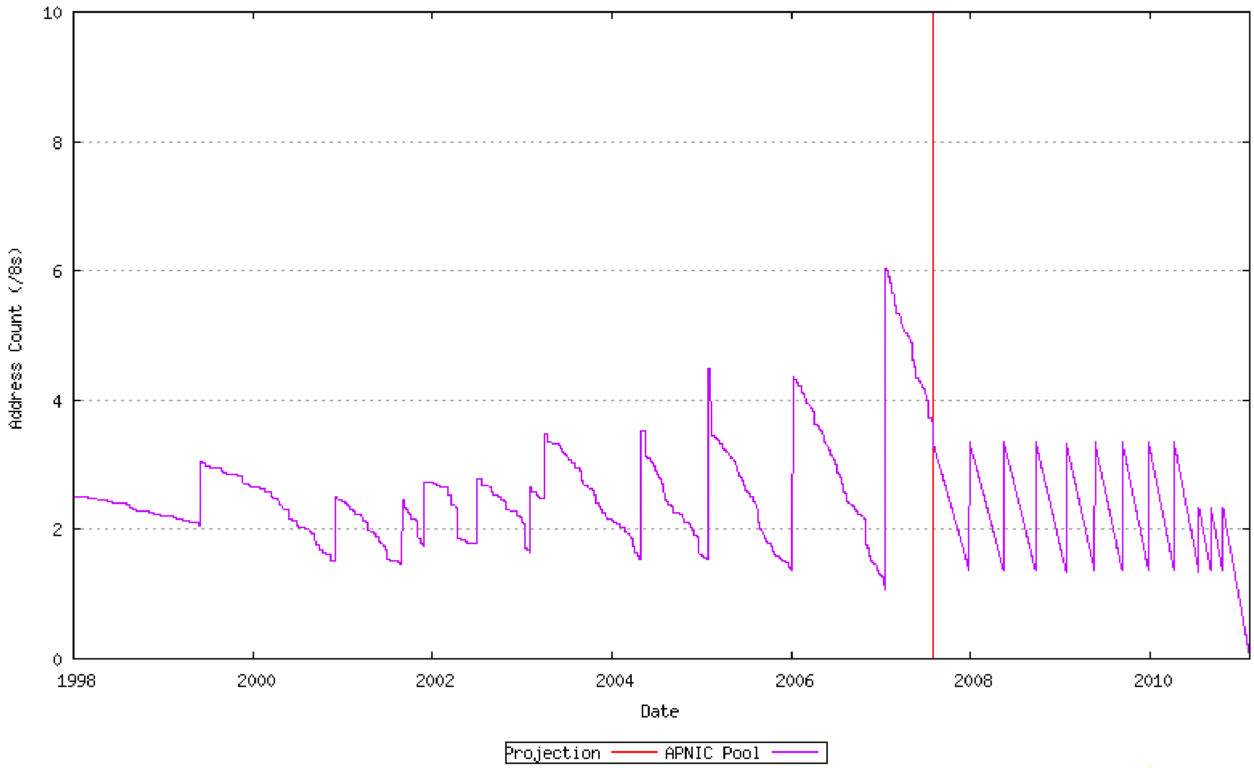

Figure 29b - APNIC Projected Address Allocations

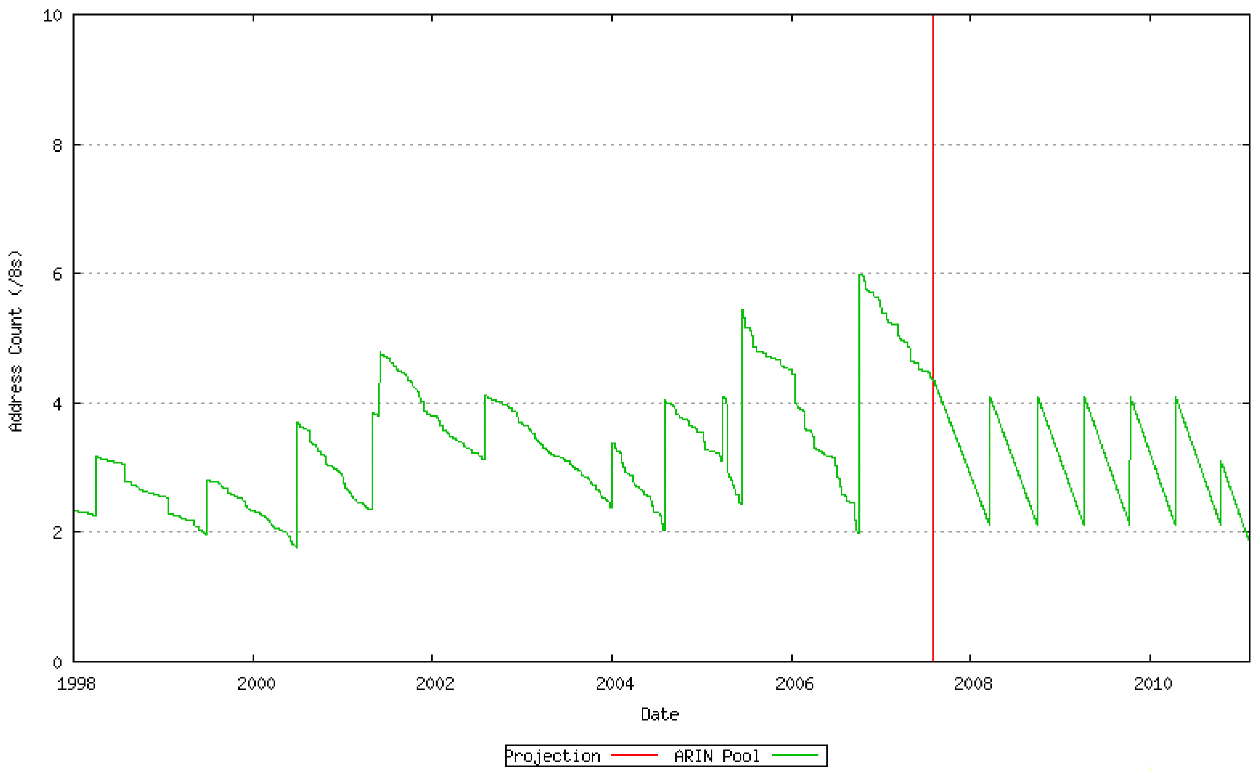

Figure 29c - ARIN Projected Address Allocations

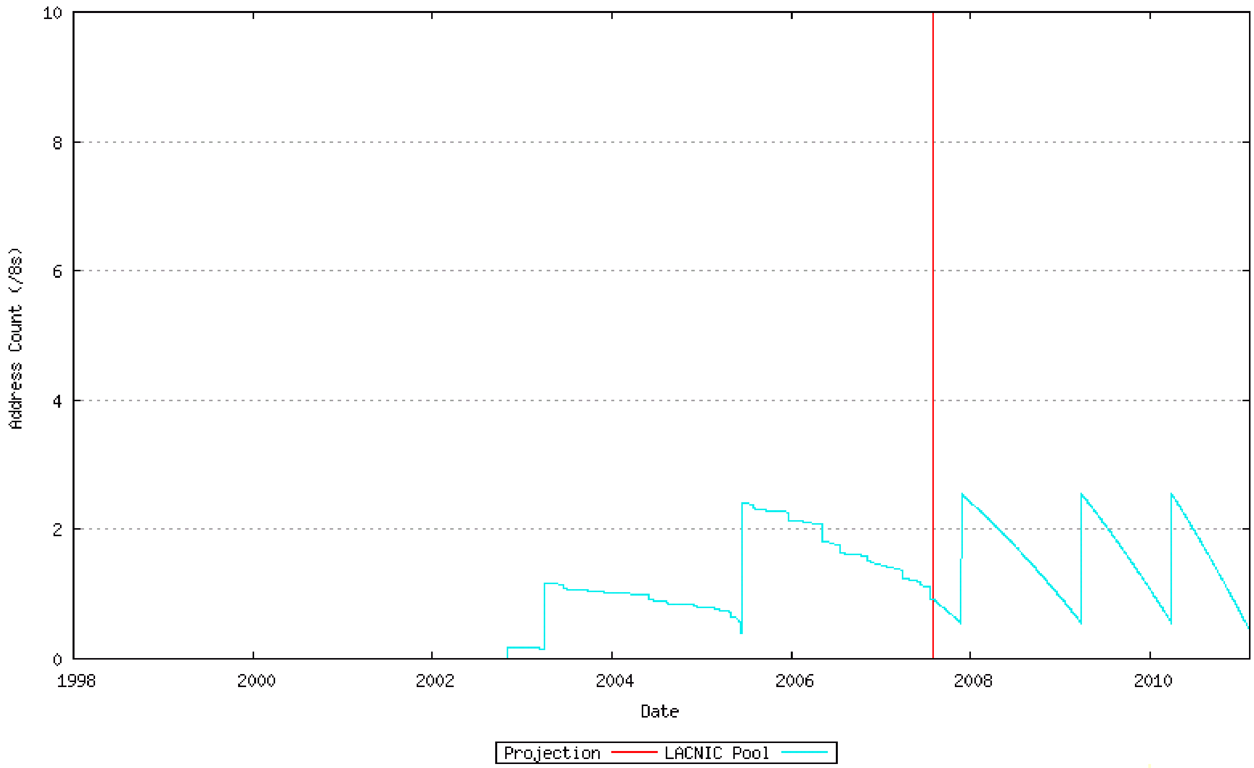

