Site Multihoming: A Microscopic Analysis of Finnish Networks

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Abstract

This paper examines the extent of site multihoming in Finnish networks. Global route advertisements have been analyzed in general in a couple of studies, but this has not yielded sufficient information about the unclear cases of site multihoming. As these macroscopic approaches to analyze site multihoming have not been very successful, we analyze the questionable route advertisements in a "microscopic" fashion, checking them one by one. We provide description of the analysis methodology and define a taxonomy of the prefix advertisements and multihoming types.

The microscopic analysis leads us to conclude that more specific route advertisements through a different path than the aggregate do contain quite a few multihomed prefixes: a large number of the sites which have an AS number are multihomed, even though they would seem to be visible through one path only, while more specific routes advertised by other ISPs have a smaller chance (around 15%) of being multihomed. In addition, we confirm the obvious result that site multihoming with your own AS number and identical route advertisements through multiple providers is on the rise; some of these (at least 17%) do not have their own address space.

1. Introduction

This paper analyzes the route advertisement data gathered at a Finnish Exchange point (FICIX) to get a feel about the extent and mechanisms of site multihoming using Border Gateway Protocol (BGP). This builds on and extends the author's earlier work on more generic routing advertisement analysis [13].

Multihoming is the process of obtaining simultaneous IP connectivity from multiple ISPs for a number of reasons such as protection against failures and gaining independence from the ISPs. Site multihoming is a subset of that: the case where an end-site, for example an enterprise, becomes multihomed.

This paper gives a short summary of site multihoming background, motivations, challenges, techniques, and problems in Section 2. Section 3 summarizes related work. Section 4 describes the research and data collection methods used prior to writing this paper. Section 5 analyzes the collected data at length. Section 6 discusses future work, and Section 7 lists conclusions.

Throughout this paper, familiarity with addressing, routing, BGP, etc. is assumed. See [13] for a brief introduction and more references.

The main contributions of this paper are:

- publication of research on the routing impacts of site multihoming, hopefully enabling further and more widespread study of the issues,
- the description of a methodology which can be used for analysis of multihoming behaviour,
- taxonomy the prefix advertisements and different observed classes of type B multihoming,
- generic overview of prefix advertisements in this data set, and detailed analysis of different types of multihoming, and
- generic summary of the amount of different types of multihoming and the trends in this data set.

2. Site Multihoming

Site multihoming terminology, motivations, challenges, techniques and problems with those techniques are only summarized for brevity; [13] and [14] provide more information and references.

Site multihoming refers to the process of a site (e.g., an enterprise) to obtain simultaneous IP connectivity from multiple ISPs. Multi-connecting or multi-attaching, on the other hand, refer to obtaining simultaneous IP connectivity from the same ISP. [14]

There are multiple motivations to multihome; at least five have been identified: independence, redundancy, load sharing, performance, and policy. We believe the most important motivation is redundancy. Independence is often also very desirable because it eliminates the need for renumbering. Load sharing may also be desirable for international sites with multiple demarcation points to the Internet [14].

Designing a site multihoming solution has a number of challenges. Inbound traffic engineering requires distribution of the traffic engineering information throughout the

Internet. Being able to maintain existing TCP sessions while experiencing a failure is important but challenging due to slow routing convergence [9]. Having to renumber the site's internal address space is a significant undertaking. And all this should be achieved without impacting the scalability of the Internet routing infrastructure. [14]

With IPv4, site multihoming is sometimes done using NAT by deploying a system which picks a working ISP for the traffic. This does not address all the multihoming problems (e.g., connection survivability, traffic engineering), but may provide some rudimentary amount of independence and redundancy. [14]

An alternative, very common approach is using BGP, as follows: [14]

- obtaining your own IP address space, or getting permission to advertise a more specific route of an ISP's aggregate,
- obtaining an Autonomous System (AS) number,
- obtaining physical connectivity to at least two ISPs,
- setting up at least two routers at the site as border routers,
- establishing BGP sessions between the ISPs and the site border router routers, advertising the address space, and
- selecting which links will be used for the incoming/outgoing traffic by configuring BGP.

3. Related Work

Interdomain routing and topology has been significantly researched. However, little of that study has been targeted at multihoming, or gained results on multihoming.

One particularly active multihoming study area has been multihoming from the performance optimization or traffic engineering point of view and comparison with overlay networks [1, 3, 2, 6, 4].

