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Analysis of Interlayer Connection Catastrophe Characteristics in Internet AS level Topology

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Abstract

Based on CAIDA's (cooperative association for Internet data analysis)statistics at AS-level collected from April 2009 to April 2010, it is found that network size, degree correlations and clustering have changed significantly three times. According to the definition of k-core, the Internet topology is divided into different levels. In this paper, by analyzing the changing connection on each level at the three time spots, we found that the connection difference between the highest and the lowest level varies cyclically. Before Internet has significant change, the connection difference between the highest and the lowest shell changes acutely. At that time point it is the later stage of the fluctuation period which is the accumulation of small fluctuation. The concept of catastrophe coefficient is proposed for quantifying the probability of Internet catastrophe so that the catastrophe coefficient of Internet could be calculated on real time, and the catastrophe time spots could be predicted. Using real data for verification, it turns out that catastrophe coefficient can accurately predict the "giant fluctuations" occurrence in the macroscopic structure. With the proposal of the concept of catastrophe coefficient, the research can play an important guiding role in understanding the actual network internal development and changes, analyzing the cause of Internet catastrophe, preventing devastating catastrophe, planning and further re-designing Ipv6.

***Keywords**: catastrophe coefficient; shell connection ratio difference; small fluctuation accumulation;*

1. Introduction

There have been huge amounts of updated effort on Internet investigation since its birth. In the early times, people paid more attention to the study of system structure, network protocol, computer interconnection and the service provided by Internet. With the rapid development of information technology and ever-growing human reliance on Internet, people have been developing novel research directions in the fields of Internet service security, QoS, TCP flow analysis, congestion control, routing algorithm and topology modelling, where tons of relevant results have been reported [1-14].

During the development of Internet technology, abnormal Internet cases also motivate the growth of Internet technology and its application. With the increase of Internet scale, the number of abnormal Internet cases also increases: worm attack, Dos, DDos attack, Probing, U2L, and R2L attack make a lot of Internet resource illegally abused, causing rejection of normal Internet service requests; Internet congestion is one of the reasons causing inadequate use of Internet resource. So people have started the study in terms of Internet catastrophe.

According to catastrophe property of Internet, many scholars proposed cascading avalanche model and self-assembling critical phenomenon; essentially these are all catastrophe process of Internet macro topology structure. However study on this problem is still not mature at this moment, and the proposed model and practical situation could not match well. The known results are based on the analysis of Internet overall structure and not from the actual data of Internet. Thus, they could not reflect the in-situ internal change of the Internet undergoing catastrophe process. So this article is focused on starting from measuring real network, and completely following the rules concluded from experimental data in order to present in-depth analysis of Internet internal change leading to noticeable catastrophe moments [15-16]. Based on the analysis of actual data, this is neglected at this stage of research and concluded differently from the only use of the Internet topology model of a similar nature. It

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reflects the evolution of the actual Internet, so it is more significant to Internet-based topology divorce and its practice. Mutation coefficient quantifies the stability of the internal network nodes from a new perspective. Research Network's main purpose, with the possibility of mutation, is to effectively prevent vicious Internet mutations in order to protect the healthy development of the Internet.

2. Internet topology characteristic quantity evolution trend analyses

CAIDA is an international cooperative institution focusing on global Internet structure and data analysis. The main purpose of its Internet study is to maximize the Internet data acquisition, analysis, research and sharing. The main participants include a number of research institutes, military institutions and higher education institutions in North America, Europe, and Asian countries. As a member of CAIDA, Northeastern University of China, not only collects its own Internet topology data, but also have access to the massive and timely updated data provided by the numerous measurement sources around the world by being identified by a collaborator of CAIDA.

This article selects six monitoring spots in different continents from 30 monitoring spots located globally from CAIDA (cooperative association for Internet data analysis). These six monitoring spots cover the entire Internet space, which can accurately reflect the overall properties of Internet. This paper measures the data in the period from April 1st 2009 to April 1st of 2010, which indicates recent Internet network topology characteristics.