Figure 29d - LACNIC Projected Address Allocations

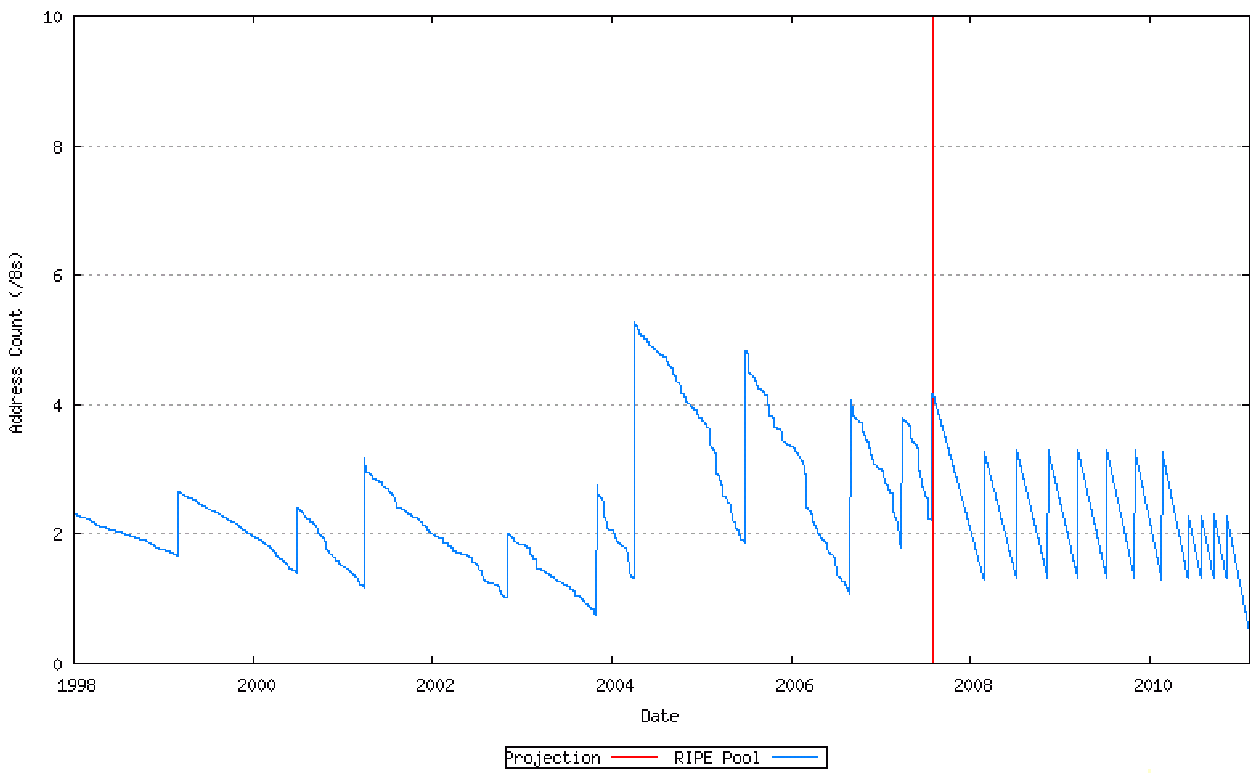

Figure 27e - RIPE NCC Projected Address Allocations

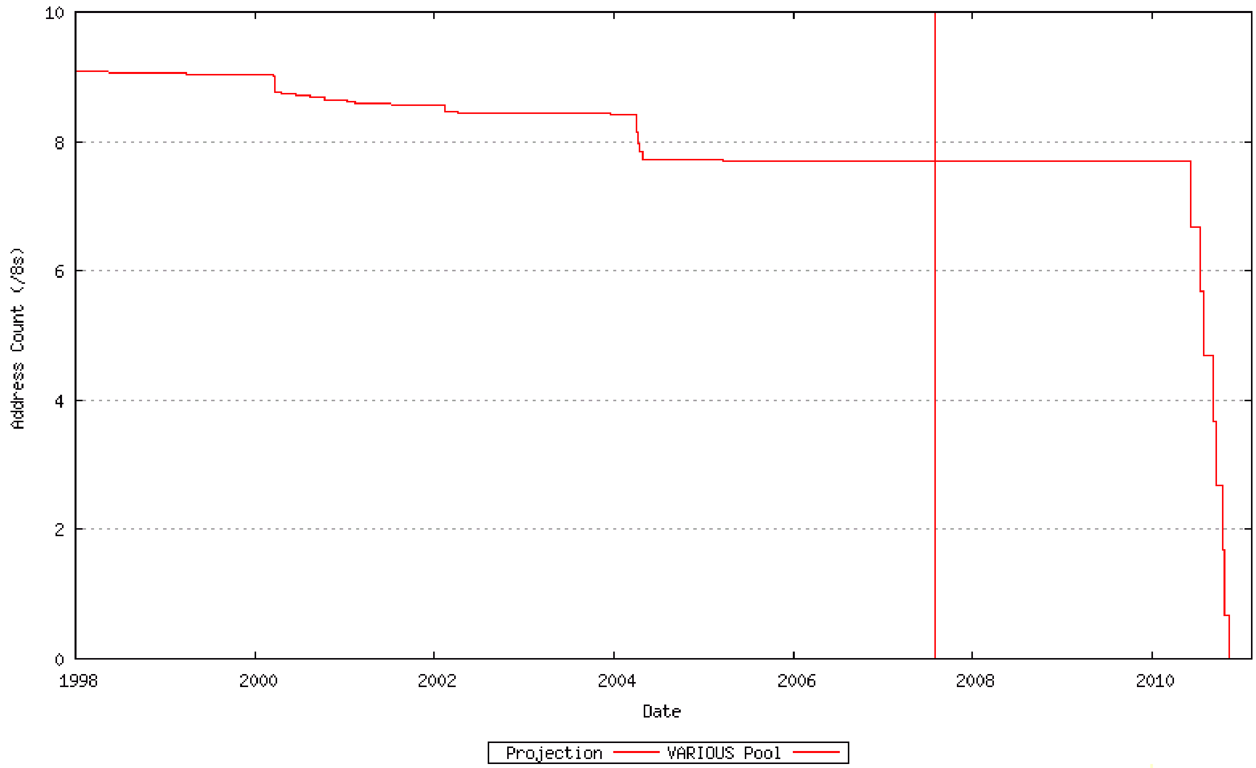

Figure 29f - VARIOUS Pool - Projected Address Allocations

These individual RIR pool behaviours can be summed, as shown in Figure 29g. Each upward movement in the RIR Pool series represents an IANA allocation to one of the RIRs, while the downward movement represents the cumulative address allocation rate across the RIR system.