At least two studies have been done from Internet-wide routing data which may be relevant: Zhao et al provide a good analysis on multiple origin AS number conflicts [16], i.e., what we refer to as "type C multihoming"; Meng et al analyze the different AS/prefix configurations [11] but cannot determine the exact amount of multihoming. Their follow-on work [10] provides statistics and a different taxonomy of more specific prefix advertisements.

Our study focuses on the amount and non-performance based motivations of multihoming.

4. Research Method and Data Collection

In this Section, we describe and justify the research method and assumptions, and describe the data collection procedures and analysis methodologies.

4.1. Research Method

Few studies have been made trying to characterize the global routing infrastructure patterns from the perspective relevant to site multihoming. On the other hand, the routing advertisement characteristics have been analyzed in general by many, among others Huston [8] and Meng et al [11]. Savola [13] presents the rough state of site multihoming on Finnish networks.

One reason for the lack of extensive study may be that the advertisements give relatively little detailed information; the advertisements yield some statistics, but due to a number of uncertainties (described later in this paper), drawing conclusions based on these results on the use of multihoming is very difficult or even impossible.

As a result, as macroscopic approaches to analyze site multihoming have not produced sufficient results, we try to use a "microscopic" approach instead: we focus on a relatively small subset of the Internet routing by looking at Finnish networks only, examining each case individually, and try to make observations. However, conducting wider research is subject for further study.

In this paper, we analyze the BGP routing advertisements at one of the two major Finnish points, FICIX2. Practically all the Finnish Internet traffic goes through these two exchange points, so analysis there should yield rather good view on the extent of multihoming in Finnish and (to an extent) neighboring countries' networks.

4.2. Data Collection

FICIX [5] is a layer 2 exchange, where offering transit is prohibited. So, all BGP sessions are pure peerings. The author works at CSC - Scientific Computing Ltd which is present in FICIX. The membership is not significantly restrictive for ISPs.

The route advertisements have been stored since June 2002, but unfortunately there are a few gaps. This also allows to observe how multihoming may have changed over time. However, this paper focuses on the situation as of April 2004.

It is also worth noting that during the data collection, both FICIX exchanges have transitioned from ATM-based to Gigabit Ethernet connectivity. Some members didn't re-connect immediately before/after these changes, which has caused temporary distortions to the data – seen as sites ceasing to be multihomed and coming back to multihomed when their ISPs reconnected.

Data is collected by taking a weekly snapshot of BGP routes (with all the associated data) advertised by peers on a production router. Note that BGP only advertises the best paths, but as all the significant Finnish ISPs connect to FICIX, no information is lost, bearing the assumptions made in mind.

4.3. Assumptions

We have to make two assumptions about the data; inferring the internal topologies of the ISPs would otherwise be impossible.

4.3.1 "ISPs behind ISPs" is Insignificant

That is, those ISPs which do not connect to FICIX but operate in Finland are considered rare and not considered sufficiently interesting for the purposes of this analysis. Only a few prefixes and ASs are present this way.

4.3.2 ISPs Prefer their Own Routes to Those They've Heard

The question is whether you prefer your own prefix if a neighbor advertises the same prefix as you do but with better parameters (e.g., a shorter AS-path) than you have.

The behavior depends on how the ISP prefers the routes it has heard from the neighbors; typically this can be done either using BGP local-preference or MED attributes. Local preference would practically always prefer the local path, but MED would prefer the received path if the local path's AS-path has been significantly prepended by the site[1].

So, while this does not give complete assurance of a full view of multihoming, we assume most networks either use local-preference or that most sites do not prepend their backup connectivity so much that it would be completely inactive.

4.4. Data Analysis

Analysis of the route advertisements provides some insight [13], but is not sufficient for making reasonable conclusions. We used the following additional manual methods in April 2004, especially for Section 5.4:

- We queried the RIPE routing database [12] for the AS number of site, looking mainly at export:, import:, remarks:, and changed: entries. These, especially if updated recently, give rather strong hints on what kind of interconnections the site has. In case something looked out of place, we also checked the site's ISPs' AS-macros for the same information. While the sites may not always keep their routing database records up to date, almost all ISPs in Finland do.
- We looked up the prefix from a looking glass[2] of the primary ISP; this would reveal if the ISP had secondary, even inactive routes,
- We ran a traceroute from the looking glass, or ran a traceroute from a Unix shell in the ISP's network, depending on which one was available, and
- We also approached a couple of ISPs directly [13], asking them to clarify the advertisements if we had not been able to figure out anything about an unclear prefix.

