

A SOURCE ANALYSIS OF THE CONFICKER OUTBREAK FROM A NETWORK TELESCOPE

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Abstract: This paper discusses a dataset of some 16 million packets targeting port 445/tcp collected by a network telescope utilising a /24 netblock in South African IP address space. An initial overview of the collected data is provided. This is followed by a detailed analysis of the packet characteristics observed, including size and TTL. The peculiarities of the observed target selection and the results of the flaw in the Conficker worm's propagation algorithm are presented. An analysis of the 4 million observed source hosts is reported, grouped by both packet counts and the number of distinct hosts per network address block. Address blocks of size /8, 16 and 24 are used for groupings. The localisation, by geographic region and numerical proximity, of high ranking aggregate netblocks is highlighted. The observed shift in geopolitical origins observed during the evolution of the Conficker worm is also discussed. The paper concludes with some overall analyses, and consideration of the application of network telescopes to the monitoring of such outbreaks in the future.

Keywords: Conficker, Zotob, malware, network telescope, geolocation.

1. INTRODUCTION

This paper explores the application and value of the use of a network telescope [1–3] in the tracking and monitoring of a global malware outbreak over the period from August 2005 to September 2009. During this period, the volume of traffic observed arriving at the research telescope destined for port 445/tcp grew dramatically, particularly over the last 14 months of the dataset, reaching a peak of nearly two orders of magnitude higher than the previously observed traffic baseline. Much of this increase can be attributed to the prevalence of the Conficker worm [4], also known as Kido and DownAdUp [5], and associated exploitation of the vulnerability in the Microsoft RPC/DCOM stack.

Conficker and other associated malware exploits a vulnerability in the Microsoft RPC stack detailed in the Microsoft MS08-067 [6] security bulletin released on 23rd October 2008. The vulnerability exploited is similar to those discovered in July 2003 detailed in MS03-026 [7] and later in MS03-039 [8] and subsequently exploited by the Blaster and Welchia worms in August 2003 [9]. A further vulnerability in the RPC stack was exploited by Sasser in April 2004, taking advantage of the vulnerability disclosed in MS04-011 some seventeen days previously [10]. The problems with the RPC/DCOM stack in Microsoft Windows Family operating systems continued and MS06-40 released in September 2006 [11] patched a further vulnerability that was exploited by various malware, such as Mocolot. Given this history of vulnerability, and the widespread adoption of the Windows operating platform, as well as the rapid development of code exploiting these vulnerabilities, researchers were justifiably concerned when the MS08-067 vulnerability was announced. A detailed analysis of the Conficker malware is beyond the scope of this research. For details on the actual origins, and analysis

from a payload and reverse engineering perspective, readers are encouraged to consult in particular the work done by SRI [12] and Symantec [13] on reverse engineering and documenting the initial spread of the malware.

This paper presents a discussion of how the spread of this malware was observed from the perspective of the network telescope system, using data as described in Section 2. An overview of the evolution of the worm is presented along with a time-line of the major points in the evolution of this software in Section 3. This is shown to match fairly accurately with the observed changes in traffic presented in Section 4. An analysis of the observed network traffic is presented in Section 5. A focus of on the traffic distribution across the target addresses is discussed in Section 6. These latter two sections present evidence for the strong likelihood of the majority of the 445/tcp traffic being Conficker related. An analysis of the network sources observed is carried out in Section 7. This is then followed by an analysis of the geopolitical distribution and observed shift in the source origins in Section 8. Considerations of the implication and application of this research, and the network telescope sensor as a malware analysis tool is contained in Section 9. The paper concludes with a reflection on the application of a network telescope to the monitoring of this kind of event, and the views of traffic as observed by other sensors.

2. DATA SOURCE

This research was carried out using TCP/IP packet data collected over a 50 month period from August 2005 to September 2009, using a /24 IPv4 network address block, within South African address space. The address space was connected to a passive network telescope [3] operated by the researcher [14]. The above period in

which data was collected includes the period of the outbreak of the Conficker worm. The analysis of traffic relating to this malware outbreak late 2008 is the focus of the remainder of this paper.

2.1 Network Telescopes

Network telescopes are a means of monitoring 'Internet Background Radiation' – network packet data which arrives at a destination network unsolicited. This method was popularised by Moore et al [3]. Specifically a network telescope makes use of unallocated IP addresses which are not being used for running services. Based on this any incoming traffic recorded can be viewed as unsolicited, as ideally no traffic would be received, as no clients or servers are operating using these addresses. Care is taken to filter traffic so as to ensure that no response traffic is sent so as to appear to remote hosts as indistinguishable from an unallocated address. A more detailed discussion of the varying modes of operation for network telescopes and related analysis methods can be found in Irwin [14]. Greynets [1, 2] are a related implementation using smaller slices of address space than have traditionally been used for the operation of network telescopes.

What is important to bear in mind when analysing the data collected using the Rhodes University system, is that one of the shortcomings of the current network telescope setup is that only the first packet of the potential TCP 3-way handshake is actually captured. Since the handshake, by design, cannot complete, no data payload can be captured. Due to this limitation it can only be inferred, albeit with a high level of certainty, that the increase in observed traffic is directly related to the Conficker malware. It is believed, based on analysis of the data, that the majority of the recorded connection attempts are automated connections from Conficker, but there is certainly a component which is scanning activity from other sources looking for operational hosts which may also be vulnerable to the MS08-067 issue and subsequently targeted for exploitation.

2.2 Data Processing

Data was collected using tcpdump and piped through an analysis framework [14]. Passive operating system fingerprinting was performed using the p0f tool in order to classify the likely origin operating system. This is a passive (in the sense it does not use live interrogation such as implemented by nmap) operating system fingerprinting tool developed by Michal Zalewski. The passive technique allows for it to be used on recorded traffic. The network telescope host itself ensured that no return packets could be sent, and was located outside of the organisational firewall. Geolocation tools were also used to relate a given IP address (or address block) to a country of allocation.

3. CONFICKER EVOLUTIONARY TIME-LINE

The evolution of the threat posed by the Conficker can be traced back to the release of the MS08-067 advisory on 23rd October 2008 as an emergency, out of sequence, malware patch by Microsoft after exploitation of the vulnerability was observed in the wild. One of the issues to be aware of when analysing Conficker and research around the threats, relates to the two different naming conventions used by Microsoft and the Conficker Working Group (CWG). The former appears to be in more widespread use. These differences are shown Table 1. In this document the Microsoft naming conventions are used. When analysing the traffic, inflexion points can be seen relating to the version changes in the Conficker malware, as seen in Section 4.2. A more detailed timeline of the evolution of Conficker is maintained by the CWG¹.

Table 1: Conficker Naming

Date	Microsoft	CWG
20 Nov 2008	Conficker.A	Conficker.A
28 Dec 2008	Conficker.B	Conficker.B
20 Feb 2009	Conficker.C	Conficker.B++
4 Mar 2009	Conficker.D	Conficker.C
8 Apr 2009	Conficker.E	-

4. TELESCOPE TRAFFIC OBSERVATIONS

Observed network traffic destined to 445/tcp makes for an interesting case study on a number of fronts. Firstly, packets targeting 445/tcp are the single most significant contributor to the total of traffic observed, both in terms of the number of packets and source addresses observed. Secondly, it is used by the Microsoft Windows family of operating systems for RPC/DCOM communications, including file sharing, and is usually enabled on such systems. The popularity of the deployment of these systems makes this an inviting target when vulnerabilities are found, with historically widespread exploitation. Furthermore, this port is generally firewalled by most organisations, and often by home users as well, although usually only for inbound traffic.

4.1. Overview

Traffic destined to port 445/tcp as a whole, can be seen to be fairly persistent over the entire duration of the network telescope observation under consideration, having been observed on all but one of the 1 429 days having data (and 98.1% of hourly observations) within the dataset. Over the period 445/tcp was consistently ranked in the top ten targeted ports observed, by both month and year. During the observation period, packet counts for traffic destined to port 445/tcp was the top ranked in 10 of the 17 quarters under study, with its lowest positions being 4th in Q1 2007 and Q4 2008. Figure 1 shows the prevalence of this traffic over the observation period.

¹ <http://www.confickerworkinggroup.org/wiki/pmwiki.php/ANY/Timeline>

Data shown in this figure reflects only that TCP traffic destined to 445/tcp that has the SYN flag set, and hence can be considered 'active' (in terms of this traffic could potentially elicit a valid response from a target). This traffic also accounted for 41.4% of the traffic overall, consisting of some 16 893 920 packets.