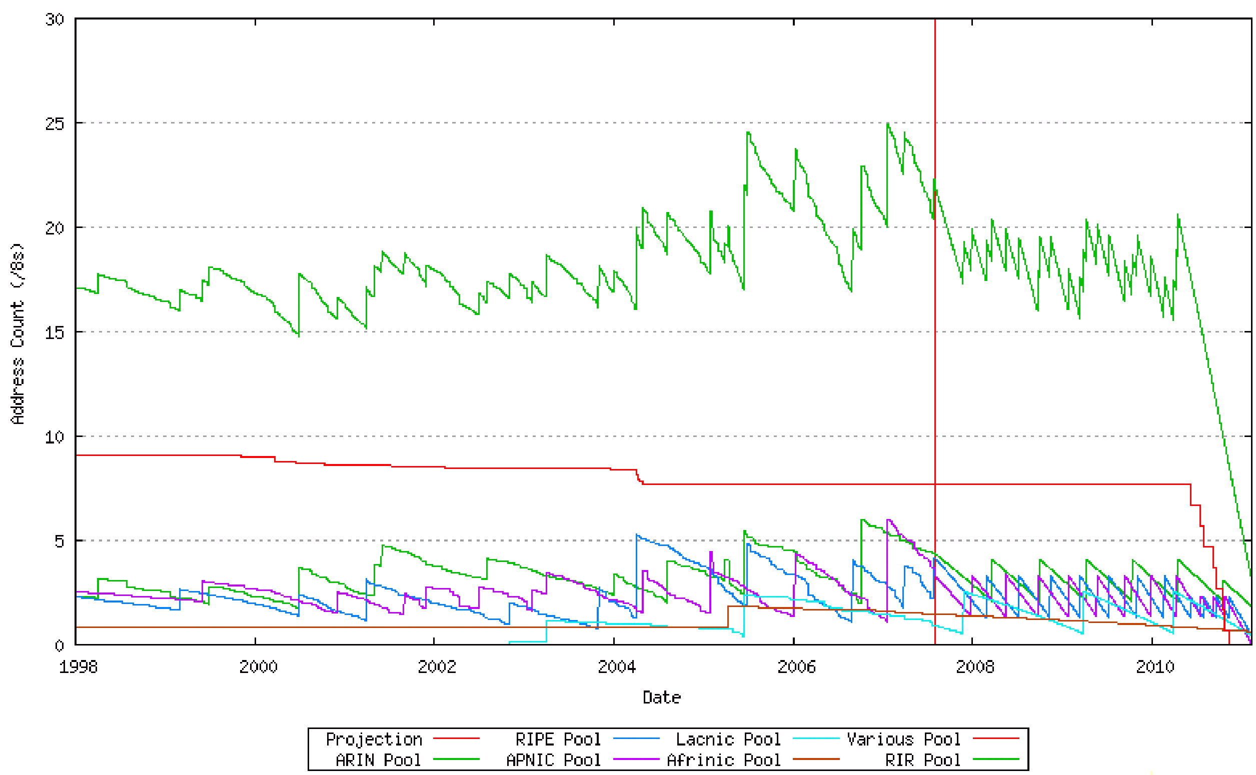

Figure 29g - Projected Address Allocations

The Address Consumption Model

It is now possible to put the components together into a complete model.

The first is the projection of the advertised address span, which uses a second order polynomial (quadratic) growth model. This is shown in Figure 30a.