[1] On the other hand, if the site uses a BGP community to have the ISP prepend the route, such route is typically still preferred by the ISP.

[2] Unfortunately, many looking glasses are either not available, or give only little information, probably due to ISPs' concerns about exposing their internal topology or business relationships.

We also considered querying the unclear end-sites directly, by asking them whether they are multihoming or not, but did not do that at this phase given that we had already reached a reasonable degree of certainty of the multihoming status.

The tracerouting methodology deserves elaboration: when analyzing whether a more specific route from a different path could be a sign of multihoming or not (see Section 5.4), we traceroute to an address from the more specific prefix from the ISP of the aggregate prefix. If there is direct connectivity to the more specific route's network and the direct connection is preferred (see the assumptions in Section 4.3 above), the site is multihomed. If the connectivity goes through the Internet exchange, very likely there is no multihoming. That is, this makes an assumption that some form of connectivity would have to be active at the backup ISP even before the more specific route has failed. There are a couple of ways how one can configure the network so that this assumption is not valid[3], but it should apply in most cases, so we use it for analysis here.

We also considered to build a system which would constantly monitor the route advertisements and if an interesting prefix would get withdrawn (e.g., due to suspected outage), try to reach the site using alternative path (i.e., through the less specific aggregate). However, this turned out to be quite complex so it is left for further study.

5. Data Analysis

In this section, we categorize the route advertisements, make a few observations about the advertisements in general, and then describe and analyze at length the three potential multihoming types.

5.1. Categorizing the Advertisements

We classify route advertisements in roughly six categories:

1. Single-homed prefixes, for which there are no more specific routes,
2. Single-homed prefixes which are being given transit by another ISP, i.e., an ISP is doing "ISP multihoming" (see figure 1),
3. More specific prefixes with the same path and origin as the less specific prefix (see figure 2),
4. More specific prefixes with a different path or origin as the less specific prefix (see figure 3),
5. Equal-length prefixes advertised from a different origin (see figure 4) also called Multiple-Origin AS number (MOAS) conflicts [16], and
6. Equal-length prefixes advertised from the same origin but through different paths (see figure 5).

[3] See Section 4.3 for one example.

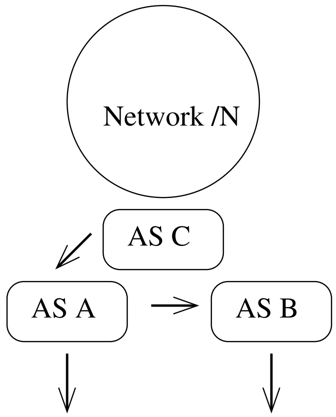

Figure 1. Case 2: ISP multihoming

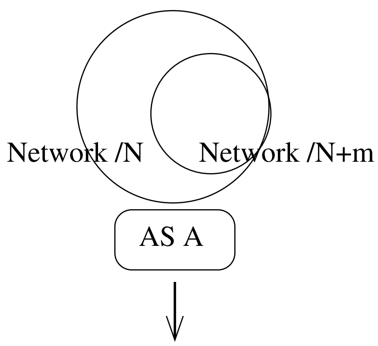

Figure 2. Case 3: More specific routes along the same path

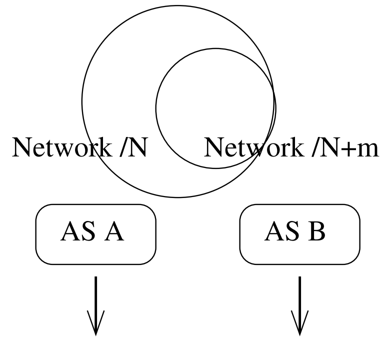

Figure 3. Case 4: More specific routes from a different origin

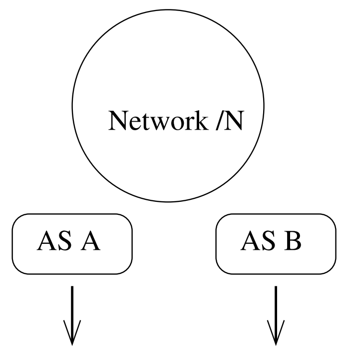

Figure 4. Case 5: Same prefix from different path/origin

A prefix may belong to multiple categories. For example, a site may advertize two equal-length prefixes with a different path (the sixth category) which are part of an ISP's aggregate (the fourth category).