The rapid increase in traffic from approximately 1 000 packets/day (ppd) in October 2008 through to nearly 100 000 ppd by the end of September 2009 can be clearly seen. The benefit of the long collection baseline was realised in this comparison, in terms of being able to quantify just how large the increase in traffic was.

The spike in observed activity in the early portion of Figure 1 is probably attributable to the Zotob worm [15] exploiting a vulnerability disclosed on 9th August 2005 in MS05-039 [16, 17], either from the worm itself or related scanning in response to this event by individuals looking for vulnerable hosts. Traffic levels had, however, decreased and became largely normalised by November 2005 and continued to drop through to mid-October 2008. This gradual decrease is likely due to the increased uptake of automated patching of systems through the Microsoft Windows Update mechanism, the release of Service Packs for Windows XP (SP3 - April 2008) and Windows Vista (SP1 - March 2008, SP2 - April 2009) resulting in the remediation of vulnerabilities in the RPC service. More significantly, the lack of any significant vulnerability affecting this protocol during the observation period would have reduced the incidence of scanning. The rapid increase in traffic observed from October 2008 onwards can be attributed to activities surrounding the exploitation of the MS08-067 vulnerability in Microsoft Windows operating systems, most notably by the Conficker worm. The remainder of this paper focuses on activity observed from October 2008 onwards.

4.2. Conficker Related

The Conficker worm was first observed on the 20th /21st November 2008 (depending on time zone), and after almost a year, over 7 million hosts were observed as still infected². After the 20th November, traffic destined to 445/tcp constituted 70% of traffic observed. Over the entire observation period, 4 002 119 unique hosts (86% of the total) were observed sending packets to a destination port of 445/tcp. Of these addresses, 95% were observed after the 20th November 2008, with only 5 544 (0.14%) having been observed prior to the 1st November 2008. Only 0.3% of the IP addresses identified as having targeted 445/tcp had sent any traffic at all prior to the beginning of November 2008. This is indicative of a marked change in observed traffic patterns.

This is not the first work to have been done on looking at Conficker from the perspective of a network telescope

with some detailed analysis having been performed by CAIDA researchers [18], and the subsequent release of a portion of their 3 Days of Conficker dataset [19]. What is novel in this paper is the fine level of detail at which analysis has been performed along with the use of data from a single /24 network telescope with a continuous long term baseline. Previously work [18] on the spread of Conficker relating to network telescopes has made use of the CAIDA /8 telescope, and a further dataset gathered on a /16 netblock.

The discussion in the remainder of this paper primarily focuses on the traffic considered Conficker related from mid-October 2008 through to the end of the dataset at the end of September 2009, in effect covering nearly a year of activity related to the MS08-067 vulnerability, and the spread of the Conficker worm through its evolutionary phases. This long uninterrupted temporal baseline in relation to other research allows for some insight to be gained into the changing behaviour of the malware over an extended period.

An overview of the total traffic observed by the telescope system is shown in Figure 2 as the calculated average number of packets received per IP addresses in the monitored range. A number of distinct spikes in the traffic are noticeable, along with the general increase in traffic over time. The increase is, however, not nearly as rapid as that observable in the latter part of Figure 1. Particularly notable events are the large spike on 28th October 2008, followed by a rapid climb on the 21st November 2008. A second rapid increase can be seen on 1st January 2009, with a consistent increase in traffic rates observed through to mid-February, and a large increase in activity on the 28th February. This is followed by a sharp drop-off mid-March and a small spike prior to 1st April. From this point the traffic continues to increase, other than two dips which were caused by network outages. On initial observation, these periods seem to coincide to those outlined in the evolution timeline in Table 1.

Looking a little deeper, and analysing the composition of the traffic by protocol, one can see that the spikes observed cannot be correlated directly to activity on port 445/tcp. This detailed breakdown of the same dataset and time period as previously shown in Figure 2 can be seen in Figure 3. In the detailed plot, ICMP and UDP traffic have been shown along with the contribution made by traffic destined to 445/tcp on the sensor network. Several points in Figure 3 are worth highlighting:

- Although the spike shown at point A ties in with the release of the MS08-067 security bulletin, it is not related to it, but rather is the result of a burst of classic back-scatter packets originated from a UNIX system located in Jordan.

² <http://www.shadowserver.org/wiki/pmwiki.php/Stats/Conficker>

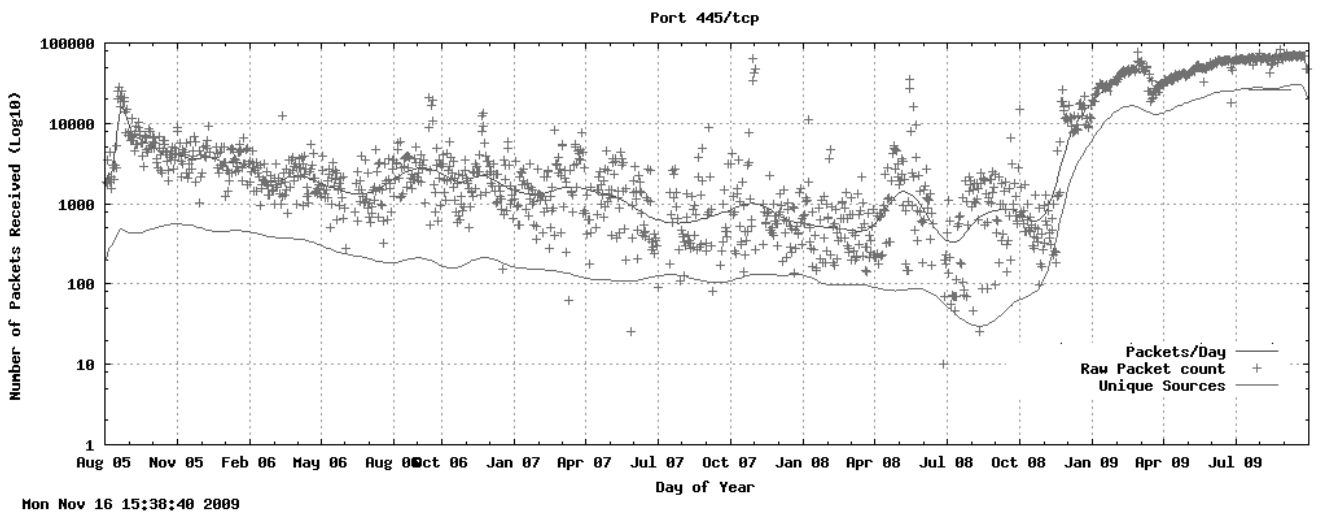


Figure 1: TCP packet received on port 445 by day.

