"Resilience of the Internet Interconnection Ecosystem"

Introduction to the Study

This document is a brief introduction to the study "Resilience of the Internet Interconnection Ecosystem", which is work sponsored by the "European Network and Information Security Agency – ENISA.

About ENISA

Communication networks and information systems have become an essential factor in economic and social development. Computing and networking are now becoming ubiquitous utilities in the same way as electricity or water supply. The security of communication networks and information systems, in particular their availability, is therefore of increasing concern to society as they deliver services critical to the well-being of European citizens.

The "European Network and Information Security Agency" (ENISA) was established on 10 March 2004. Its purpose is to ensure a high and effective level of network and information security within the Community and to develop a culture of network and information security (NIS), for the benefit of the citizens, consumers, enterprises, and public sector organisations within the European Union (EU), and thereby contributing to the smooth functioning of the Internal Market.

Objectives of the Agency

The Agency's objectives are as follows:

- to enhance the capability of the Community, EU Member States and, as a consequence, the business community to prevent, to address, and to respond to network and information security problems.

- to assist and advise the Commission and EU Member States on issues related to network and information security falling within its competencies as set out in the Regulation[1].

- building on national and Community efforts, to develop a high level of expertise.

- to use this expertise to stimulate broad cooperation between actors from the public and private sectors.

Additional Information

Further information about ENISA can be obtained from its website: www.enisa.europa.eu.

The Subject of the Study

The Internet connects a large number of independent networks, which cooperate to ensure that each network's users can reach every other network's users – directly or, much of the time, indirectly.

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[1] *Regulation (EC) No 460/2004 of the European Parliament and of the Council of 10 March 2004 establishing the European Network and Information Security Agency.*
See: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004R0460:EN:HTML

The resilience of the Internet as a whole depends on each network – from its end users to its interconnections with other networks – being resilient That is under the control of each network, individually and independently.

Each direct connection between two networks is a bilateral and generally private arrangement. Each direct connection is under the shared control of the two networks.

Most traffic, however, does not pass directly between networks, but crosses one or more other networks between source and destination. These indirect connections are underpinned by a system of incentives and bilateral agreements (formal and informal).

The system of direct and indirect connections between networks, and the incentives and agreements that underpin those are, together, the Internet Interconnection Ecosystem.

The resilience of the Internet as a whole depends on the resilience of that interconnection ecosystem, which is beyond the control of any network.

That is the subject of this study.

In the following the Internet Interconnection Ecosystem will generally be referred to simply as the ecosystem.

The Motivation for the Study

Internet technologies are designed to cope with change whatever the cause.

Individual networks are designed to cope automatically with some anticipated level of change. Where a change exceeds the capability of the automatic systems to adjust, the network operations centre will step in. Network operators constantly monitor and maintain their networks, and their day-to-day work is dealing with changes and events.

The interconnection ecosystem is not the entire Internet, but it is an important and central part of it. There is no design or management of the ecosystem. An invisible hand causes tens of thousands of individual networks to work coherently to provide the Internet.

It is believed that the ecosystem is resilient. Experience suggests that it is.

But, there is no way to verify either that it is, or that it will remain so.

Given the importance of the ecosystem, that is a serious deficiency.

That is the motivation for this study.

The Scope of the Study

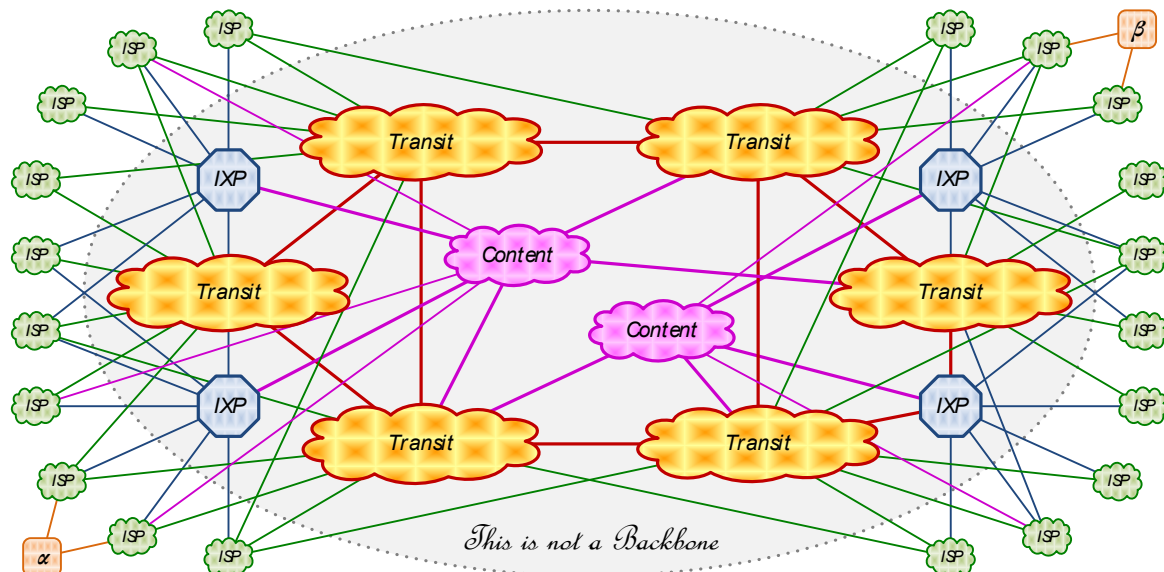This study is interested in the resilience of the ecosystem, looking at:

- its response to events with medium to high impact, and which have a medium to low probability.
- how that resilience may be assured and improved.
- what may influence that resilience in the long term.

particularly from a European perspective but, as with anything to do with the Internet, the context is clearly global.

