Detection of NS Resource Record DNS Resolution Traffic, Host Search, and SSH Dictionary Attack Activities

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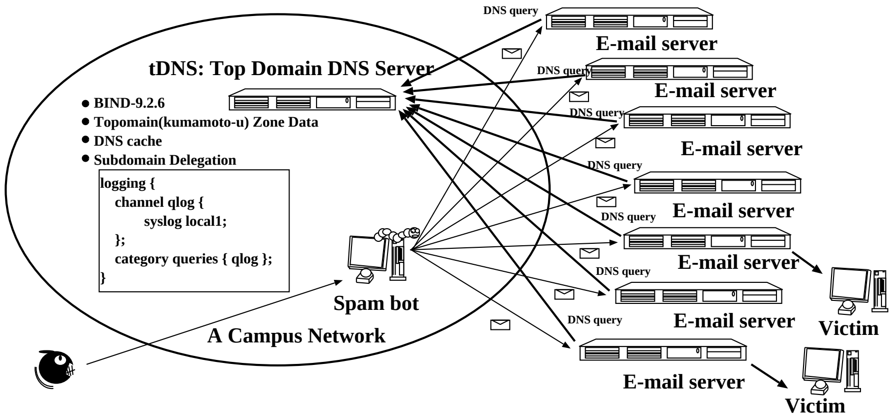
We performed an entropy study on the DNS query traffic from the Internet to the top domain DNS server in a university campus network through January 1st to March 31st, 2009. The obtained results are: (1) We observed a difference for the entropy changes among the total-, the A-, and the PTR resource records (RRs) based DNS query traffic from the Internet through January 17th to February 1st, 2009. (2) We found the large NS RR based DNS query traffic including only a keyword "." in the total DNS query traffic from the Internet. (3) We also found that the unique source IP address based PTR DNS traffic entropy slightly increased, while the unique DNS query keywords based one drastically decreased in March 9th, 2009. We found a specific IP host which was an already-hijacked classical Linux PC that carried out the SSH dictionary attack to the Internet sites in March 9th, 2009. From these results, we can detect the unusual NS RR based DNS traffic and SSH dictionary attacks by only watching DNS query traffic from the Internet.

1. Introduction

It is of considerable importance to raise up a detection rate of Bots, since they become components of the bot clustered networks that are used to transmit a lot of unsolicited mails including like spam, phishing, and mass mailing activities and to execute distributed denial of service attacks.[1)–4)]

Wagner *et al.* reported that entropy based analysis was very useful for anomaly detection of the random IP search activity of Internet worms (IWs) like an W32/Blaster or an W32/Witty worm, respectively, since the both worms drastically changes entropy when after starting their activity.[5)]



```
logging {
   channel qlog {
         syslog local1;
   };
   category queries { qlog };
}
```

Fig. 1 A schematic diagram of a network observed in the present study.

Then, we reported previously that the unique DNS query keyword based entropy in the PTR resource record (RR) based DNS query packet traffic from the Internet decreases considerably while the unique source IP addresses based entropy increases when the random spam bots activity is high in the campus network.[6)] This is probably because the PTR RR based DNS query packet traffic was generated by the spam bots activity sensors like a spam filter of the E-mail server and/or the intrusion detection/prevention system (IDS/IPS) on the Internet. Therefore, we can detect spam bots activity, especially, a random spam bot (RSB) in the campus network, by watching the DNS query packet traffic from the other sites on the Internet (see Figure 1). We also reported that we observed not only an increase in the unique DNS query keyword based entropy in the PTR RR based DNS query packet traffic from the Internet but a decrease in the unique source IP address based one in the DNS query packet traffic when performing host search activity from the Internet.[7)]

In this paper, (1) we carried out entropy analysis on the total- A- and the PTR resource records (RRs) based DNS query packet traffic from the Internet through January 1st to March 31st, 2009, and (2) we assessed the bot attack detection rate among the entropies for the total- A-RR, and the PTR-RR based DNS query packet traffic.