Catastrophe phenomenon widely exists in both natural world and human society. Catastrophe phenomenon is destined to have catastrophe trace due to its realistic property, which is the fundamental characteristic of catastrophe phenomenon and used to tell the formation of catastrophe.

Normally the easiest noticed and imagined catastrophe phenomenon is the sudden-jumping characteristic as mentioned in catastrophe theory. Catastrophe in Internet structure is reflected as the change of static physical quantity which describes macroscopic topology. The revolution rule of overall network characteristics by time can very clearly reveal macro-structural changes and its intrinsic connection mechanism.

2.1. The change trend of Internet macroscopic characteristic quantity

Network node number reflects the size of the network in some degree. Connection number is another measure of network size; it represents the total side number of links between nodes. The diversity of connection choices causes the complexity of network topology. Average degree describes the connectivity of network nodes. The larger the average degree, the higher the average connectivity is, and this network is more likely to have robustness.

Figure 1 shows the variation evolution regularity of node number at AS-level Internet topology, the link side number, and average degree versus time. It also calculates the change trend of every quantity and sorts out the time spot with the biggest change.

It can be seen from Figure 1(a) which shows change of network link side number, on June 24th of 2009, October 8th of 2009 and January 19th of 2010, the value of link side number was significantly increased, by 2.4%, 5.7% and 1.8% respectively.

In Figure 1(b) which shows change of network node number, node number only increases significantly on Oct. 8th of 2009, from the 15,275 to 16,191, by 6%. The synchronous jumping increase of network node number and the link side number is due to the change of Internet core number has increasing trend with time. As time passes, climbing pace increases, and Internet level and structure tend to be complex. In the initial stage of core number increasing, there is obvious fluctuation wave, which then gradually becomes stable. Internet has certain degree of self-stabilization capability, which could self-adjust in certain scope, maintaining and recovering original ordered state, original structure and function.

Detection manner. The increase of detected node number causes the increase of link side number.

In Figure 1(c) which shows change of average degree, the average degree varies between 1.6 and 2.0 in the entire time period. It has significant jumping increase on June 24th of 2009 and October 8th of 2009. The link side number increases while network node number doesn’t. This causes increased network connectivity and robustness. Internet average connectivity degree of nodes increases with better connectivity; as any of the average shortest path between two nods decreases, the information can be transmitted more smoothly between them, thus quality of service provided by Internet will improve.