Note that this excludes the day-to-day running of the ecosystem and individual networks. It also excludes the resilience of end-user connections to their ISPs.

A Working Model of the Interconnection Ecosystem

The ecosystem is very complicated, or at least very large. Some model is required, and the following diagram provides a simple one:

where the ecosystem comprises:

1. a relatively small number of (large) transit providers, generally connected to each other (but not universally), either directly or at an IXP. Those transit providers each serve a number of ISPs and content providers/distribution networks.

2. a number of Internet Exchange Points (IXPs), at which transit providers, content providers/distribution networks and ISPs connect to each other.

3. a small number of content providers/distribution networks, connecting to transit providers, IXPs and ISPs.

4. a much larger number of Internet Service Providers (ISPs), connected in various ways to transit providers, to IXPs and to content providers/distribution networks.

5. a still larger number of customers of the ISPs – represented on the diagram by just two of their number: networks α and β. These are relatively sophisticated, multi-homed customers. There is a yet larger number of single homed end users.

The system is, of course, much richer and more varied than the diagram suggests. The model isintended to be simple enough to be tractable, without being too simple to be useful.

Consider for a moment the exchange of traffic between α and β: the resilience of this interconnection depends on all the networks and connections between them, and the interlocking incentives and agreements that keep those willing and able to carry the traffic.

The term backbone suggests some centrally managed infrastructure on which the rest of the system depends. There is no Internet Backbone in that sense. However, as the diagram suggests, key parts of the ecosystem may be treated as a "de facto backbone". The resilience of the ecosystem is then the resilience of this "backbone" and the connections with that.

In general this study is not concerned with the resilience of individual networks. However, where a network is a component of the de facto backbone, its resilience directly affects the resilience of the ecosystem.

The Approach to Resilience

A system is resilient if it continues to offer acceptable service despite damage to, or failure of, parts of the system. This begs a lot of questions about what represents acceptable service for any given degree of damage or failure. Almost any analysis of resilience can quickly become complex as the number of possibilities to consider grows rapidly.

This is a large system so the problem of its resilience is only tractable if a broad approach is taken. It is important to remember that the ecosystem is the sum of a large number of independently managed networks – so considering its resilience is not quite like considering the resilience of even a very large individual network.

Having identified the major components of the ecosystem, it may be possible to identify key factors which affect its resilience. For example:

   a. physical diversity – which is not easy for an individual network to achieve and maintain, and much, much harder for a system of independently managed networks.

   b. spare capacity –which may be designed into an individual network, but may or may not exist, in the right places, in the system of interconnections between networks.

   c. management systems – which in this context means the ability to organise the recovery of the system as a whole, not just individual operator's networks.

   d. systemic problems – which, by definition, may be capable of simultaneously affecting large parts of this large system.

   e. cascade failure – which could also simultaneously affect large parts of the system.

The other side of the coin is some consideration of what sorts of events might have medium to high impact, and whether, given the nature of the ecosystem, it is possible to identify some general effects on the system. By linking real possibilities to (hopefully) a relatively small number of general effects, it may be possible to draw real conclusions without having to consider an impossibly large number of cases.

Mapping the Ecosystem

To assess the resilience of the ecosystem first it must be possible to see it.

Assuming that a practical model for the ecosystem and its resilience can be devised, little further progress can be made while the system is almost completely hidden.

The model suggests that the IXPs and a relatively small number of networks make up a de facto backbone. Mapping that ecosystem is, at least, a much smaller task than mapping the entire Internet. However, it is still more or less impossible to discover:

   a. how the components are connected to each other,

   b. whether that mesh is diverse,

   c. if there is suitable spare capacity,

   d. how well it would respond to a major event,

...or anything else.

The connections and relationships with the clients of a de facto backbone are also part of the ecosystem. For any analysis of this to be tractable it will be necessary to divide the clients into a (hopefully) small number of classes.

The Wider Issues

The Internet works because a system of incentives causes the networks in it to behave coherently, without any central coordination. Internet insiders not only believe that this is the best way to organise such a large system, they believe it is the only way.

However, there appears to be little incentive for a network to spend time and money making the ecosystem as a whole resilient or more resilient. Each individual network gets no direct benefit from such expenditure. Further, it is not clear that the resilience of the ecosystem arises naturally out of the resilience of the individual networks or their individual interconnections, at least when considering large scale events.

With falling prices and increasing demand, the resilience of the ecosystem may not be a priority – even if an operators knew how to help achieve that resilience. Does continual cost reduction reduce the resilience of the components of the ecosystem ?

Customers have no way of assessing whether the suppliers they are choosing between are better or worse than each other in terms of resilience, even if they were sophisticated enough to care. There does not appear to be any consumer choice or price signal to promote resilience – even though that appears to be in the end-users' interests.

Customers are motivated by price, and applications are moved to the Internet to reduce costs. Much of the time the Internet works. It is not clear to anyone what risk they are accepting in return for the cost saving.

As transit prices continue to fall, apparently inexorably towards zero, how will that affect the incentives, and what will that do for the resilience of the ecosystem ? Indeed, is the ecosystem sustainable in the long term ?

The speculative boom created a lot of infrastructure which became very cheap when the bubble burst. If that is still a factor, what happens when new infrastructure has to be paid for at real prices ?

The Objectives of the Study

The resilience of the Internet Interconnection Ecosystem is central to the resilience of the Internet and the services delivered over the Internet.

The importance of the Internet means that its resilience cannot simply be assumed, or be accepted as an article of faith.

The objectives of the study are to:

- survey of the current state-of-the-art:

  - what the ecosystem is

  - what may affect its resilience

  - whether or how that resilience may be assessed (or even verified)

- where possible, make recommendations for:

  - further work

  - action to improve resilience

  - other research