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2. Observations

2.1 Network Systems and DNS Query Packet Capturing

We investigated on the DNS query request packet traffic between the top domain (**tDNS**) DNS server and the DNS clients. Figure 1 shows an observed network system in the present study, which consists of the **tDNS** server and the PC clients as bots like a random spam bot and a host search one in the campus network, and the victim hosts like the E-mail servers on the Internet. The **tDNS** server is one of the top level domain name (kumamoto-u) system servers and plays an important role of domain name resolution including DNS cache function and subdomain name delegation services for many PC clients and the subdomain networks servers, respectively, and the operating system is Linux OS (CentOS 4.3 Final) in which the kernel-2.6.9 is currently employed with the Intel Xeon 3.20 GHz Quadruple SMP system, the 2GB core memory, and Intel 1000Mbps EthernetPro Network Interface Card.

In the **tDNS** server, the BIND-9.2.6 program package has been employed as a DNS server daemon.[8] The DNS query packet and their query keywords have been captured and decoded by a query logging option (see Figure 1 and the named.conf manual of the BIND program in more detail). The log of DNS query packet access has been recorded in the syslog files. All of the syslog files are daily updated by the cron system. The line of syslog message consists of the contents of the DNS query packet like a time, a source IP address of the DNS client, a fully qualified domain name (A and AAAA resource record (RR) for IPv4 and IPv6 addresses, respectively) type, an IP address (PTR RR) type, or a mail exchange (MX RR) type.

2.2 Estimation of Entropy

We employed Shannon's function in order to calculate entropy $H(X)$, as

$$H(X) = -\sum_{i \in X} P(i) \log_2 P(i) \tag{1}$$

where X is the data set of the frequency $freq(j)$ of IP addresses or that of the DNS query keyword in the DNS query packet traffic from the outside of the campus network, and the probability $P(i)$ is defined, as

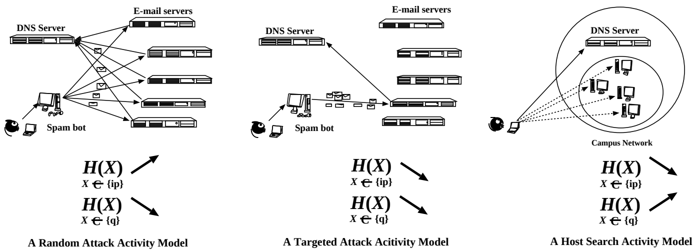

Fig. 2 Random attack bots (RAB), targeted attack bots (TAB), and host search (HS) activity models

$$P(i) = \frac{freq(i)}{\sum_j freq(j)} \tag{2}$$

where i and j $(i, j \in X)$ represent the unique source IP address or the unique DNS query keyword in the DNS query packet, and the frequency $freq(i)$ are estimated with the script program, as reported in our previous work.[9]

2.3 Attack Activity Models

We define three incidents detection models for random attack (RA) activity, targeted attack (TA) activity, and host search (HS) activity (See Figure 2), respectively.

A random attack (RA) activity model – since a random spam bot (RSB), a typical example for the RA activity model, randomly attacks various victim E-mail servers, the E-mail servers can try to check IP addresses and fully qualified domain names (FQDNs) for the RSB, with referring to the top domain DNS (**tDNS**) server in the campus network. This causes an increase in the number of the unique source IP addresses in the DNS query traffic but a decrease in the number of the unique DNS query keyword *i.e.* the unique source IP addresses- and the unique DNS query keyword-based entropies simultaneously increase and decrease, respectively, when the RA activity is high in the campus network.

A targeted attack (TA) activity model – since the targeted spam bot (TSB), for example, attacks a small number of specific victim E-mail servers in the campus network or on the Internet, the E-mail servers can check IP addresses and FQDNs for the TSB, with referring to the **tDNS** server in the campus network. This causes decreases in the unique IP addresses- and the DNS query keyword-based entropies when the TA activity is high.

A host search (HS) activity model – the host search activity can be mainly carried out by a small number of IP hosts on the Internet or in the campus network like bot compromised PCs. Since these IP hosts send a lot of the DNS reverse name resolution (the PTR RR based DNS query) request packets to the **tDNS** server, the unique IP addresses- and the unique DNS query-keywords based entropies decrease and increase, respectively.