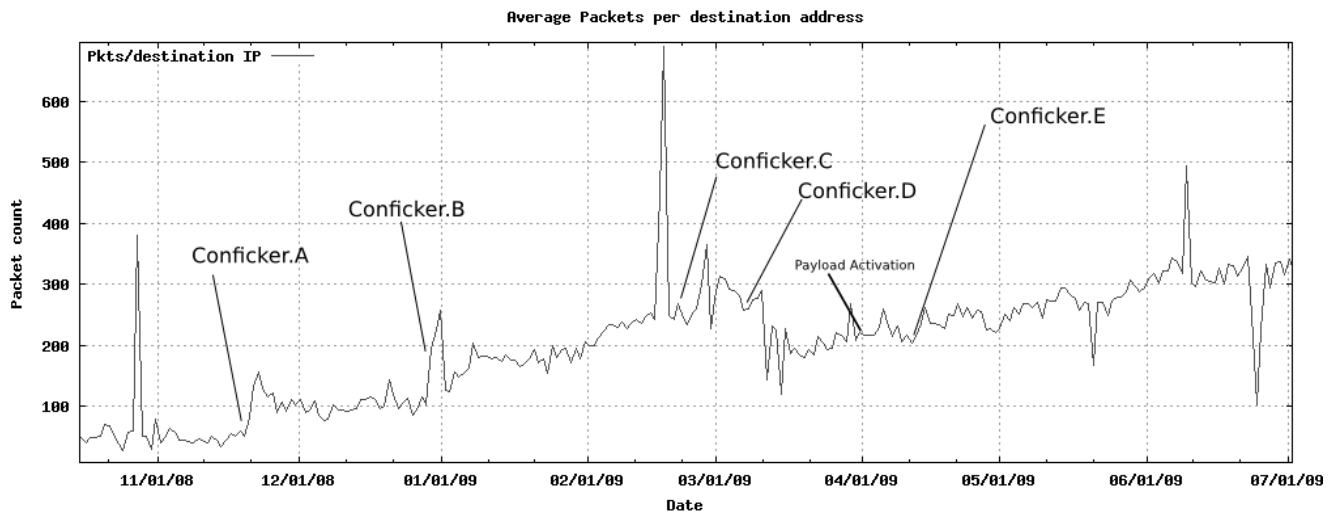


Figure 2: All Traffic November 2008 - July 2009

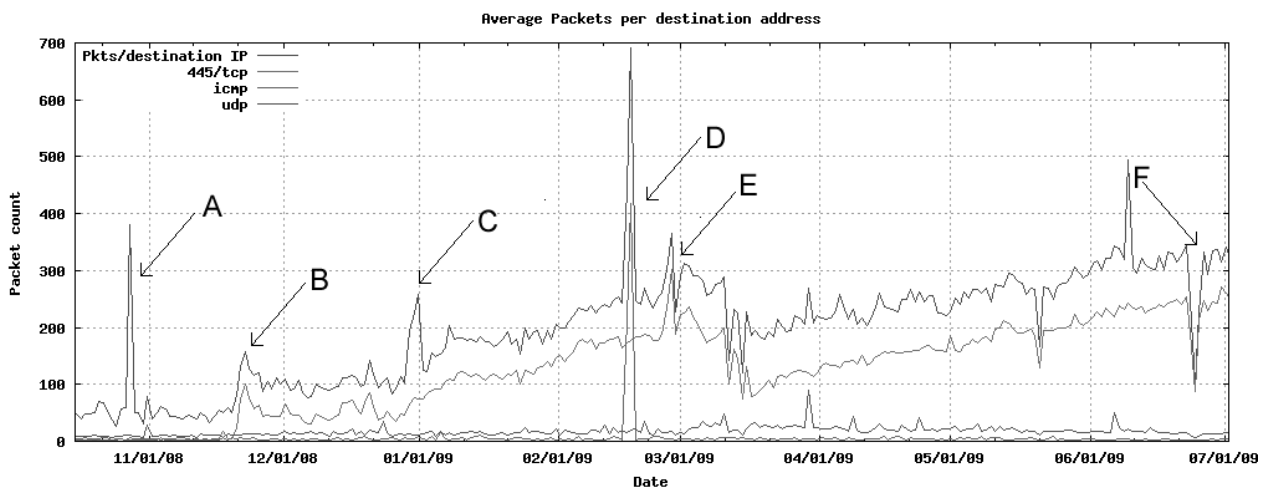


Figure 3: Traffic Protocol Breakdown (November 2008 - July 2009)

- The ‘birth’ of Conficker on the 21 November 2008 (point B) can be seen by the sharp rise in 445/tcp traffic as a portion of the whole. Conficker.B was released on the 28th December 2008 and although there is a spike in total traffic (point C) this was not due to Conficker, but a reflected back-scatter SYN-ACK packets from a web server located in Costa Rica.
- Point D indicates a further anomaly in the traffic pattern, with the spike caused by a flood of 159 000 ICMP TTL expired messages, received from a host in China on the 17th and 18th February 2009.
- The spike in late February 2009 (point E) can be attributed to the release of Conficker.C on the 20th February.
- Point F is worth noting in that the drop in recorded traffic was due to a series of extended network outages adversely affecting Rhodes University’s upstream Internet connection over the period 24th - 26th June 2009.

4.2. Conficker Outbreak

Analysis of the data in the first few days of the Conficker outbreak revealed some interesting trends. The first of these is illustrated in Figure 4, which plots data relating to traffic received on 445/tcp during the period 21st -24th November 2008. Times noted in the Figure are SAST (GMT+2:00). What is immediately noticeable is that while the packets follow a rough circadian rhythm, this trend is even more noticeable when the number of distinct sources for each hour interval is plotted. Similar results were found with the data processed in the CAIDA Conficker report [18]. Considering the 24 hour period from midnight on the 21st November, the number of observed sources per hour can be seen to climb rapidly, from fewer than ten at 05h00 to over 250 by midnight the following day. What is interesting is that there is a large

increase in packets observed around 06h00, yet only twenty source hosts had been observed at this stage. From this point the packet rate per hour dropped dramatically and the host count started to climb — in essence, more hosts were sending relatively fewer datagrams. By 16h00 traffic had reached a low point and subsequently started to increase again, with a rapid growth in the number of sources observed; a high sustained rate being maintained for nearly ten hours before dropping back. This is pattern can be seen to be repeated over the next two days.

An interesting anomaly was found in the data for 445/tcp, with a significant spike in scanning activity detected over a period from late on the 30th September, through to the evening of the 1st October 2008. This increase in scanning was particularly noticeable due to there being almost no traffic targeting 445/tcp in the days leading up to this and very little afterwards. A plot of the relevant traffic is presented in Figure 5. The traffic is also seen to originate from a relatively high number of sources, with 3 476 IP addresses being logged between 03h00 and 18h00 on the 1st October, having sent some 14 808 packets targeting 445/tcp. The top five geopolitical sources as determined by geolocation tools were Brazil (BR), France (FR), the USA (US), Japan (JP) and the Philippines (PH). Together these accounted for nearly half (46%) of the traffic sources observed during this period, a summary of which is shown in Table 2. Brazillian and US hosts achieved an almost complete coverage of the network telescope range. Sources of traffic targeting 445/tcp were observed from 100 countries, although only 30 of these had more than twenty distinct sources. This would indicate a fairly low spread of dispersion of hosts involved in the scanning. This could in turn point to localised networks of previously compromised systems being used.

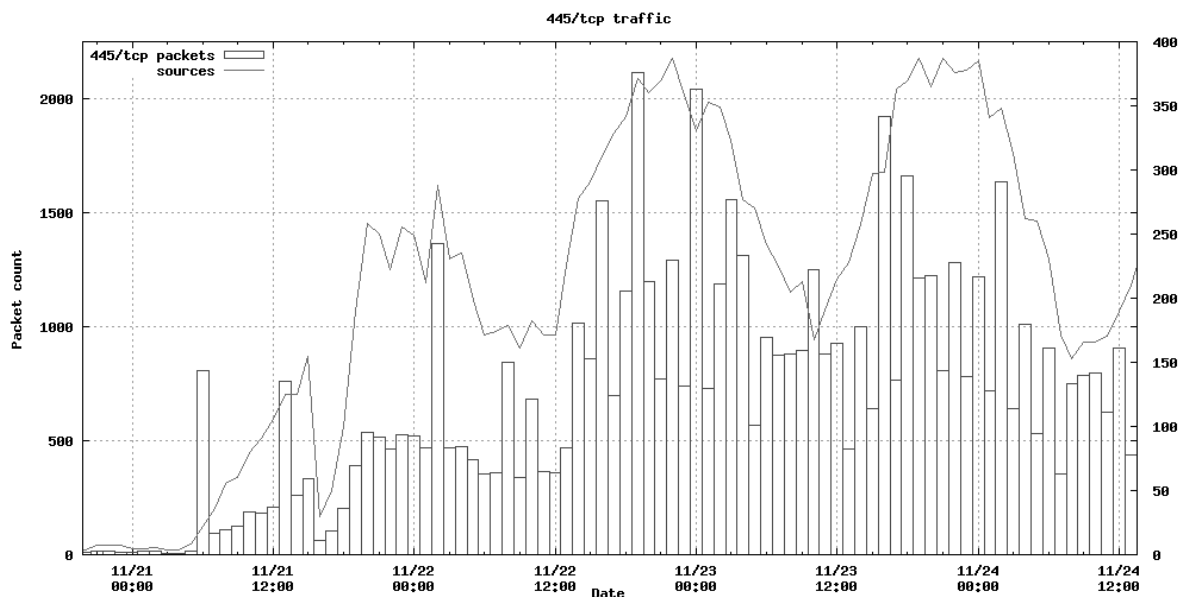


Figure 4: Early days of Conficker (21st - 24th November 2008)