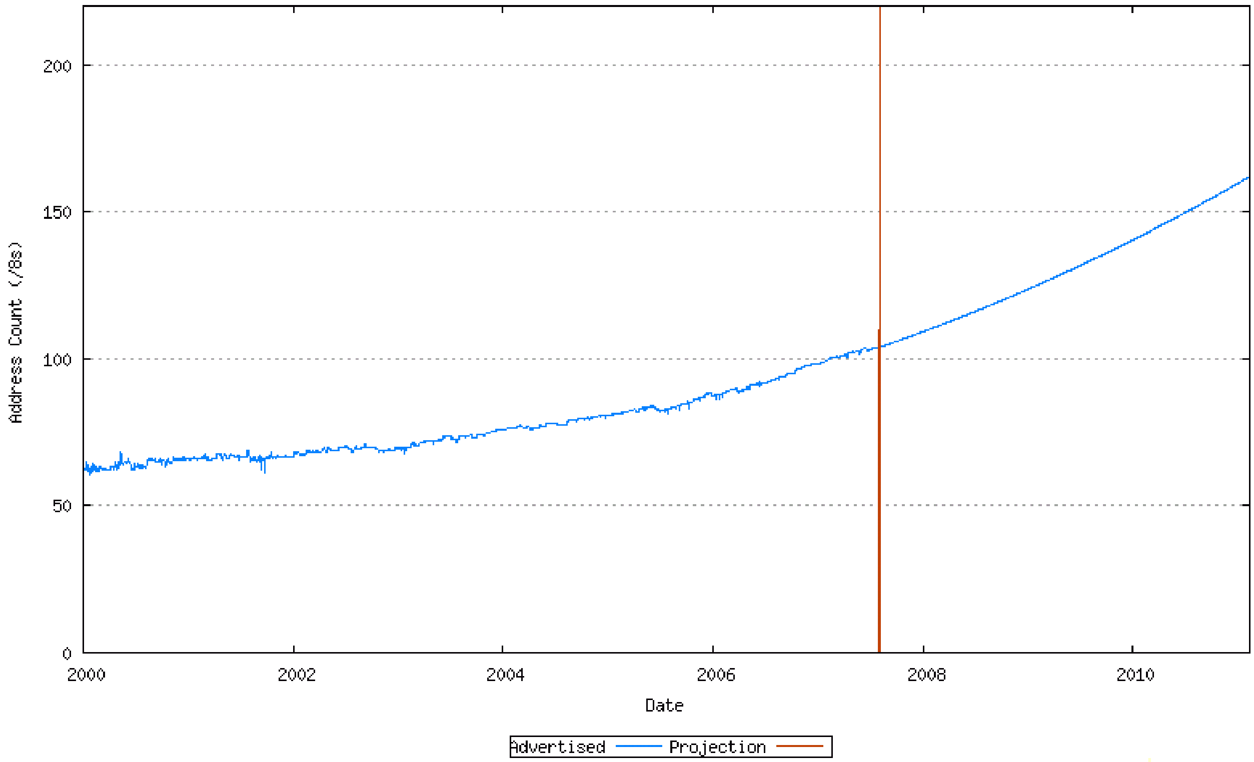

Figure 30a - Projected Advertised Address Span (/8s)

To this can be added the projected unadvertised address span, which is modelled as a slower second order polynomial growth series. This is shown in Figure 30b.

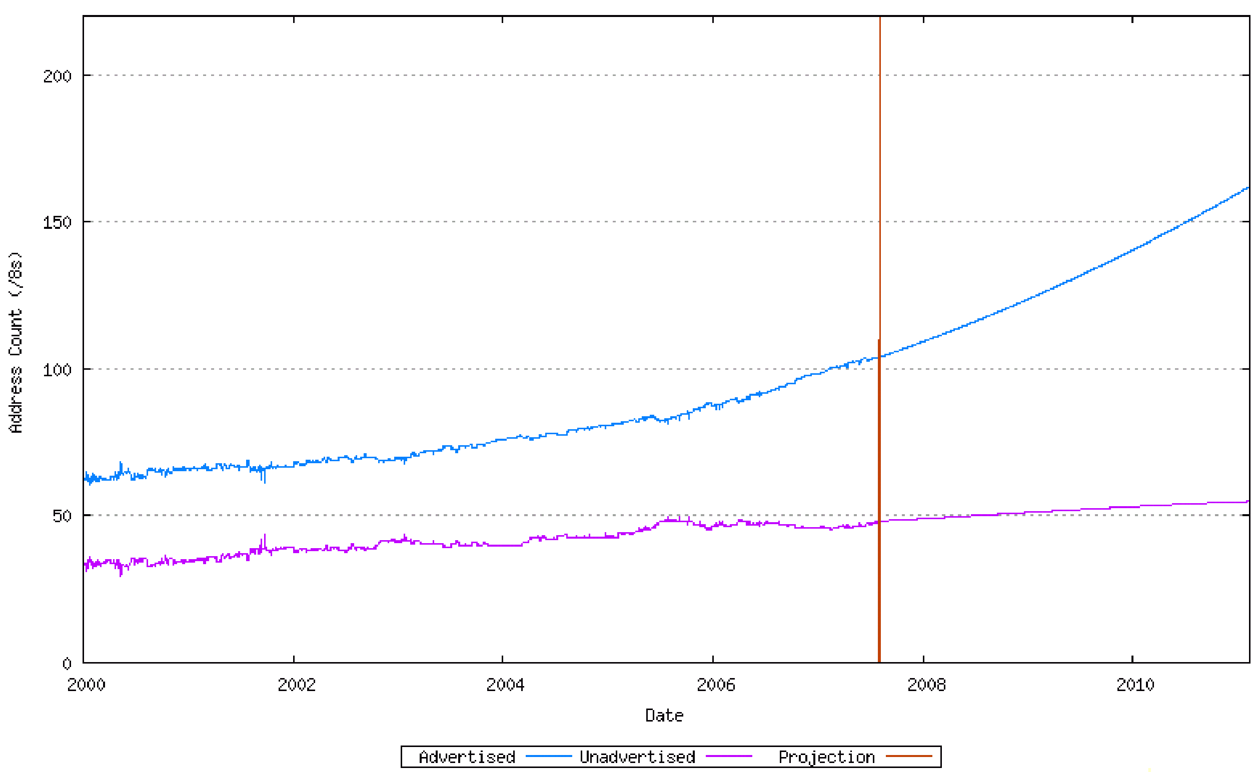

Figure 30b - Projected Advertised and Unadvertised Address Span (/8s)

The total address demand is the sum of these two address pools. This is shown in Figure 30c