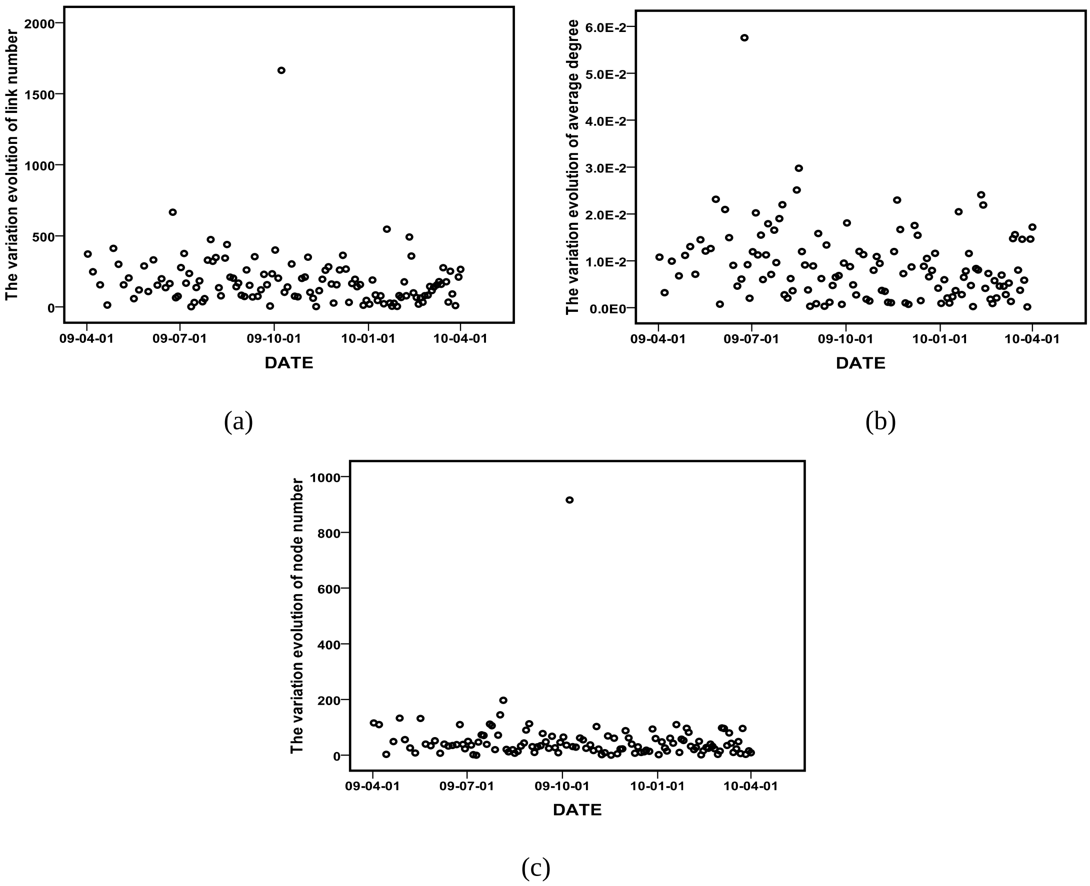


Figure 1. The Variation Evolution of Link Number, Node Number, Average Degree

So we select 3 catastrophe time spots which have jumping Internet integral characteristic number for detailed investigation, i.e. June 24th of 2009, October 8th of 2009 and January 19th of 2010.

2.2. The change trend of Internet core number

“k-core” in network is a collection of all nodes and edges left after removing nodes which have less than k-connected neighbors and edges. The nodes removed and the links between these nodes constitute a (k-1)-shell. Based on the conception of shell formed by k-core, the nodes in each shell have the same core. The number of this shell is not constant, but changing with the evolution of network. Therefore, it can externalize the hierarchy of Internet topology in a better degree.

Figure 2 shows the evolution regularity of core at AS-level internet topology and it can be found out as below:

Internet core number has increasing trend with time. As time passes, climbing pace increases, and internet level and structure tend to be complex. In the initial stage of core number increasing, there is obvious fluctuation wave, which then gradually becomes stable. Internet has certain degree of self-stabilization capability, which could self-adjust in certain scope, maintaining and recovering original ordered state, original structure and function.

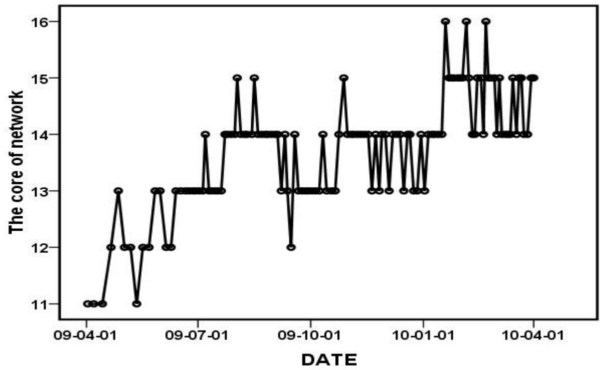


Figure 2. The Evolution of Core

The network presents increasing trend steadily which is valid according to the Internet development law. Internet has three jumping change catastrophe time spots in macroscopic characteristic quantity: June 24th of 2009, October 8th of 2009 and January 19th 2010 have larger core number fluctuations, indicating that Internet is in wave period on these 3 catastrophe time spot, with changed internal structure visibility.