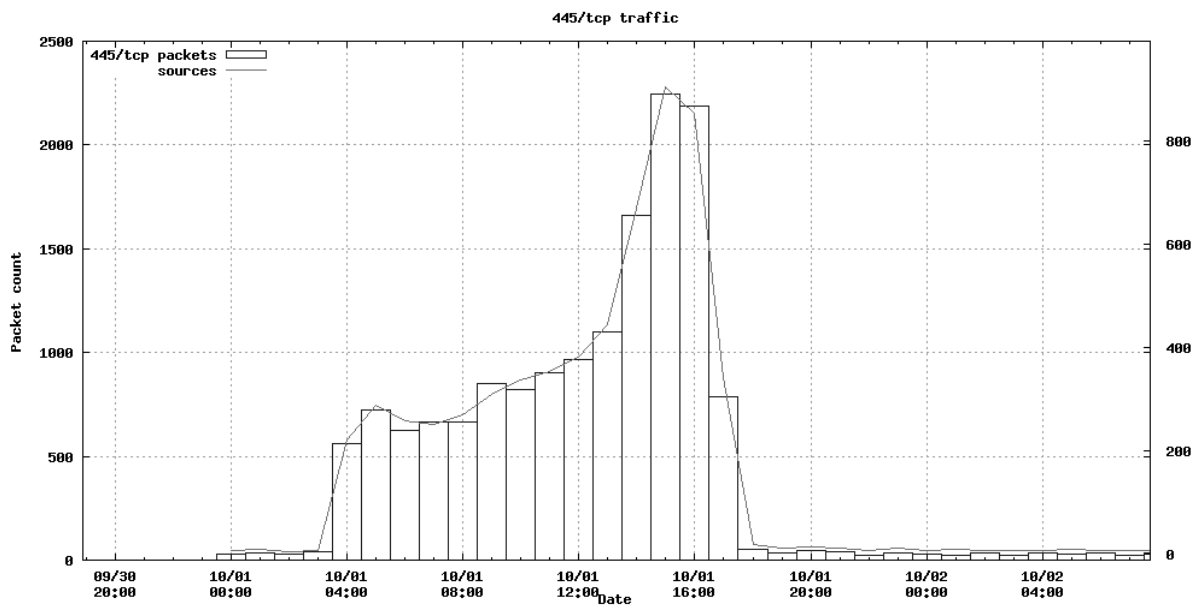


Figure 5: Early reconnaissance (30th September - 2nd October 2008)

Table 2: Top 5 countries (1st October 2009)

Rank	CC	Count _{Packets}	Count _{Source}	Count _{Dest}
1	BR	2203	625	249
2	FR	1551	388	231
3	US	1877	279	249
4	JP	654	167	177
5	PH	573	155	157
Total		6858	1614	

Without payloads, it is impossible to determine the exact nature of this traffic, or the means of its generation. While it could plausibly be activity from the Gimmiv trojan [20], it was noted that there were problems with its replication mechanisms. Another possibility is that it could be some custom malware utilising the Chinese exploit kit based on the Gimmiv trojan. It is nonetheless interesting to note that there is a fairly even distribution across the entire monitored IP range, in contrast to what is seen with the actual Conficker malware post release, as explored in Section 6. The majority of the sources (99%) scanned less than ten target addresses, with 1 832 (52%) only probing one host. Only three hosts scanned more than 100 addresses, while the majority of sources sent two packets which were in relatively quick succession, before disappearing. This type of activity would indicate some form of optimised scanning identifying live networks, and possibly using a distributed scan to minimise detection.

It is the researcher's hypothesis that there is a strong likelihood of this having been a distributed scanning attempt, with multiple sources scanning to look for vulnerable hosts possibly for further targeted exploitation, or as a means of seeding initial distribution points for later malware release. The fact that such a high number of hosts only probed a single target points to a well-

coordinated, distributed scan, or to these addresses possibly being used as a decoy scan. The three top hosts (by packet count) were determined to be in Taiwan (TW) and the USA, and are most likely the real hosts. This is supported by the fact that hosts that are geolocated as originating from locales such as the Philippines (PH), Croatia (HR), Turkey (TR) and Austria (AT) all have TTL values above 240. This is highly unlikely given that Rhodes University's Internet connectivity which had, at the time of collection, at least ten hops to get to international peering points in London. Further examination of the TTL values of traffic targeting 445/tcp shows that a significant number of the hosts have the same TTL values despite being geolocated to vastly different parts of the globe, further strengthening the likelihood of packet forgery. The fact that only two packets are sent is also interesting as generally most TCP/IP stacks send three SYN connection attempts before timing out. This could point to the fact that custom code was being used with a short time-out, or that packets were being constructed using 'raw' sockets.

5. PACKET DATA

This section evaluates aspects of the packets received on 445/tcp by the network telescope, considering the observed TTL, packet structure, packet retransmission, and source operating system.

5.1. Time to Live

An analysis of the TTL values recorded for all incoming traffic destined to 445/tcp showed a very narrow banding where it was observed that the values were, with few exceptions, between 50 and 100. This range covers default TTL settings for both Windows and UNIX platforms, having default base TTL values of 128 and 64 respectively. This banding is further evident when plotted against packet counts for TTL values received overall as

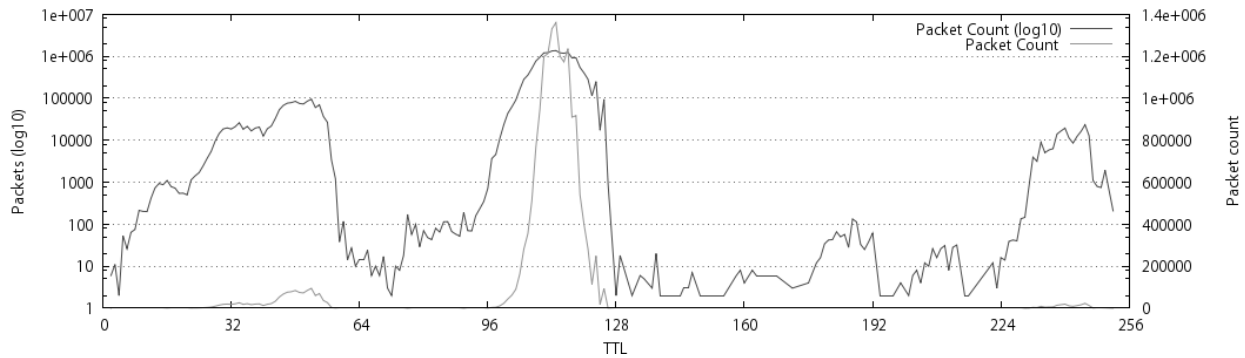


Figure 6: Packet counts by TTL for 445/tcp

presented in Figure 6. In this Figure the TTL values for 445/tcp packets can be seen to be largely grouped in the 96-128 range, with very few packets recorded in the 32-64 and 224-255 ranges.

This provides strong evidence towards Microsoft Windows platforms being the origin of the packets. This was confirmed by the passive operating system fingerprinting that was performed (Section 5.4). This would in turn lend weight to the supposition that when considering the number of distinct sources, the packets observed were actually generated by the automated scanning modes of the Conficker worm, rather than other automated tools.

5.2. Packet Structure

Table 3: Size of packets targeting 445/tcp

Size	Count _{packet}	Packet %	Count _{source}	Source %
62	12 207 669	86.18	3 248 492	85.16
66	1 281 603	9.04	443 325	11.62
78	423 043	2.98	153 076	4.01
60	150 549	1.06	25 211	0.66
74	100 043	0.70	31 278	0.81
Total		99.96		102.26

$$N_{\text{Packets}} = 14\ 165\ 097 \quad N_{\text{Sources}} = 3\ 814\ 447$$

Source % total is >100% as hosts may have sent different size packets

Based on an analysis of the datagrams received, the majority were found to be of 62 bytes in size. A summary of packet sizes is given in Table 3. In this Table, it can be seen that more than 85% of both the hosts and packets match this sizing. This is reached by having a TCP packet with no data and encapsulated inside an IP and finally an Ethernet datagram. In order to reach the value of 62 bytes, rather than the default of 60, TCP options are set. The combination found set most often was “MSS:1460, NOP NOP TCP SACK:True”, which accounted for 8 bytes. These options enabled the Selective Acknowledgement (SACK) on the connection being established, along with a maximum sent size of 1 460 bytes. These settings were found to match captured Conficker propagation traffic. Thus there is a fairly high

probability that the TCP SYN packets being sent to addresses on the telescope actually originated from the Conficker malware.

This provides an example of how, despite being somewhat handicapped by the lack of payloads in a network telescope dataset, comparative data from honeynet or other systems with higher levels of interaction can be used to augment the analysis process. While absolute certainty is not possible without payload analysis, researchers can attain a high level of confidence in their analyses.