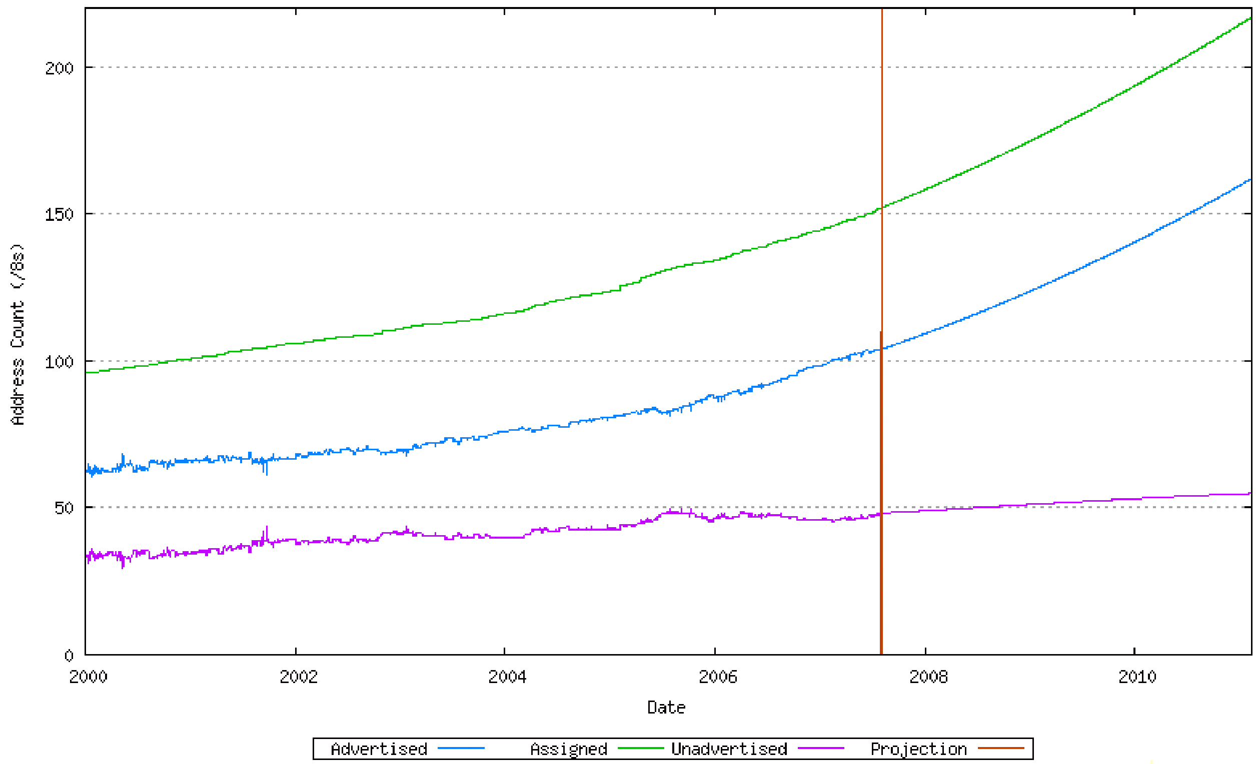

Figure 30c - Projected Address Consumption (/8s)

The RIR behavior to meet this demand rate can be added to this model, together with the demands on the IANA unallocated address pool, as shown in Figure 30d.

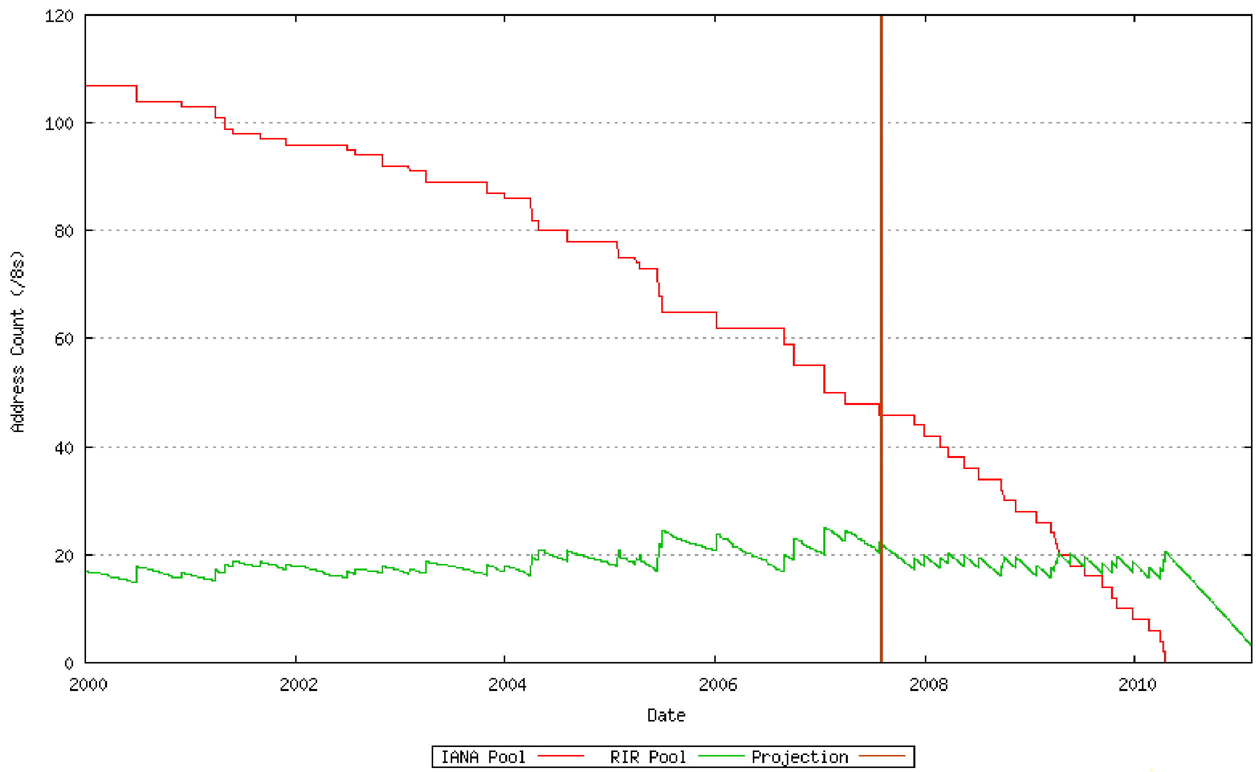

Figure 30d - Projected RIR and IANA Consumption (/8s)

These components can be combined to create an overall model of address consumption, as shown in Figure 30.