Of the six categories listed above, the first is not interesting from the multihoming perspective as the prefixes are single-homed and they have no more specific routes which could potentially be multihomed. The second are not interesting from the site multihoming perspective as it is a form of ISP multihoming. The third come from the same path as the less specific prefix and cannot be multihoming but rather traffic engineering, configuration mistakes, e.g., result of improper aggregation, etc. These are not described at more length in this paper.

The fourth can be either the sites switching ISPs but taking the IP addresses with them, improper aggregation (i.e., an ISP advertising an aggregate even though it shouldn't, e.g., because a classic "B-class" prefix is automatically summarized to a /16), or a special kind of multihoming using provider-dependent addresses. It is impossible to distinguish these cases based on the route advertisements alone, so they have to be further analyzed using the other methods. We call this type B multihoming; some examples are listed in Appendix B.

The fifth is a rare case where multiple ASs advertise the same prefix. While this is done e.g., with certain anycast prefixes (such as the 6to4 anycast prefix, 192.88.99.0/24 [7]), it is indistinguishable from prefix hijacking. This is often called a MOAS conflict [16]. This could also be multihoming in the case where the site does not have a (public) AS number. We call this type C multihoming; an example is mentioned in Section 5.5.

The sixth is a clear case of multihoming; this can happen with either your own IP addresses (i.e., the prefix advertised doesn't have either more or less specific routes, i.e., is a so-called "root prefix"), or a more specific chunk from an operator's address space. We call this type A multihoming; some examples are listed in Appendix A.

5.2. Prefix Advertisements

Before analyzing the multihoming characteristics, we take a quick look at prefix advertisements in general.

Figure 6 depicts the number of route advertisements per peer. AS5400 has been excluded, as it only participated in FICIX2 where the snapshots were being taken for a short while, and it advertises a couple of thousand (foreign, and thus non-interesting) prefixes which would make the make the graph more difficult to read.

The total number of prefixes has risen from around 1300

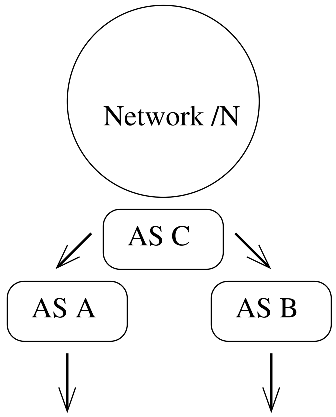

Figure 5. Case 6: Clearly multihomed

in July 2002 to around 2200 in April 2004. TeliaSonera (AS1759) is well represented, mainly due to the fact that it is advertising its Russian and Baltic customers' routes in FICIX as well. The rest are either in the category of a couple of hundred prefixes, or in a category of a couple of dozen prefixes or less. Unfortunately, data from November 2003 to February 2004 is missing.

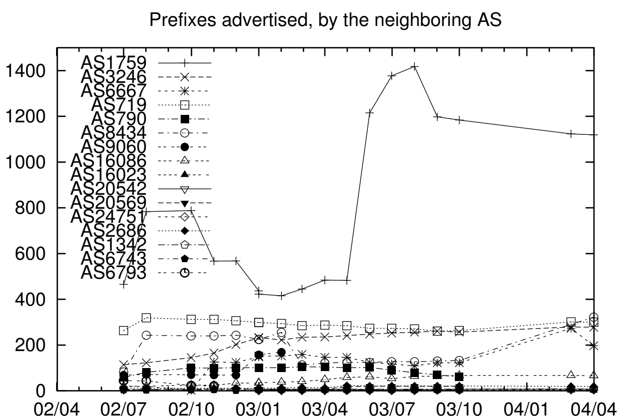

Figure 6. Prefix Advertisements

It is worth noting that during the observation period, AS9060 ceased to exist, AS790 has merged with AS6667, AS20569 has merged with AS16086, and AS6793 has merged with AS3246.

5.3. Case 6: Type A Multihoming

Figure 7 shows the total number of type A multihomed sites, measured by the number of ASs. As described in Section 5.2, AS5400 is caused disturbance between June and October 2003, so data between those dates has not been plotted. The figure also lists the number of new ASs and removed ASs, compared to the previous month. This gives an idea of dynamicity of the multihoming; ignoring the AS5400 incident, the change rate is rather modest.

The number of multihomed sites has risen from 16 in July 2002 to 30 in April 2004 (i.e., 88% increase over 21 months). Even in the "stable" topologies, there is still fluctuation with the sites: about every month a couple of new sites crop up, and a few old ones disappear.

We compare the situation of April 2004 to that of April 2003, and ignore the non-Finnish mergers, and do a bit of investigation. The full results are listed in Appendix A.