Through analyzing network topology, it is found that: network exhibits steady increasing trend. Network is balancing small fluctuations formed by structure changes of the macro-topology constantly in the process of structural metabolism and self-replication. However, if the Internet errors generated by macro-topology catastrophe are constantly amplified, internet macro-topology will be significant affected, reflected as the jumping changes of network characteristic quantities.

3. Interlayer connection variations

AS-level Internet topology is classified by core; Connections of node set between different shells reflect the relationship between each shells of the network. Earlier results demonstrate: when there is fewer connection inside layer, interlayer connection will play dominate role, there is no much change of connection number inside layer but noticeable interlayer connection number. When internet characteristic quantity has catastrophe phenomenon, internet high layers, low layers have noticeable connection change with cores in other layers. Core number of internet has increasing trend with time, so it is very difficult to tell high layers from low layers. This section only uses the connection ratio change of the highest and lowest layer for detailed analysis.

3.1 The ratio of layer connections

The connection ratio of the highest and lowest layers is actually the ratio of internet highest, lowest layer nodes connection side number to the whole network connection side number. The changed part of highest and lowest layer connection indicates the connection change of Internet high and low layers.

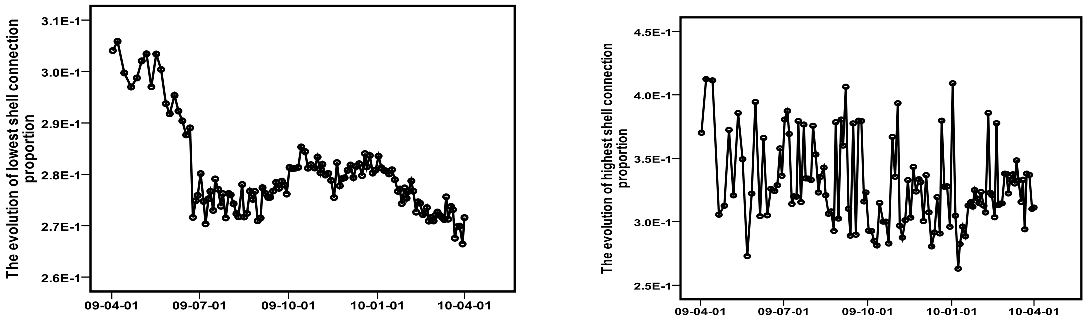


Figure3. The Evolution of Shell Connection Proportion

Figure 3 shows the change trend of lowest and highest layers connection ratio versus time respectively. From Figure 3 (a), it could be seen that the change of the lowest layer nodes and all the other layers have decreasing trend. Comparing with the evolution trend of average degree in Figure 1, the lowest layer connection ratio decreases noticeably on the time spots that average degree value obviously increasing. The lowest layer nodes connection mode plays certain role in the change of the whole internet connection.

In Figure 3 (b), despite the fluctuation change of highest connection ratio, as a whole it still exhibits a tiny decreasing trend. Because internet core number increases with time, the effects of every core on the whole all decrease. Despite that the highest level does not have many nodes; there is a lot of contribution to connection. This layer not only has a lot of connections, but also has these connections distributed in every layer. The connection of the highest layer with other layers is very close and is the real core of the Internet.

3.2. Change ratio of every layer connection ratio

Before the occurrence of catastrophe, the connection ratio of Internet layers has increasing trend with more active nodes. The difference between connection probability of lowest layer and other layers and the connection probability of highest layer and other layers is too large and makes the internet unstable. After accumulating the small variations into a certain degree, internet could not achieve balance by itself and catastrophe happens.

Calculate the highest and lowest layer connection ratio difference; understand the layer connection change mode. The specific calculation method is shown as equation 1:

$$\left.\begin{aligned} r &= h \div l \\ d(n) &= r(n) - r(n-1) \end{aligned}\right\} \quad (1)$$

r represents highest, lowest connection sides number ratio; d represents the change degree of r which is the wave mode of highest and lowest connection ratio number; h represents the highest shell connection proportion; l represents the lowest shell connection proportion.