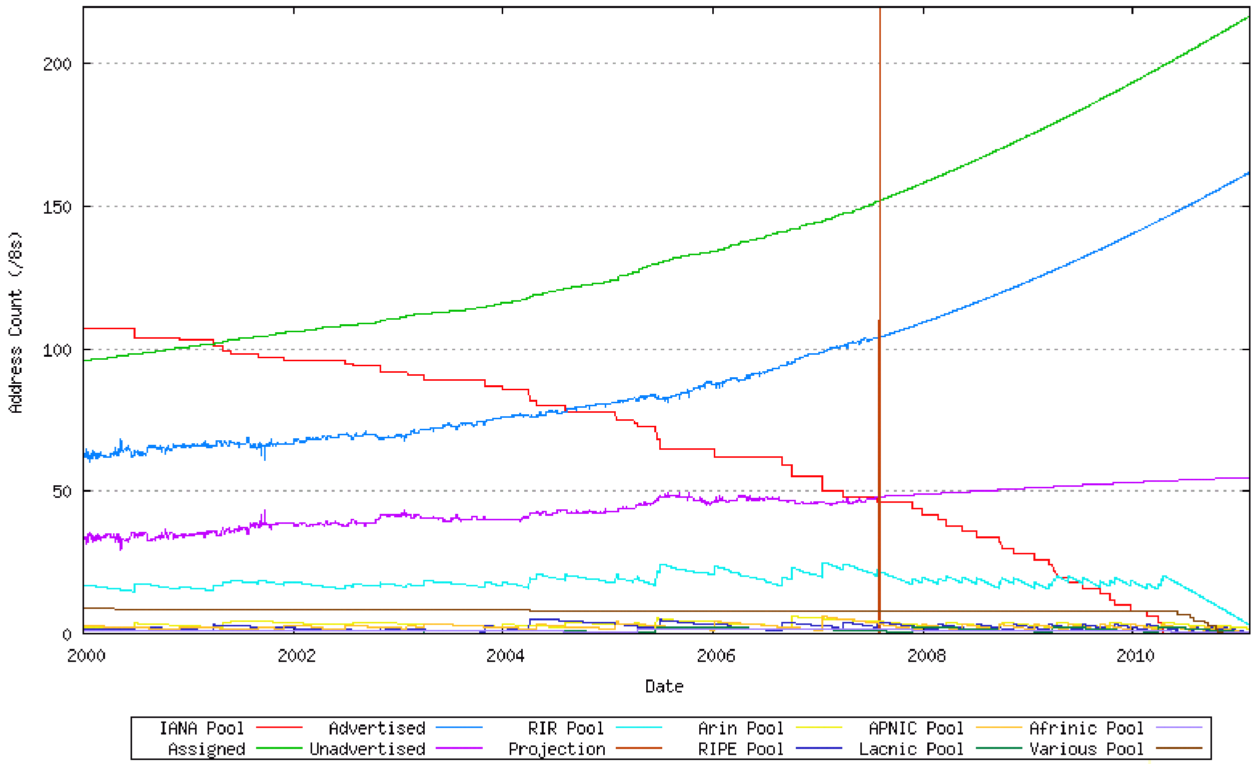

Figure 30 - Address Consumption Model

Here the exhaustion point is the date where the first RIR has exhausted its available pool of addresses, and no further numbers are available in the IANA unallocated pool to replenish the RIR's pool. The data available suggests a best fit predictive model where this will occur on **09-Feb-2011**.

A related prediction is the exhaustion of the IANA unallocated number pool, which this model predicts will occur on **13-Apr-2010**.

Further Consumption

At this point it appears unlikely that all forms of IPv4 address distribution will cease at the time when the unallocated address pool is exhausted. One possible outcome is that some form of address distribution mechanism may bring the unadvertised address space back into play to fuel further demands for address space in the public IPv4 Internet. Without concern as to precisely what mechanisms may produce such an outcome, the question here is "how many years of additional growth in the advertised public Internet could be sustained if the unadvertised address pool were available for use by the public Internet?" In attempting to pose an answer to this question, the model used here assumes that a pricing function may apply to such addresses, and there would be a strong incentive to use various forms of address compression technologies to maximize the utility of such address blocks. The model used here assumes that the efficiency of the deployed address block would be a little over twice as efficient in such a regime.