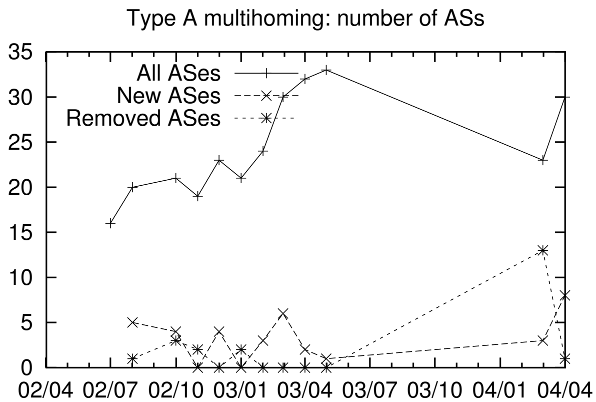

Figure 7. Type A Multihoming

To summarize: ISP acquisitions/mergers change the multihomed status of the sites; some ISPs cease operations and their address space may or may not "live" on; a number of organizations which have their own addresses can easily start multihoming just by getting an AS number; multihoming seems to be on the slight rise.

Of the 11 cases analyzed, in 2 there had been no real changes, 2 are no longer multihomed due to ISP mergers, 5 have started multihoming, 1 has ceased operations, the IP block continuing with another site, and 1 has stopped multihoming probably due to internal topology restructuring.

We also examined how many of the multihomed sites in April 2004 were using a part of their provider's aggregate, and how many of them had their own IP addresses. 5 of 30 sites (17%) advertised more specific routes from another AS's aggregate.

5.4. Case 4: Type B Multihoming

Figure 8 shows the number of less specific routes, with a different path than the more specific route, advertised by the neighbor AS. In other words, this shows which aggregates (advertised by whom) are being "punched through" with a certain kind of more specific routes. The figure only includes the routes where the more specific route is advertised from a different path than the aggregate, and the range of the y-axis has been chosen so that AS5400 is excluded from the view to make out the AS's with a small number of prefixes better.

Figure 9 shows the other side of the coin, the number of more specific routes, with a different path than the aggregate, advertised by the neighbor AS. One can compare these two figures. One conclusion is that Elisa (AS719)

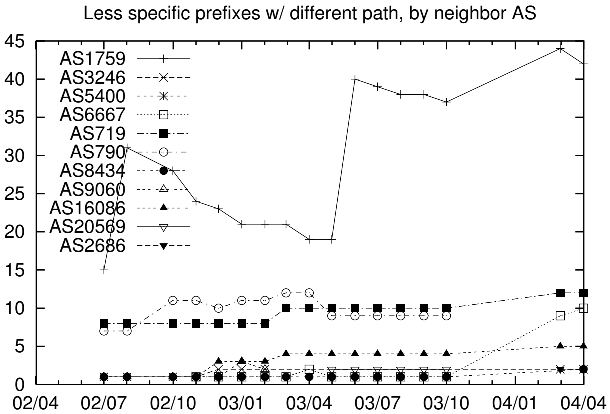

Figure 8. Type B Multihoming: distribution of less specific routes

is advertising (relatively) many more more specific routes than others – compare this to TeliaSonera (AS1759) and the combination of Eunet and Jippii (AS790 and AS6667), for example.

The advertisement of more specific routes with a different path appears to be in the slight rise, but this is not conclusive.

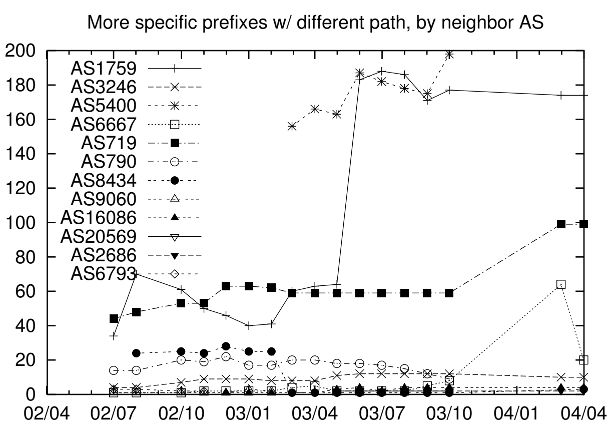

Figure 9. Type B Multihoming: distribution of more specific routes

Obviously, not all of these are an instance of type B multihoming: they are just the ones that could be. To get a better idea of the extent of type B multihoming, compared to just changing providers, we've investigated the more specific routes in detail using public traceroute servers, looking glasses, personal home computer, and querying the ISP in question; this methodology was described at more length in Section 4.4.