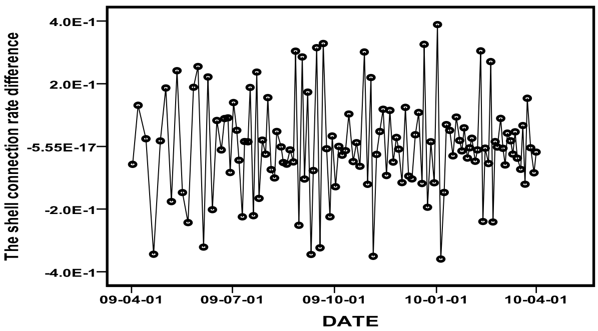


Figure 4. The evolution of shell connection rate difference

Figure 4 shows the change of the highest and lowest layer connection ratio number difference versus time, which could clearly tell us:

Connection ratio number difference changes periodically, exhibiting the regularity of “flat-fluctuation-fluctuation”, with the largest number 0.389, Here we conFigure each "smooth - shock - smooth" process as a period; the difference number fluctuates largely indirectly (waving period) followed by a relatively stable period.

Ratio difference number average value is a little lower than 0, which tells that the connection ratio exhibits small decreasing trend versus time, with decreasing high core effect.

Corresponding to the internet characteristic number calculated in chapter 2.1, 3 catastrophe time spots all exist in the transition moments from wave period to stabilization period, which are also the end of wave period. Compared with other wave periods without noticeable characteristic value change, the wave periods of June 24th of 09 and October 8th of

09 have relatively longer fluctuation time; the wave period of January 19th of 10 has a larger fluctuation degree.

Deduced from the above, the jumping change of internet integral structure is the summation of the accumulation of “tiny variation” in a period of time. This analysis proves again that the occurrence of catastrophe is directly related with the excessive connection ratio difference between the highest and lowest layer. The jumping change of internet characteristic is caused by the increasingly-amplified error of self-imbalance of internet. After catastrophe, the difference value of connection ratio decreases and internet becomes stable gradually.

4. Quantitative Internet catastrophe degree and prediction of catastrophe

The merit of catastrophe study lies in the study of inconsecutive catastrophe phenomenon in both natural and social world, which could be used to explain real objectives, predict future catastrophe act of objectives, and then control the occurrence of catastrophe.

4.1. The catastrophe degree of quantitative Internet

Catastrophe turned the state space of the system into non-differentiable. So the description and explanation of catastrophe phenomenon could not be achieved by classical calculus mathematics. According to the 1st and 2nd section of conclusion of internet topology character analysis and the extraction and finding of relevant characters: catastrophe of internet structure is due to the accumulation of “tiny fluctuation” caused by the self-duplication error in a period of time. This article proposes the concept of catastrophe coefficient, aiming at focusing on simplifying the measurement of possible Internet catastrophe probability.

(1) Concept proposal

Catastrophe coefficient: the catastrophe coefficient value of time spot k is the mean value of the absolute value of highest and lowest layer connection ratio difference in n days before k spot, which is also used to describe the accumulated fluctuation degree. As equation 2 shows:

$$c(k) = \sum_{i=k}^{k=n} \left| d(i) - q \right| \div m \tag{2}$$

In this equation, m is the times of measurement in n days before k spot; q is the mean value of the highest and lowest layer connection ratio difference. The value of $\left|d(i)-q\right|$ is selected in the period $[0,0.389]$, the degree of Internet stability could be estimated through $\left|d(i)-q\right|$: the more close it is to 0, the more stable it is.

Ideal condition estimation: the value of $d(i)$ is 0 for consecutive n days, then $c(k)$ value is 0, which means no catastrophe probability.

(2) The analysis of catastrophe time spot

Calculate the catastrophe coefficient of Internet in the time period between April 1st of 2009 and April 1st of 2010 and get $q = 5.55 \times 10^{-17}$.