Here, we should also define thresholds for detecting these three kinds of malicious activity models, as setting to 1,000 packets day^{-1} for the frequencies of the top-ten unique source IP addresses or the DNS query keywords. The evaluation for threshold was previously reported.[9)]

3. Results and Discussion

3.1 Entropy Changes in Total- A- and PTR-RRs DNS Query Packet Traffic from the Internet

We demonstrate the calculated unique source IP address and unique DNS query keyword based entropies for the total-, A- and PTR-resource records (RRs) based DNS query request packet traffic from the Internet to the top domain DNS (**tDNS**) server through January 1st to March 31st, as shown in Figure 3.

In Figure 3A, we can find ten peaks and they are categorized into three groups, as: {(1), (7), (8), (10)}, {(2)-(6)}, and {(9)}. In the first peak group, all the peaks show a decrease in the unique source IP address based entropy and an increase in the unique DNS query keywords based one *i.e.* this feature indicates the host search (HS) activity. It is very important to detect the HS activity because the HS activity is mainly performed as pre-investigation on the campus network for the next cyber attack. In the second group, we can observe the five peaks in which all the peaks demonstrate simultaneous decreases in the unique source IP address- and the unique DNS query keyword-based entropies. This feature shows that the peaks (2)-(6) can be assigned to a targeted attack (TA) activity model. In the last group, we can find only a peak (9) which demonstrates nothing in the unique source IP addresses based entropy but a significant decrease in the unique DNS query keyword based one. This feature will be discussed later.

In Figure 3B, surprisingly, we can find only two peaks (1) and (2). In the peak (1), we can observe small increase and decrease in the unique source IP address- and the unique query keyword based entropies, respectively. The peak (1) is assigned to January 24th, 2009. This is probably because we had a half-day hardware trouble in the campus network core switches in the day, and this fact could affect the entropy change. The peak (2) can be assigned to the same situation in the peak (9) in Figure 3A. As a result, we can observe no peak corresponding to the peaks for the targeted attack (TA) activity in Figure 3A.

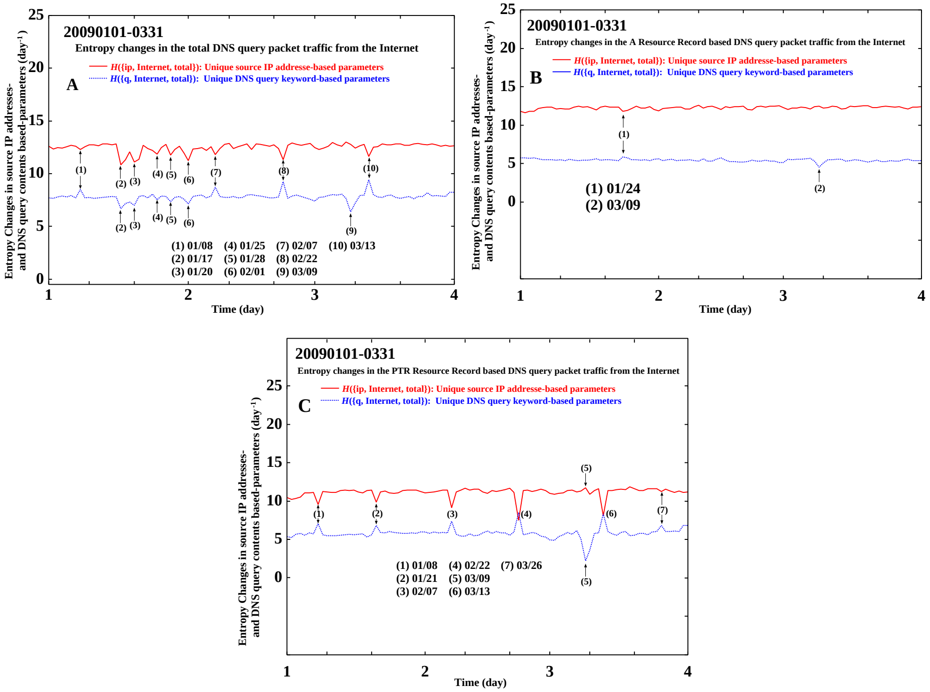

Fig. 3 Entropy changes in the total- A- and PTR-resource records (RRs) based DNS query request packet traffic from the campus network to the top domain DNS (**tDNS**) server through January 1st to March 31st, 2009. The solid and dotted lines show the unique source IP addresses and unique DNS query keywords based entropies, respectively (day^{-1} unit).