We've managed to obtain this information from AS719, AS1759, AS3246, AS6667/790, and AS16086. In other words, all the relevant ISPs which had an aggregate where more specific routes with a different paths were being advertised.

We categorized the cases as follows:

1. Sites where the more specific route is originated by a site with an AS number, and may be multihomed,

2. ISPs advertising more specific routes which might be multihoming if the site uses private AS numbers or the advertisements are proxied by the ISP, or some IGP such as OSPF is used instead of BGP,

3. Illogical cases e.g., where an ISP is advertising a more specific route, overriding a part of a site's aggregate,

4. Prefixes relating to internal reorganization of an ISP, when the ISP uses multiple AS numbers, and

5. Prefixes which we excluded due to insufficient advertisement coverage (mostly Russian, Baltic or Swedish/Norwegian prefixes).

These are analyzed at more length below.

5.4.1 Sites with an AS Number

For the first category, the extended testing and analysis results are listed in detail in Appendix B.

To summarize, those sites which have an AS number seem to have rather high probability of having at least some kind of multihoming setup, even if they didn't have their own address space. This is only logical as a public AS number is only needed if you are using BGP for advertising your prefixes to the whole Internet.

Of the 7 cases analyzed, 2 didn't appear to be multihomed, 2 were type A multihomed using their provider-independent addresses but not multihomed with their more specific route(s), and 3 appeared to be multihomed.

5.4.2 More Specifics from a Different ISP

The second category, more specific routes from an ISP, not an end-site, produced the following results:

- You can reach 10 more specific prefixes advertised by AS719 also through the 3 aggregates advertised by AS16086: this is due to the special way these had been set up in the past. These can be counted as type B multihomed.

- There are about 80 more specific prefixes advertised by various ISPs, under 23 aggregates. There appears to be no indication of multihoming, only switching providers. These were tested by running manual traceroutes.

- There are 5 more specific prefixes advertised through various ISPs, which seem to be reachable through 4 aggregates, as measured with traceroute. These prefixes are: 192.126.19.0/24, 193.94.100.0/24, 193.94.101.0/24, 194.136.72.0/23, and 194.215.50.0/24. There is reasonable grounds to believe these may be type B multihomed.

To summarize, the amount of multihomeing with more specific routes originating at ISPs' networks seems to be a bit lower than expected; in [13] we estimated the ratio to be between 30-50%, but it appears that it is apparently closer to 15% (or so).

Of about 95 prefixes analyzed, only 5 were clearly multihomed, and additional 10 seemed to be multihomed due to the historical reasons; therefore the percentage of multihoming inside case B was relatively low.

5.4.3 Illogical Advertisements and Others

The third category, illogical advertisements, includes a few interesting entries, described in detail in Appendix C.

Of the 5 illogical advertisements analyzed, in 2 cases the site is already type A multihomed, but another ISP advertises a more specific from the site's provider-independent address range, in 1 case the ISPs' internal reorganization seem to have changed a site's status from multi-homed to multiconnected, 1 appears to be a single-homed site with an AS number for historical reasons, and 1 might be multihomed but information on that seems so out of date that that seems unprobable.

About 60 prefixes were excluded from the analysis as the more specific routes appeared to be coming from a different branch of the same ISP (for example, through path ”719 5487” from 719).

About 130 prefixes were excluded from the analysis due to insufficient coverage – for example, routes originated in Russia, Baltic countries, Sweden/Norway, but which were advertised in Finland by international carriers. That is, as one cannot get advertisement from every ISP the organizations in these regions could be multihomed to, the data would be too partial to be useful for analysis.

To summarize, some ISPs appeared to be advertising a small part of a site's or another ISP's aggregate; it is difficult to find justification for this – we can only guess that it is either related to connecting branch office(s) or advertised if the site has outsourced some infrastructure services (e.g., mail servers). The number of ”internal organization” prefixes (especially coming from AS719) was surprisingly large. It is also interesting that the operators wish to exchange non-Finnish traffic at FICIX – but this is in the spirit of ”hot potato routing”.

5.5. Case 5: Type C Multihoming

While originating the same prefix from multiple places is a common form of load-balancing, identical prefixes are only very rarely advertised from different autonomous systems in this manner [16]; an exception is, for example, the 6to4 anycast prefix [7]. On the other hand, when the operator of a DNS root server distributes the address with anycast, typically all the advertisements use the same origin AS.