Figure 5 shows the catastrophe change trend versus time when n=20, n=30 and n=40 separately.

n=20: the catastrophe has 3 noticeable local peaks: June 9th of 2009, September 21st of 2009 and January 8th of 2010.

n=30: the catastrophe has 3 noticeable local peaks: June 9th of 2009, September 27th of 2009 and January 8th of 2010.

n=40: the catastrophe has 3 noticeable local peaks: June 13th of 2009, October 2nd of 2009 and January 8th of 2010

Corresponding to the catastrophe time spots June 24th of 2009, October 8th of 2009 and January 19th of 2010, every catastrophe coefficient peak spot is 3 or 4 measurement times ahead of the catastrophe time spot, about 13 days. This is consistent with the characteristics of lag mentioned in catastrophe theory.

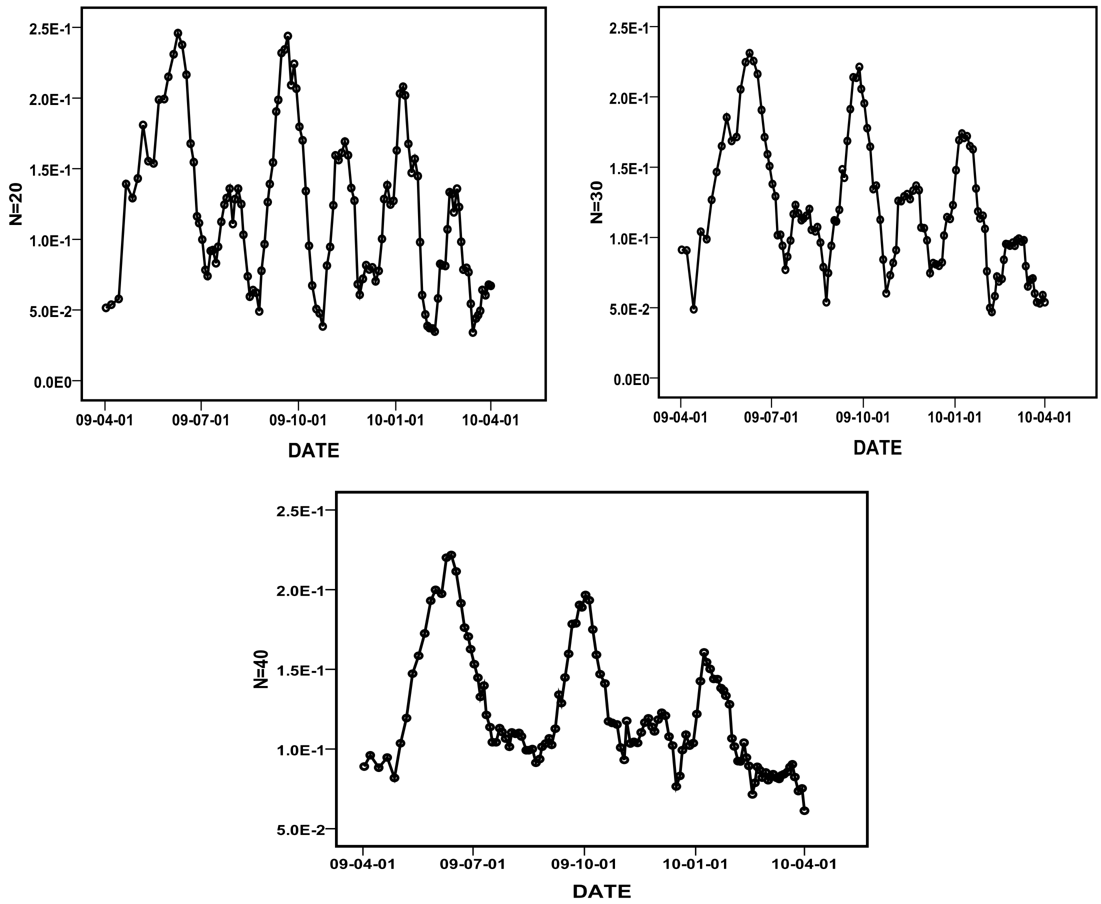


Figure 5. The evolution of Catastrophe Coefficient When n=20, 30, 40

It could be noticed that the smaller the n value, the more noticeable peak value and the earlier the peak occurrence, even small fluctuation could also be clearly indicated, which means that it could predict the occurrence of internet catastrophe earlier and more clearly; the larger the n value, the more noticeable the big fluctuations become (catastrophe state), ignoring the small fluctuation. The choice of n depends on the actual requirement.

Using the actual data to verify, it is found that catastrophe coefficient equation could express the degree of internet obvious change probability very well.