In Figure 3C, we can find eight peaks which can be categorized into two groups,

Table 1 Detected top/2nd unique query keywords and their frequency through January 17th to February 1st, 2009. (day^{-1} unit).

Peak	Date	Query keyword	Frequency (day $^{-1}$)
(2)	Jan. 17th	.	69,927
		133.95.a1.181	1,473
(3)	Jan. 20th	.	72,291
		133.95.a1.181	1,619
		133.95.a2.55	1,384
(4)	Jan. 25th	.	40,419
(5)	Jan. 28th	.	51,810
		133.95.a1.181	1,523
(6)	Feb. 1st	.	47,690

Table 2 DNS resource record (RR) based component analysis on the total DNS query packet traffic from the Internet including a root "." as the query keywords at the two peaks, January 17th and 20th, 2009. (day^{-1} unit).

	Peak (2)	Peak (3)
	(Jan 17th, 2009)	(Jan 20th, 2009)
Total	69,927	72,291
A	274	162
AAAA	0	0
PTR	0	0
MX	0	0
TXT	0	0
NS	69,653	72,129
Others	0	0

as: {(1)-(4), (6), (7)} and {(5)}. In the first group, we can observe the same peaks (1), (3), (4), and (6) corresponding to the peaks (1), (7), (8), and (10), respectively, in Figure 3A. This means that these peaks and the other peaks (2) and (7) can be allocated to the HS activity. Interestingly, in the peak (5), the unique source IP address based entropy increases in a slight manner, while the query keyword based entropy decreases significantly. This feature indicates a random attack (RA) activity model. Usually, however, we can observe clear symmetrical changes in the both entropies for the RA activity like a random spam bot (RSB) activity *i.e.* it has a possibility that the peak (5) demonstrates a different RA activity unlike a random spam bot (RSB) attack. Also, in Figure 3C, we can find out no TA activity peak like the peaks (2)-(6) in Figure 3A.

Table 3 Detected top, 2nd, and third unique source IP addresses and their frequencies through January 17th to February 1st, 2009. (day^{-1} unit).

Peak	Date	Source IP address	Frequency (day $^{-1}$)
(2)	Jan. 17th	69.50.a1.b1	44,002
		69.50.a2.b2	18,935
(3)	Jan. 20th	76.9.c1.d1	65,315
(4)	Jan. 25th	206.71.e1.f1	33,751
(5)	Jan. 28th	64.57.g1.h1	32,896
(6)	Feb. 1st	65.23.i1.j1	13,876
		71.6.k1.l1	13,875
		64.27.m1.n1	13,875

Therefore, we need to investigate further the total DNS query packet traffic at the TA activity peaks (2)-(6) in Figure 3A and to confirm the possibility showing a new instance for the RA activity at the peak (5) in Figure 3C.

3.2 The NS-RR DNS Query Packet Traffic from the Internet

We investigated statistics of the query keywords in the DNS query request packet traffic from the Internet at the peaks (2)-(6) in Figure 3A. The top query keywords was obtained when the frequency takes more than 1,000 packets day^{-1} and the FQDNs or IP addresses of the network servers are discarded, as listed in Table 1.

In Table 1, the top DNS query keyword is a root "." at each peak. Then, we performed DNS resource record (RR) based component analysis on the total DNS query packet traffic from the Internet including the root "." as the query keywords at the peaks (2) and (3) shown in Figure 3A. Usually, we can observe that the root "." included DNS query packet traffic takes only about 1,100 packets day^{-1} (an average value by observation through March 8th to 31st, 2009).