5.3. Transmission

A further interesting characteristic observed in the 445/tcp traffic after the advent of Conficker, is that it has a very noticeable signature ‘on the wire’ in terms of the way connection attempts are made. Most operating system TCP/IP stacks will send at least three TCP SYN packets in an attempt to establish a connection. By contrast, in the majority of the 445/tcp traffic received after the 20th November 2008, one observes only two connection attempts. An example of this is shown in Figure 7, where source addresses (in the 4th column) make two connection attempts approximately three seconds apart. Similar behaviour has been observed by Aben [18]. This was further validated by the researcher with captures of live propagation traffic obtained from hosts with confirmed Conficker infections.

Considering the total number of sources observed and the total number of packets targeting 445/tcp after 20th November, these are in a ratio of approximately 1:4, indicating that on average most sources scanned two hosts at most. This is discussed further and an analysis of the target addressing is provided in Section 6.

5.4. Operating System Fingerprinting

Operating System attribution was performed using p0f. While it is recognised that this method is not flawless, and may be skewed by the use of NAT and dynamic address allocation, it nevertheless provides a useful measure. The results are presented in Table 4. Microsoft

1	01:16:21.685360	IP 190.50.x.80.2725 > 196.x.y.3.445: S 2062323770:2062323770(0)
2	01:16:23.509228	IP 77.28.x.55.4853 > 196.x.y.34.445: S 1323192692:1323192692(0)
3	01:16:24.677814	IP 190.50.x.80.2725 > 196.x.y.3.445: S 2062323770:2062323770(0)
4	01:16:26.514630	IP 77.28.x.55.4853 > 196.x.y.34.445: S 1323192692:1323192692(0)
5	01:16:27.693010	IP 79.0.x.248.1731 > 196.x.y.18.445: S 1786561877:1786561877(0)
6	01:16:29.808481	IP 189.101.x.133.2499 > 196.x.y.3.445: S 3114908412:3114908412(0)
7	01:16:30.696890	IP 79.0.x.248.1731 > 196.x.y.18.445: S 1786561877:1786561877(0)
8	01:16:32.751635	IP 189.101.x.133.2499 > 196.x.y.3.445: S 3114908412:3114908412(0)

Figure 7: Example of the two packet repetitions

Windows family of operating system platforms accounted for 99.7% of the sources that could be attributed, which is unsurprising given that the Conficker malware targets these platforms, and the TTL data as seen in Section 5.1.

Table 4: Traffic to 445/tcp by attributed Operating System

Rank	Protocol	Number	%
1	Windows	16336052	99.671
2	Proxyblocker	19401	0.118
3	MacOS	10066	0.062
4	FreeBSD	7114	0.043
5	Linux	4361	0.026
6	NetBSD	3981	0.024
7	Cisco	3230	0.019
8	Solaris	1910	0.011
9	Checkpoint	1343	0.008
10	NMAP	1258	0.007
			99.992

N=16 389 887 % of Packets attributable to an IP address with an identified OS N is calculated as packets received after 2008-11-20 00:00 GMT+2

What is surprising is that machines are being observed as infected, despite the patch having been out since 23rd October 2008, and the Microsoft malware removal tool having had functionality to clean the Conficker malware off a system since January 2009. The removal tool is automatically run by the patch update procedure that occurs as part of Microsoft's monthly 'Patch Tuesday' patch cycle. One of the actions taken by the Conficker malware as a means of self-preservation is to disable the automatic update and patching mechanism provided by Microsoft operating systems. What can be concluded from this is that these machines remain infected due to one of the following reasons:

User unaware — The user is unaware of the infection.

User unable to update — The user is unable to update because of the defence mechanisms put in place by the malware.

System unable to update — The user is unable to apply updates due to the system

platform likely being pirated and therefore unable to update³.

6. TARGET ANALYSIS

Changing focus away from the sources of the traffic to the addresses being targeted in the network telescope address space, a very uneven distribution pattern is observed. The lower half of the monitored space, i.e. 196.x.x.0/25, is targeted substantially more than the upper half (196.x.x.128/25). Particularly heavily targeted is 196.x.x.1, closely followed by other addresses in the lower 16. The first eight addresses in the address block all received more than 100 000 distinct sources. This bias is shown in Figure 8, which considers the number of distinct sources rather than packets observed for each IP address in the monitored range.

The strong bias towards the lower portion of the address space can be seen clearly. Notably, the last address in the monitored range (196.x.x.255) received a much higher coverage than other IPs in the upper /25 portion. The reason for this bias is most likely a naive scanning optimisation, which attempts to probe one or more addresses on a range and, if no response is received, moves onto another range. The probes to the last address on the range may serve a similar purpose. By convention default gateways on most IP networks either make use of the first or last address in a given subnet.

The packet counts received for each address, presents a markedly different picture, as shown in Figure 9. A significant change in the levels can be seen occurring at 196.x.x.128, with a drop in recorded traffic of nearly two orders of magnitude. Figure 9 contains the number of sources, and the packet count observed for each address. A third value is plotted on the right y-axis, being a ratio of the number of packet to distinct sources. This value also makes a change as the target address moves into the upper half of the range, doubling from just over 2 to 4. The dip at the beginning of the graph is due to some traffic having been recorded to 196.x.x.0, which is not normally targeted as it would be regarded as the 'network address', rather than a host address.

³ Interestingly this is a policy that Microsoft changed with the advent of the Windows 7 platform. Even pirated copies of this OS will be able to receive security updates.