Excluding the anycast prefixes, only one real prefix (192.49.166.0/24) was originated by two different AS's during 2002 (learned through paths 719 and 1759 5515). This route is used by AS375. This might have been a configuration mistake, as AS375 is originating a lot of routes on its own and has no need for this kind of techniques.

As noted, this is very rare. For example, analysis of full Internet routing table showed only 13 such prefixes in April 2004 [8].

6. Future Work

Non-Finnish networks being advertised caused a lot of disturbance and made real measurements of only Finnish networks more difficult. It might make sense to filter out such paths and prefixes after processing the data. It might also make sense to combine the data from FICIX1 and FICIX2 (we only analyzed FICIX2, because that dataset is more complete), to be able to include e.g., Finnish networks advertised by BT Ignite which was only present at FICIX1. However, such data exclusion lists would require significant amount of work and manual maintenance.

Also, one should examine whether one can reasonably assume that all type A multihomed networks have indeed been detected; this depends a lot on the assumptions how secondary ISPs have been set up, as described in Section 4.3. This should be explored at more length, e.g., through looking glasses, if available and yielding sufficient information; the problem is that even if a looking glass existed, the secondary paths might not be shown. So, in practice, getting 100% certainty appears to be very difficult using any methodology.

Section 5.4.1 noted that more specific routes from site's own AS are a common source of multihoming. It might also make sense to examine the root prefixes heard from sites' AS numbers. This might also catch some of the cases which fail the type A multihoming detection assumptions, above.

This study is intentionally ”microscopic” by nature. Generalization or detailed verification of the results is a matter of further study.

One particular more study case could be doing more extensive research on stub AS numbers with multiple transit ISPs based on the public routing policy databases (in particular, RIPE DB). One could possibly leverage the methodology of Siganos and Faloutsos [15]. This could yield generic results on the cases which might not be observable just from the routing tables.

7. Conclusions

We provide a taxonomy for prefix advertisements and different types of multihoming which should prove useful for any future studies in this problem space.

Based on the investigation, we conclude that:

7.1. Type A Multihoming

Advertising identical prefixes from multiple paths can be relatively easily distinguished with a few caveats[4]. This

[4]Such as how ”secondary” ISPs prefer the advertisements heard from primary ISPs, depending on the techniques used. See Section 4.3 for

form of "complete" multihoming has been on the rise. Some sites (at least 17%) use more specific routes from their ISP, not getting their own address space. In April 2004, there were 22 Finnish type A multihomed sites.

Analysis of apparent changes in this class during a year indicates that some sites have first obtained address space and are single-homed, and later obtain an AS number and multihome; ISP reorganizations/mergers affect the site multihoming of the customers of those ISPs; a few (although a lot fewer than new multihomers) ASs have indeed stopped multihoming.

7.2. Type B Multihoming

Advertising a more specific route from a different path is more common. However, the research seems to indicate that a significant portion of these is just switching providers without renumbering, not type B multihoming. When a more specific route was advertised by site's AS number (and not an ISP's), type B multihoming was quite common – 5 of 7 analyzed cases, where 2 were additionally type A multihomed. More specific routes advertised by another ISPs, however, had a lot smaller degree of type B multihoming, around 15% at most – 5-15 prefixes out of about 95.

7.3. Type C Multihoming

Originating the same prefix from two ASes is very rare. There seem to be reasonable grounds to believe this is close to non-existant technique for multihoming [16].

8. Acknowledgements

We thank the anonymous reviewers for their review and suggestions for improvement.

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A. Type A Multihoming: Changes from 2003 to 2004

- Nokia has started multihoming more aggressively with AS1248. It has recently joined FICIX as well.

- Kemira (AS5420) is no longer multihomed through AS5400 (This is due to lack of visibility of AS5400 in FICIX2; it's still present at FICIX1, so Kemira is actually still multihomed.)

- Oulu Telephone Company (AS12375) has more or less merged[5] with AS16086, and the connectivity to AS3246 seems to have been taken down, no longer making it multihomed.

- Suomi Communications (AS16302) is not even in the routing table anymore. Its prefix is advertised, single-homed, by Nebula Networks (AS29422); AS29422 is also a recently joined new FICIX member. One can guess the former has either ceased operations or been sold.

- Tumsan Network (AS16331) is no longer multihomed through AS5400 (This is due to lack of visibility of AS5400 in FICIX2; it's still present at FICIX1, so Tumsan Network is actually still multihomed.)