There has been no clear quantification standard to judge catastrophe occurrence probability reported in previous analysis of internet catastrophe phenomenon. The proposal of catastrophe coefficient could tell the intensity of jumping phenomenon occurrence more visually.

4.2 Prediction of occurrence of catastrophe

Prediction of possible internet catastrophe time and degree could provide important instruction for preventing internet destructive structure change, investigating internet future development and layout and further redesign of internet.

For catastrophe phenomenon prediction, it is still necessary to use real data for verification. According to equation 2, we calculate the catastrophe coefficient from April 1st to August 1st of 2010 based on real time. We take the balanced value n=30, which could have early peak value for easy notice and preparation. In addition, it could also clearly express noticeable catastrophe state, which is easier to compare and verify.

Figure 6 shows catastrophe coefficient change trend versus time from April 1st to August 1st of 2010. The testing times are more densely distributed as compared with before, so catastrophe coefficient change is relatively less noticeable.

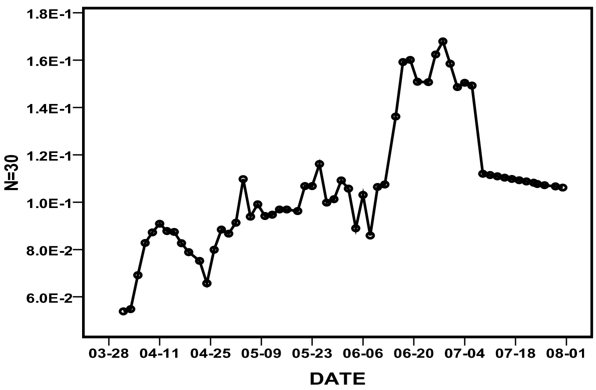
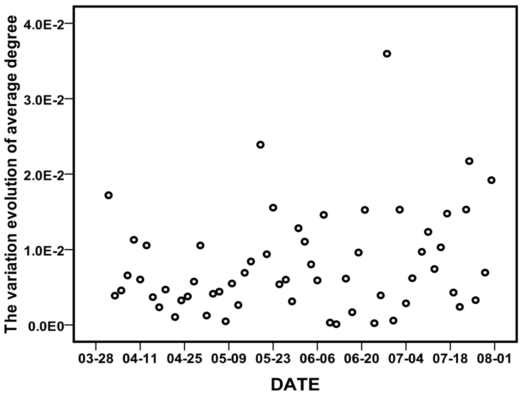
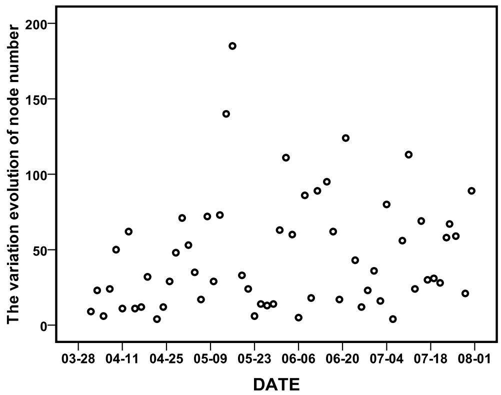