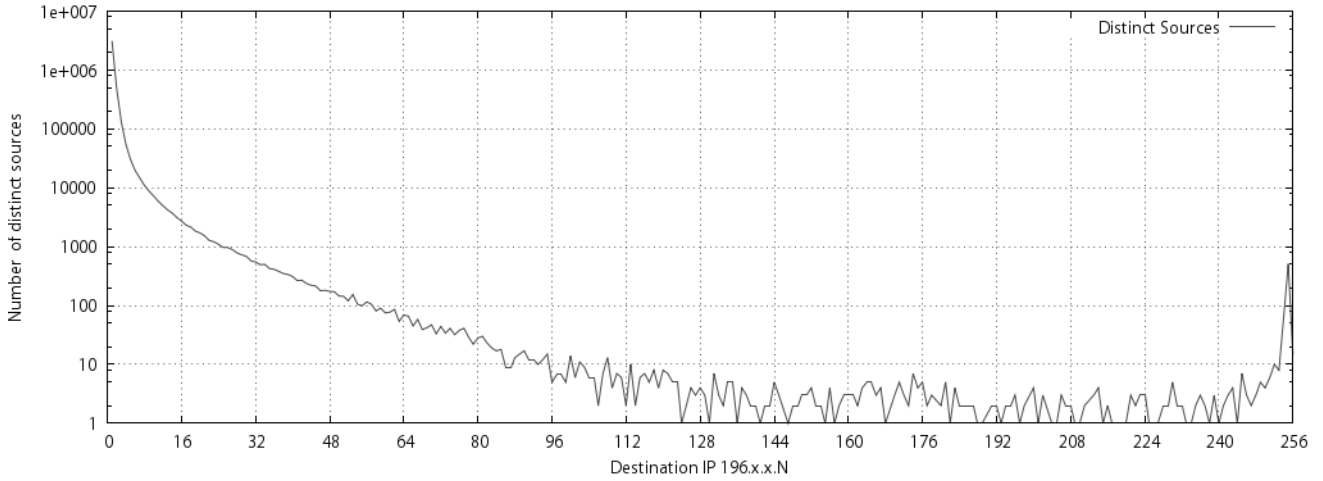


Figure 8: 445/TCP traffic - distinct sources per sensor IP

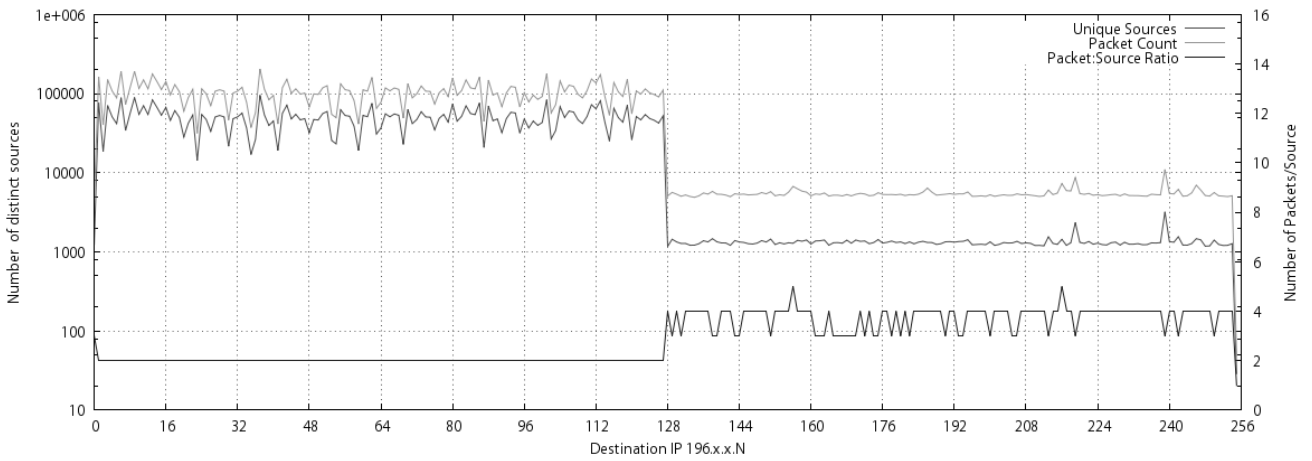


Figure 9: 445/TCP total traffic received per IP in the sensor network

Table 5: Top 445/tcp origins by packet count

Rank	/8	count	%	/16	count	%	/24	count	%	/32	count	%
1	196.0.0.0	1 118 121	7.921	196.21.0.0	287 270	2.035	196.21.218.0	266 790	1.890	196.21.218.x	258 615	1.832
2	189.0.0.0	600 718	4.255	196.20.0.0	234 092	1.658	196.20.164.0	22 734	0.161	196.20.17.x	21 611	0.153
3	190.0.0.0	586 827	4.157	78.106.0.0	91 845	0.650	196.20.17.0	21 655	0.153	196.14.169.x	21 576	0.152
4	92.0.0.0	565 721	4.007	93.80.0.0	91 248	0.646	196.14.169.0	21 576	0.152	196.20.13.x	15 992	0.113
5	95.0.0.0	539 401	3.821	93.81.0.0	83 169	0.589	196.20.165.0	20 762	0.147	196.21.125.x	8 848	0.062
6	89.0.0.0	494 255	3.501	95.28.0.0	76 423	0.541	196.38.187.0	20 077	0.142	196.21.218.x	8 175	0.057
7	78.0.0.0	463 784	3.285	89.178.0.0	75 996	0.538	196.20.167.0	18 283	0.129	59.162.166.x	6 549	0.046
8	79.0.0.0	387 708	2.746	95.24.0.0	68 342	0.484	196.20.166.0	17 758	0.125	196.32.152.x	6 302	0.044
9	93.0.0.0	367 343	2.602	190.51.0.0	54 041	0.382	196.20.13.0	15 992	0.113	196.15.239.x	5 958	0.042
10	201.0.0.0	353 829	2.506	196.205.0.0	53 587	0.379	196.20.140.0	14 668	0.103	196.34.217.x	5 841	0.041
		38.801			7.902			3.115			2.542	

$$N_{Packets} = 14115791$$

This observed bias towards the lower 128 hosts in the network is due to a bug in the scanning algorithm implemented by Conficker [21, 22]. Due to the way the pseudo random number generator works, a 15-bit value is generated and is then used in a 16-bit field, resulting in the most significant bit of the 2nd and 4th octets (bytes) in an IPv4 address to being zero; in effect limiting these values to the range 0-127. The side effect of this is that it significantly reduces the portion of the Internet that can possibly be scanned [18, 23], limiting it to only 25% of total address space — although it will attempt to scan all the /8 blocks and half of all /16 blocks. Taking this into account, one can use the traffic to the upper 128 address to quantify the other scanning activity present on the port that is not attributable to the Conficker worm propagation, but rather other sources.

Looking at the sources of the traffic directed to the lower half of the monitored range, 26% (1 049 562) had a 2nd octet greater than 127, and 46% (1 842 784) with the last octet having a value greater than 127. Common to both these groupings were 515 834 hosts. What is interesting is that these could not have been infected by direct scanning, although given dynamic addressing they could have had other addresses previously, or have changed networks (as is common with mobile systems).

Infection is still possible though other measures such as via the Windows 'autorun' mechanism on removable media, which was used by the earlier Conficker variants. These sources are analysed further in Section 7.

It is worth noting that the differences in traffic observed between the upper and lower ranges are substantially more than the three times differential described by Wustrow et al [23] and attributed to this activity. This bug most likely accounts for the fact that the second telescope operated by the researcher recorded minimal traffic destined to 445/tcp, since both its 2nd and 4th octets are greater than 127. In addition to this bug in the way random IPs are generated, IP ranges known to belonging to security research firms, and Reserved IPv4 Address space are also avoided by the malware. This is an interesting case which shows the value in having distributed IP address space for monitoring global trends. It is also an argument for chunks of contiguous space rather than smaller fragmented blocks as advocated with the use of greynets [1].

7. SOURCE ANALYSIS

Analysing the source address data for the Conficker provides an interesting insight, especially when comparing the top sources ranked by packet count and host count. These are presented in Tables 5 and 6 respectively, and discussed in the sections following. The value in discriminating between these two means of ranking data is that the packet count quantified the volume, and to some extent the persistence of the infection. In contrast, ranking and subsequent analysis by the number of distinct sources (hosts) observed provides

a means for assessing how widespread the infection and related scanning activity was.

7.1. Packet Count

Considering the rank order of /8 netblocks, 196.0.0.0/8, managed by AfriNIC, can be seen to have the highest packet count by a significant margin. It is worth taking note that a single host within this block accounted for 23% of the packet count in this netblock. This host was located numerically close to the network telescope address block, and provided a sustained source of traffic over an extended period. The top ten /8 blocks accounted for over 38% of the total packet count can be observed. The numerical sequencing, of the top ten /8 netblocks have very close numerical groupings. The allocations within 189.0.0.0/8, 190.0.0.0/8 and 201.0.0.0/8 are controlled by LACNIC, with the remainder of the top ten being under the control of RIPE. Three adjacent groups of netblocks are observed. This is most likely due to the scanning and propagation mechanisms used by the Conficker malware.

This numerical closeness is also evident when considering the /16 rankings, with two contiguous address blocks in positions one and two. This can also be seen with the two blocks in 93.80.0.0/15. In the /24 rankings four contiguous blocks can be observed in 196.20.164.0/24, contributing to the high rankings of both the 196.20.0.0/16 and subsequently 196.0.0.0/8 netblocks. However, even combined, these four blocks comprising 1 024 addresses account for less than a third of the volume the top observed host. The traffic attributable to individual hosts shows a rather dramatic decrease, with the top ranked host of 196.21.218.x accounting for more than two and half-times the sum of the remainder of the top ten hosts. A second host from the same /24 netblock appears in 6th position.

A comparison of the percentage contribution for each of the netblock aggregation levels decreases sharply from the level covered by the /8 netblocks. However there is relatively little difference between the /24 and /32 levels, largely due to the contribution by the hosts in 196.21.218.0/24. It is still significant that the top host rankings accounted for 2.5% of the total, despite there being over 3.8 million hosts observed, even more so the percentage of traffic attributable to the top ranked hosts. The nearly 80% decrease in composition moving from /8 to /16 is an indicator of how widely spread the scanning activity was, although the proportion covered (7.9%) is less than the 12% observed in the overall dataset, with the values for /24 and host level proportions being much closer.