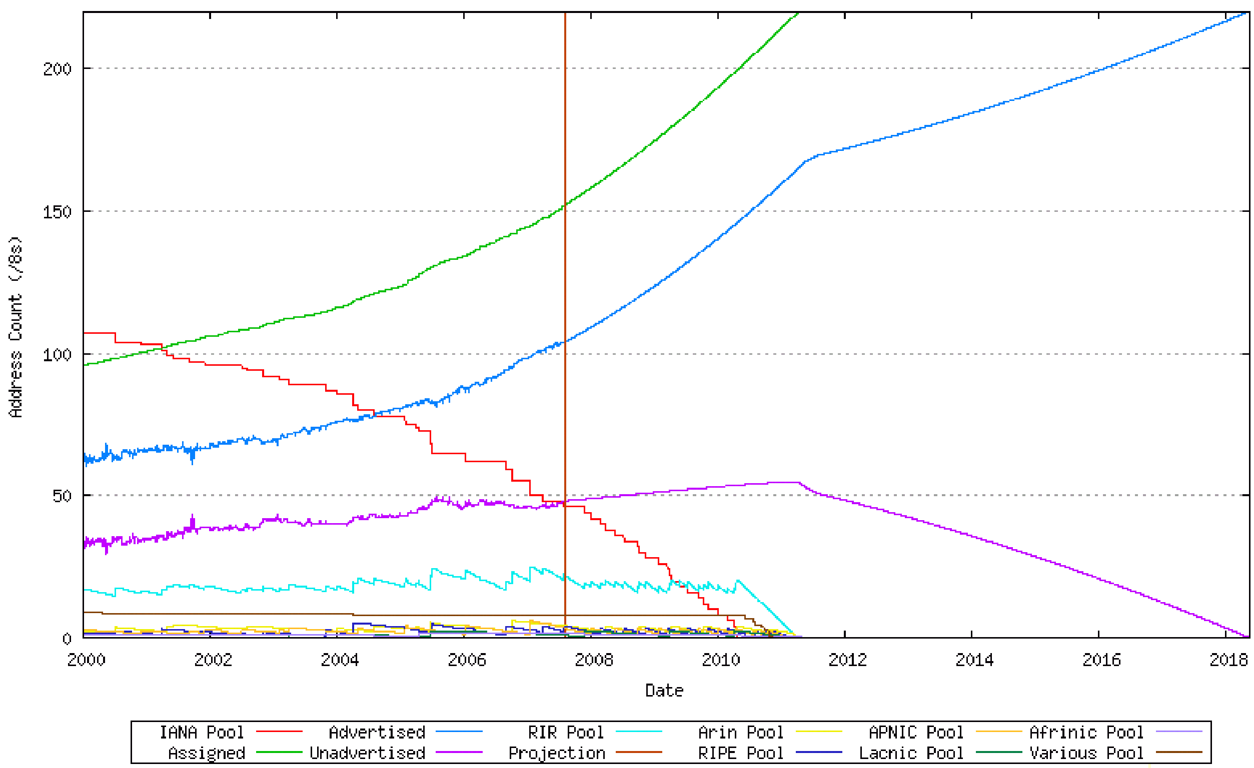

Figure 30e - Projected Consumption of the Unadvertised Address Pool

This particular model predicts that the use of the unadvertised address pool to sustain further growth on the IPv4 public Internet may provide addresses to meet demands until **14-May-2018**.

How Accurate is this Date?

This work indicates that if current consumption trends continue then some other form of address distribution mechanism will be needed before the IANA unallocated address pool exhaustion date of 13-Apr-2010, let alone prior to the RIR exhaustion date of 09-Feb-2011. However this is perhaps a very conservative projection of a date for the exhaustion of the current address allocation policies. Its probable that an industry response to this forthcoming situation is one of increasing levels of demand for the remaining unallocated address resources, given the impetus of a "last chance rush" on the registries. If such a run on the unallocated address pool eventuates, and industry players bring forward their requests for additional address space, it is possible that this unallocated address pool exhaustion date may occur sooner than the model studied would apparently indicate. Such a run is difficult to model from existing data, and this exercise here has not attempted to undertake such forms of modelling of a run on the address pool. About the best we can conclude from this study is that in terms of an agenda for development of address distribution policies, this work supports the proposition that such policy development should have started by the end of 2005. There is a clear need for detailed consideration of what are the most appropriate ways to support the continued operation and growth of the Internet when the IPv4 unallocated address pool is exhausted. The response that the global Internet industry will undertake an overnight transition to use IPv6 is perhaps at one somewhat improbable end of a rather broad spectrum of possibilities here.

Data Sets and Reports

- Listing of the IPv4 space with status and dates

- Listing of the IANA address pool
- Listing of the RIR address pool
  - Listing of the AFRINIC component of the RIR address pool
  - Listing of the APNIC component of the RIR address pool
  - Listing of the ARIN component of the RIR address pool
  - Listing of the LACNIC component of the RIR address pool
  - Listing of the RIPE NCC component of the RIR address pool
  - Listing of the VARIOUS component of the RIR address pool (summary, .csv)
- Listing of the Unadvertised address pool
- Listing of the Advertised address pool
- RIR Pool - per prefix size count
- Breakdown of address pools for each /8 prefix
- Breakdown of address pools by original allocation date
- Assignment records ('delegated' files published by the RIRs)
  - Assignment record: AFRINIC
  - Assignment record: APNIC
  - Assignment record: ARIN
  - Assignment record: LACNIC
  - Assignment record: RIPE NCC
  - Assignment record: IANA

Resources Used to Generate this Report

Code:

lsq.h
smooth.h
lsq.c
smooth.c
ipv4.c
Makefile
ipv4.pl
index.template.html

The code calls the packages *wget* and *gnuplot*. The code is run by invoking the Perl script *ipv4.pl*.

The data used in this model is based on public data sources, derived from data published by the IANA and the Regional Internet Registries.

The data used in this exercise is a combination of the RIRs' statistics reports and the RIRs' resource databases. There are some inconsistencies in this data, and the analysis here has had to make some assumptions regarding the status of address blocks and the allocation dates. Reports on these inconsistencies can be found at:

- http://www.cidr-report.org/bogons/rir-data.html
- http://bgp.potaroo.net/stats/nro/
- http://www.potaroo.net/drafts/draft-huston-ipv4-iana-registry-01.html