Figure 6. The evolution of catastrophe coefficient

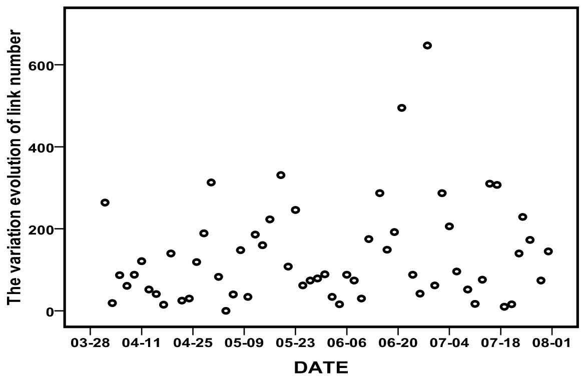
As shown in the Figure 6: on June 17th of 2010, internet catastrophe coefficient significantly increases and exhibits noticeable peak value. It could be predicted based on this that after about 13 days which is June 30th of 2010, internet macro-characteristic quantity will have significant change.

Through calculating the internet topology nodes number, connection number, mean degree change amount from April 1st to August 1st of 2010, we will verify the occurrence of catastrophe phenomenon as below.





(a) (b)



(c)

Figure 7. The variation evolution of link number, node number, average degree

Figure 7 shows the change trend of topology nodes number, connection number, and mean degree value change amount versus time. As indicated in Figure 7: Internet mean degree, nodes connection change amount has the local largest value on June 28th of 2010, which is expressed as the noticeable increase of mean degree and nodes connection number, with the amount 1.84% and 1.98% respectively; the nodes number change account increases 1.34 % on June 28th of 2010, indicating that the “jumping” change of internet on June 28th in of 2010 is mainly the change of node connection degree. The internet scale change is not the main cause of catastrophe occurrence. From this it could be concluded that internet catastrophe will occur on June 28th of 2010.

Considering the prediction result, it could be shown that the establishment of catastrophe coefficient could more precisely predict internet catastrophe phenomenon, making quantifying catastrophe possible.

The investigation of complicated Internet stability could help us better recognize and understand the dynamics phenomenon exhibited by real internet on one hand, and on the other hand, we could apply the internet stability research result into practice. For example, introducing the catastrophe coefficient into the classical internet model (BA model, PFP model) can highlight catastrophe characteristics in internal variation of network structure, which could enable us to take early actions to prevent internet catastrophe that might be devastating to the internet, design internet with better quality or improve the state of internet.

5. Conclusions

This article starts from CAIDA autonomy degree real data, analyzes internet topology characteristic quantity change trend, reaches the conclusion that internet is in increasing state and finds out the 3 jumping change time spots of topology characteristic quantity; Te interlayer connection change of internet between the 3 catastrophe time spots is analyzed-the result reveals that as Internet characteristic value jumping degree increases, the core number of topology structure has large fluctuation.

The connection ratio of highest and lowest layer exhibits periodic fluctuation and catastrophe spots are located in the transition from wave period to stability period. Jumping change drives internet into unstable state, but internet has certain degree of self-adjust ability. High layers of internet will recover its dominance, and internet will go back to stable state.

This article proposes the concept of catastrophe coefficient; calculates real data and selects value for corresponding coefficient. It predicts internet catastrophe probability and time based on catastrophe coefficient, and the prediction results match real data very well. Catastrophe coefficient could precisely describe the internal cause of internet jumping change, which is also the accumulation of “small fluctuation”.

Analyzing the catastrophe change in real internet macro-topology structure provides support for understating its internal change, evolution mechanism. We not only pay attention to the macroscopic network growth trend, but pay more attention to the internal links between the nodes change. Network mutation characteristics are used in the IPv6 construction of next-generation Internet, which can effectively prevent the mutation from having a devastating impact on the network, and this is our future work to be done. It also provides instruction for optimizing the existing models and effectively preventing catastrophe from damaging the internet.

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