7.2. Source Count

Rankings of the number of distinct sources observed as origins for traffic destined to 445/tcp, aggregated of by network block is presented in Table 6. This presents a somewhat different picture to that discussed in the

Table 6: Top origin netblocks for 445/tcp by source count

Rank	/8	Sources	%	/16	Sources	%	%	/24	Sources	%	
1	189.0.0.0	209 921	5.511	78.106.0.0	30 407	0.798	46.397	196.1.232.0	233	91.015	
2	92.0.0.0	204 970	5.381	93.80.0.0	29 643	0.778	45.231	79.114.134.0	229	89.453	
3	190.0.0.0	191 752	5.034	93.81.0.0	25 766	0.676	39.315	79.114.135.0	226	88.281	
4	95.0.0.0	190 630	5.004	95.28.0.0	25 703	0.674	39.219	89.179.78.0	224	87.500	
5	79.0.0.0	151 942	3.988	89.178.0.0	25 677	0.674	39.179	89.179.104.0	222	86.718	
6	78.0.0.0	143 154	3.758	95.24.0.0	23 763	0.623	36.259	89.179.105.0	215	83.984	
7	201.0.0.0	113 530	2.980	190.51.0.0	19 982	0.524	30.490	89.179.106.0	213	83.203	
8	89.0.0.0	113 106	2.969	77.28.0.0	17 173	0.450	26.203	89.179.107.0	211	82.421	
9	59.0.0.0	111 005	2.914	59.93.0.0	15 446	0.405	23.568	93.81.128.0	209	81.640	
10	87.0.0.0	110 858	2.910	77.29.0.0	14 024	0.368	21.398	93.81.132.0	209	81.640	
			40.449	Total			5.970				

$$N_{SourceIP} = 3809104 \quad N_8 = 194 \quad N_{16} = 14896 \quad N_{24} = 495602$$

previous section. This ranking provides an indication of how widespread the activity was within a particular netblock, and can be used as a means of determining infection rates. These are not absolute values, and may well be influenced by the use of NAT and dynamic addressing of endpoints or even a combination of these—as is particularly common in modern broadband networks.

At the /8 aggregation level, the first eight ranked netblocks also occur in the top ten by packet count, with 196.0.0.0/8 and 93.0.0.0/8 being omitted. These placed 54th (with 14 914 sources) and 72nd (4 268 sources) respectively. The top four aggregated blocks had a fairly equitable portion of the total hosts served, at just over 5% each. The top ten accounted for over 40% of the total hosts. Again sequential netblocks are seen to occur indicating a strongly likelihood of propagation activities favouring 'near' or 'local' addresses, although this could have been influenced by some of the other propagation mechanisms used. This sequential locality is repeated again with the /16 aggregation. A strong geopolitical bias can be seen at this level, with five of the top 6 ranks netblocks being under the control of Corbina Telecom (AS8402), head-quartered in Moscow, Russia.

Finally, when considering the top ten /24 netblocks, the top source network (196.1.232.0/24) originates from the Sudan (SD) operated by SudaTel (AS15706). This is significant as 233 individual IP addresses have been observed out of a possible 254 operable host addresses, providing a coverage factor of over 90%. Further sequential address blocks can be seen with 79.114.134.0/23, and the aggregate block of 89.179.104.0/22. Other /24 blocks in the top also exhibit both numerical and topological (being part of the same ASN in global routing tables) closeness. Of interest is that despite 89.179.0.0/16 containing five of the top ten /24 netblocks, it is not in the top ten when aggregation is performed by /16, appearing only in 39th place in these rankings.

The final aspect to be considered regarding sources related to the construction of the observed addresses. This is of interest given the flawed random number generation issue previously discussed in Section 6. Evaluating the data presented in Tables 5 and 6, one can observe that the majority of the /16 networks had a 2nd octet with a value of less than 128. Regarding /24 networks, only the 89.179.104.0/22 as this octet greater than 127. Considering the individual hosts in the top ten, six have a 4th (least significant) octet value > 127. Further analysis of the top 100 000 IP addresses, showed 28% had a second octet greater than 127, with 40% having a 4th octet meeting this criteria.

One explanation for the observed behaviour is that the flaw only affects the random IP selection and scanning phase of Conficker's propagation. It also implements localised scanning on infected hosts, scanning those addresses nearby numerically. Thus given that IP addresses may be sparsely allocated when one considers the last octet, the influence of the second octet may be seen to be more significant. Considering the total sources identified sending traffic to 445/tcp after the advent of the Conficker worm, just over a quarter (27.5%) of the hosts originated from networks with the second octet greater than 127. Such sources could be considered to be under represented, given an even statistical distribution. These hosts accounted for 3 920 612 packets representing 27.77% of the total traffic directed at 445/tcp, again a somewhat lower contribution than would be expected. Repeating this analysis, for those having both the 2nd and 4th octets greater than 127, resulted in coverage of 27.99% of the traffic, again highlighting the significance of the 2nd octet.

8. GEOPOLITICAL ANALYSIS

The last aspect of the case study of Conficker related traffic, is that of the geopolitical origins of the traffic, and particularly how these changed over time. The origins have to some extent been touched on in Section 7., but rather than focusing on specific network address blocks and IP addresses, this section takes an aggregate view at a

country level⁴. This approach is taken in order to provide a bigger picture of the spread and evolution of the worm on a global scale. Country codes as assigned in ISO 3166 are used in tables for brevity.

8.1 Pre-Conficker

Prior to the advent of Conficker in November 2008, some 2.7 million datagrams were observed targeting 445/tcp, from 198 thousand source addresses. The geopolitical origins of this traffic are shown in Table 7, which provides a top ten ranking of countries by the number of sources observed, and the number of packets received. Notable in both rankings is the high proportion of the whole with in excess of 70% of both IP addresses and packets being covered. This is was observed to change dramatically following the publication of the MS08-067 vulnerability, and subsequent widespread exploitation.

Table 7: Top Sources for 445/TCP - pre Conficker

CC	SrcIP _{count}	SrcIP	Rank	CC	Packet _{count}	Packet _%
TW	40 072	20.187	1	ZA	981 349	35.326
US	39 728	20.014	2	US	275 276	9.909
JP	12 772	6.434	3	EG	251 975	9.070
FR	12 436	6.264	4	TW	185 946	6.694
DE	11 574	5.830	5	MU	82 372	2.965
CN	7 307	3.681	6	JP	78 462	2.824
GB	5 902	2.973	7	CN	68 403	2.462
PL	5 449	2.745	8	DE	60 138	2.165
EG	5 217	2.628	9	FR	52 297	1.882
IT	3 492	1.759	10	NG	39 578	1.425
		72.517	Total		74.724	

$$N_{SourceIP} = 198503 \quad N_{Packets} = 2777950 \quad N_{Countries} = 190$$

$$Avg_{Packets/Src} = 13.994$$

Comparing the two rankings, seven countries are common to both of the top ten rankings. The United Kingdom (GB), Poland (PL) and Italy (IT), while having fairly significant host counts ranked in positions 14, 17 and 19 when packet counts were considered, significantly still within the top twenty. Conversely, South Africa (ZA), while the top ranked source by packet count, was only placed 16th by the source ranking, with 2 592 hosts observed. This serves as an example, where a relatively small number of hosts were responsible for a fairly significant volume of traffic – on average these host sent 378 packets each, or 1.479 packets per address monitored. This rate can be seen to drop off significantly, and should be compared to similar rates after the advent of Conficker.

Consideration needs to be given to the potential bias in the observation towards ZA IP address space, due to the placement of the network telescope sensor. A significant

⁴ Readers can explore the individual attributions of the netblocks described previously using several tools such as whois and online geolocation services.

portion of the observed traffic originating from ZA was from hosts numerically close to the netblock being monitored. This localised numerical bias is often due to poorly implemented scanning algorithms in malware. Several hosts with high packet counts were located at higher education institutions within South Africa. This bias was noted, and was deemed to be less significant as traffic volumes increased post the Conficker outbreak.

8.2 Post-Conficker

The situation observed after the widespread exploitation of the MS08-067 vulnerability in Microsoft Windows family systems changed dramatically. The top ten ranked attributable countries of origin by source and packet count are presented in Table 8. While the relative percentage coverage for top ten rankings both by sources and count decreased, the impact on the latter was most notable. Although only a 55% representation of total packet count was achieved by the top ten source countries, this was far more evenly distributed than that given in Table 7.

Table 8: Top Sources for 445/TCP - post Conficker

cc	SrcIP _{count}	SrcIP	Rank	cc	Packet _{count}	Packet _%
RU	577 261	15.154	1	RU	1 791 475	12.691
BR	357 982	9.398	2	BR	1 062 521	7.527
IT	267 660	7.027	3	US	802 232	5.683
CN	265 809	6.978	4	TW	706 241	5.003
TW	233 693	6.135	5	IT	669 286	4.741
DE	215 123	5.647	6	CN	633 169	4.485
AR	181 141	4.755	7	DE	592 773	4.199
IN	149 420	3.922	8	ZA	552 573	3.914
JP	119 299	3.131	9	RO	548 204	3.883
RO	109 987	2.887	10	AR	519 605	3.681
		65.038	Total		55.810	

$$N_{SourceIP} = 3809104 \quad N_{Packets} = 14115791 \quad N_{Countries} = 214 \quad Avg_{Packets/Src} = 3.706$$

Comparing the top sources as ranked, shows that although India and Japan had a significant number of sources identified, they ranked much further down when looking at their contribution to the total traffic, ranking respectively in positions: 13 and 14. The remainder of the top ten by number of sources are all present in the top ten by packet count, joined by US, ZA. These two countries ranked 14th and 60th, by the number of identified sources. Hosts from the Russian Federation (RU) and Brazil (BR) maintained their first and second placings in both rankings.