- TietoEnator (AS24714) was multihomed through two providers. The AS is no longer visible at all. The prefixes have been moved to TietoEnator's another AS, AS375, and are single-homed in FICIX.

- Power-IT (AS24752) was multihomed through AS16086 and AS12375, but when AS12375 more or less merged with AS16086, the multihoming property was (apparently) lost.

[5] AS12375 is a significant shareholder of AS16086; the details go beyond the scope of this paper.

- Partek (AS25213) was single-homed to AS3246 with its /16 prefix, but obtained an AS and started multihoming to AS6667 as well.

- Fingrid (AS29093) was not seen (either the /24 prefix or the AS) in 2003, but is now multihomed.

- MMD Networks (AS29243) had its /20 prefix routed single-homed from AS3246, but has obtained an AS, and started multihoming through AS6667 as well.

- TNNet (AS30798) was not seen (either the /20 prefix or the AS), but is now multihomed through three providers.

B. Type B Multihoming - Sites with an AS Number: Changes from 2003 to 2004

- AS375 (TietoEnator) has about 40 more specific routes from different operators' aggregates. These do not seem to be multihomed based on traceroute results, and RIPE database has no import/export policies for AS375 either. TietoEnator has at least one, but possibly more, private peerings.

- AS8812 (Nokia Mobile Phones Wireless Future Lab) has a prefix which is advertised through one path only. However, a note in the AS-macro indicates that the backup advertisement becomes active only when the first one disappears, so they may in fact be multihomed; this is impossible to test.

- AS3274 (Cygate) has a couple of prefixes that it is advertising using just one path, while some others use type A multihoming. Based on traceroutes, these prefixes do not seem to be multihomed. This is caused by the desire to not renumber certain IP addresses to their new provider-independent prefixes.

- AS20774 (Univ. of Jyvaskyla Commercial Services) advertises two more specific routes through AS1759. Their AS-macro indicates that they are multihoming to AS6667 as well, and traceroutes from AS6667 indicate that this is the case. Note that AS20774 is also doing type A multihoming for their provider-independent addresses.

- AS28883 (Samlink) has a /24 prefix which is advertised through the owner of aggregate only. AS-macro indicates that they should also advertise it through another provider, UUnet (AS702) who is not present at FICIX. Traceroute from UUnet's looking glass indicates that this network is in fact multihomed.

- AS29240 (Nordic Lan & Wan) has a /19 prefix, but only advertises a more specific route through one provider. AS-macro indicates that they should be multihoming through two providers. We conclude that their multihoming set-up is mostly broken.

- AS29601 (UPM-Kymmene) has about 6 prefixes which are advertised only through AS1759. Their RIPE DB AS-macro states that some prefixes should be multihomed using AS2874, and the AS-macro of AS2874 agrees. However, this is impossible to verify as there is no looking glass to use; running traceroute from a few networks associated with AS2874, however, do not use this route, and it is probable that multihoming is not operational at the moment.

C. Type B Multihoming - Illogical Cases: Changes from 2003 to 2004

- AS764 (Prime Minister's Office) has an AS, but is only advertising through one provider, and the AS-macro indicates the same. One can wonder why to have an AS number in the first place if not multihoming; this is probably a historical remnant as the AS number was assigned a long time ago.

- AS5420 (Kemira) advertises a /21 (through AS3246), but AS1759 advertises a more specific route overriding a part of that. The more specific route is not directly reachable through AS3246. The AS-macro indicates that the organization should be multihoming, but one AS listed does not exist, and the other one does not provide transit. Despite these inaccuracies, we already concluded that AS5420 is actually still type A multihomed through FICIX1; this more specific route is just an illogical advertisement.

- AS24752 (Power-IT) advertises prefixes on only one path, but its AS-macro indicates they are using both AS12375 and AS16086. However, nowadays AS12375's only upstream appears to be AS16086, so this form of multihoming doesn't show outside of AS16086, and could instead be considered multiconnecting.

- AS25213 (Partek) advertises a /16 (through AS6667), but AS1759 advertises a more specific route overriding a part of that. The more specific route is not directly reachable through AS1759. This prefix was already identified as type A multihomed, but the more specific route is illogical.

- AS29132 (IW-Net) advertises a number of prefixes through AS6667, but AS3246 overrides a part of that. The more specific route is not directly reachable through AS6667. The AS-macro indicates that it should be multihomed but is hopelessly out of date and incorrect. It seems unlikely that there is multihoming here.