Looking at the average traffic contribution by host for these countries, Russia and Brazil achieved values of 3.1 and 2.96 respectively. This is significantly lower than the average packet contributions observed before the Conficker worm. This measure, while crude, can be used to determine the level of activity. The values themselves would be expected to tend towards 2.0 where only two packets were observed before a host stopped, as discussed

in Section 5. The observed values being higher than this can be attributed to a relatively small number of hosts which scanned the entire monitored range, often on a number of occasions.

These rankings can be broken down and evaluated smaller time frames. This is explored in the next section which provides an overview of the dynamics of the spread of the Conficker malware by geographic region.

8.3 Conficker Evolution

The final geopolitical analysis of the Conficker Traffic, considers the changing composition of the traffic as the malware evolved. Table 9 shows the lifetime of the Conficker worm segmented into five phases designated A to E. These phases correlate to the five worm variants that were identified (using the Microsoft naming scheme). While it is acknowledged that the actual traffic observed may have originated from multiple variants of the malware, the dates on which new variants were identified serve as a useful means by which to segment the traffic. The dated bounding the periods, as well as the percentage contribution (by packets count and host) to the total traffic directed to 445/tcp after the advent of Conficker is given at the bottom of the table. The first consideration is that of the ranking by packet count as shown in the upper portion of Table 9. The increasing prevalence of the malware on a global scale can be seen by the dilution shown in the overall percentage of traffic covered by the top ten countries in each of the periods, from a high of 70% in A to 57% in D and E. The low of 53.79% in period B would appear to be anomalous.

Looking at the changing composition of top geopolitical sources, countries consistently appearing in all periods are Taiwan (TW), the United States of America (US), China (CN) and Brazil (BR), which are highlighted in bold font in Table 9. The absence of Russia (RU) from the top rankings in period A may be due to a condition in the original variant of the malware that checked for Cyrillic keyboard types, resulting in Russia appearing in 14th and the Ukraine in 42nd place, leading many researchers to initially believe that these countries were the possible origin of the worm. South Africa ranked highly in all but the last period, where the dilution due to the in excess of 10 million packets received, resulted in a rank of 16. For each of the periods, with the exception of B, the top three ranks represent a significant portion of the traffic.

Re-evaluating the same dataset, but ranking countries by the number of hosts observed provides a slightly different picture (as seen in Sections 8.1 and 8.2). Five countries were found to constantly maintain a top ten ranking across the five periods. These were Argentina (AR), Taiwan (TW), China (CN), Brazil (BR) and Russia (RU), and have been boldfaced in the lower half of Table 9. One possibility for these countries having a persistent ranking is that they are regarded as having fairly high

incidence of software piracy⁵. A general dilution of the percentage of hosts covered by the top ten can be seen, and is similar to that observed with packet counts. The proportion of hosts covered drops from 74% in the starting period to only 61% in period B, this then increased up to 66% by period E. Interestingly the Ukraine (UA) makes an appearance in period B, possibly as a flood of hosts were infected with Conficker.B which removed the restriction on not infecting host with Cyrillic, and particularly Ukrainian keyboard settings.

9. SIGNIFICANCE AND FUTURE WORK

The dataset used in the research can still be further analysed, particularly from the point of an extended temporal or geopolitical analysis, such as that performed in [14]. Since the Conficker outbreak, there has not been another significant Internet scale event similar to this. As such, further exploration of the dataset on which this work is based, and other subsequently collected datasets may provide better insight into the spread of malware and related malicious activity on a global scale, as well as how to better monitor and defend against these threats.

The information produced by a network telescope can be used in conjunction with existing network security technologies to allow for a means of shunning or otherwise managing potentially hostile hosts, and protecting clients inside a network. This could be achieved through a variety of means, as appropriate for an organisation, ranging from route blackholing to blacklist population.

9.1 Significance

The research presented here is significant in relation to existing analysis work in that it has been able to verify findings and observations made by others using much larger network telescopes. The marked difference in traffic targeting the two halves of the monitored network range is important for considering the diversity of placement of network telescope sensors in the future – particularly those with relatively small address space being utilised, something likely to become more prevalent as IPv4 address space becomes more scarce. The work done relating to geopolitical changes observed over the evolution of the malware is also of interest.

10. CONCLUSION

This focused analysis of traffic destined to 445/tcp has covered two distinct global malware threats — that of Zotob in August 2005, and Conficker in November 2008. In the intervening period traffic levels remained consistent, and can be attributed to remnants of the Zotob malware and other similar software, and scanning by individuals for hosts having services on 445/tcp exposed to the Internet at large in order to potentially exploit their

⁵ <http://portal.bsa.org/idcglobalstudy2007/>

Table 9: Changing Geopolitical sources by Evolutionary Phase

Period				
A	B	C	D	E

Packet Count

	cc	%	cc	%	cc	%	cc	%	cc	%
1	MU	18.53	RU	9.50	ZA	16.84	RU	13.03	RU	13.84
2	TW	11.67	US	6.00	RU	10.31	ZA	9.77	BR	8.51
3	AR	10.40	BR	5.53	KR	6.07	BR	5.74	US	5.69
4	ZA	6.94	TW	5.51	US	4.62	US	5.39	IT	4.92
5	US	6.32	ZA	5.08	BR	4.51	KR	4.64	TW	4.86
6	CN	5.64	IT	5.02	CN	4.27	IT	4.50	DE	4.44
7	ES	3.16	CN	4.97	IT	4.02	CN	4.03	CN	4.41
8	CL	2.85	KR	4.56	TW	3.60	TW	3.46	RO	4.28
9	CO	2.71	DE	4.29	EG	3.53	RO	3.44	AR	3.59
10	BR	2.50	AR	3.33	DE	3.52	DE	3.27	IN	3.34
		70.72		53.79		61.29		57.27		57.88

Source Count

	cc	%	cc	%	cc	%	cc	%	cc	%
1	AR	19.57	RU	13.74	RU	15.89	RU	18.27	RU	15.97
2	TW	18.98	IT	7.66	CN	6.54	BR	7.25	BR	10.25
3	CN	9.26	CN	7.34	IT	6.23	IT	6.59	IT	6.87
4	CL	5.19	BR	6.66	BR	6.21	CN	5.99	CN	6.61
5	ES	4.67	TW	6.11	KR	6.02	DE	4.33	TW	5.92
6	US	4.61	DE	5.78	DE	5.03	TW	4.32	DE	5.67
7	CO	3.93	AR	4.56	TW	4.75	IN	4.29	AR	4.46
8	BR	2.97	KR	3.29	RO	3.69	AR	3.95	IN	4.21
9	RU	2.96	UA	3.05	AR	3.54	KR	3.84	JP	3.32
10	DE	2.43	IN	3.03	IN	3.14	RO	3.43	RO	2.96
Total		74.57		61.22		61.04		62.26		66.24

Range	Start	End	Packets	%	Hosts	%
A	20 Nov 2008	28 Dec 2008	482 311	3.41	93 103	2.44
B	28 Dec 2008	20 Feb 2009	1 751 334	12.40	484 931	12.73
C	20 Feb 2009	4 Mar 2009	640 640	4.53	180 631	4.74
D	4 Mar 2009	8 Apr 2009	1 194 125	8.45	348 844	9.15
E	8 Apr 2009	30 Sep 2009	10 047 561	71.17	2 912 630	76.46

vulnerability. Over the period of the Dataset, and particularly in the last 14 months, traffic destined to 445/tcp made a significant contribution to the whole. Given this, it is important to investigate the nature and origins of the datagrams.

While the analysis carried out in this paper is by no means complete, it provides an good example of the kind of focused analysis that can be done with a network telescope, even when considering the limitations of not having packet payloads.

The evolution of the Conficker worm is plotted. The problem with the random scanning and propagation algorithm identified in the reverse engineering of the malware can be clearly observed, and this is seen to be a plausible explanation for the significant difference in traffic observed by the researcher between the dataset being considered for this work, and others utilising different address space. Furthermore, the work presented shows how a network telescope can be used to track the spread and distribution dynamics of widespread Internet worms in the future.

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