As shown in Table 2, the total root "." included DNS query packet traffic consists of the NS- and A-RRs DNS query packet traffic in January 17th and 20th, 2009. Also, we can observe that the NS RR based DNS query traffic takes

Table 4 Detected top, 2nd, and third IP addresses as query keywords and their frequencies through March 9th, 2009. (day^{-1} unit).

	Query Keyword	Frequency (day $^{-1}$)
1	133.95.s1.62	40,919
2	133.95.s2.73	6,110
3	133.95.s3.163	1,115

almost 1,300 packets day^{-1} (an average value by observation through March 8th to 31st, 2009).

We further obtained statistics of the source IP addresses in the root "." included DNS query packet traffic in January 17th and 20th, 2009, as shown in Table 3. We can see the specific IP addresses in Table 3, and these IP addresses can be assigned for targeted attack activity corresponding to the peaks (2)-(6) in Figure 3A.

3.3 A New Instance for the Random Attack Activity

We carried out statistics on the query keywords in the total PTR resource record (RR) based DNS query packet traffic from the Internet at March 9th, 2009, in order to investigate further the peak (5) in Figure 3C. The results are shown in Table 4, in which the top IP addresses are obtained when the frequency takes more than or equal to 1,000 packets day^{-1}.

In Table 4, we can find the three top IP addresses of 133.95.s1.62, 133.95.s2.73, and 133.95.s3.163, as query keywords in which the top IP address is assigned to the old Linux PC in the campus network. Fortunately, we received an automatic notifying E-mail in which they complained about that a PC terminal in the campus network had carried out the SSH dictionary attack[11] to them and which shows the same IP address as the top one. Therefore, we can identify the peak (5) corresponding to the random SSH dictionary attack activity. Also, we calculated rate for the unique source IP address in the PTR RR based DNS query packet traffic including a query keyword "133.95.s1.62", in which the rate is calculated to be 11%. In January 17th, 2008, we detected a spam bot kicked by USB silicon disk, and we observed 11,263 packets day^{-1} for the DNS query packet traffic including an IP address of the spam botted PC terminal.[10] The rate for the unique source IP address was estimated to be 72%.

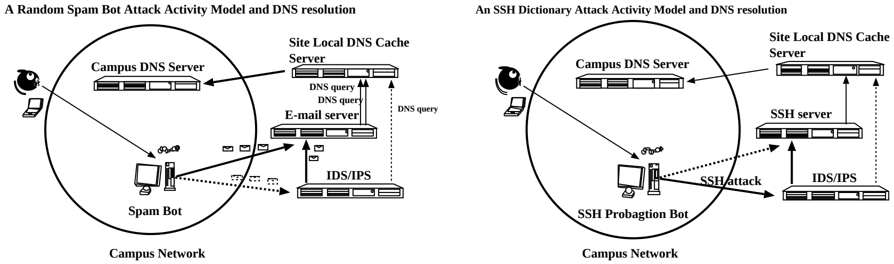
A Random Spam Bot Attack Activity Model and DNS resolution
Site Local DNS Cache Server
Campus DNS Server
DNS query
DNS query
DNS query
E-mail server
IDS/IPS
Spam Bot
Campus Network
An SSH Dictionary Attack Activity Model and DNS resolution
Site Local DNS Cache Server
Campus DNS Server
SSH server
SSH attack
IDS/IPS
SSH Probagtion Bot
Campus Network

Fig. 4 Random Spam Bot and Random SSH Dictionary Attack Activity Models

Interestingly, the unique DNS query keyword based DNS traffic entropy considerably decreases while the unique source IP address based one increases slightly in the peak (5). This situation is different from the previous instances in the random attack (RA) activity like a random spam bot (RSB), since we previously reported that the both DNS traffic entropies change symmetrically in the peaks for the random spam bot activity.[10] This feature is probably interpreted in terms of the difference whether or not the PTR RR based DNS query packet traffic from the Internet includes the DNS reverse resolution traffic from the E-mail servers on the Internet, or not (See Figure 4).

4. Conclusions

We investigated entropy analysis on the total, A, and PTR resource record (RR) based DNS query request packet traffic from the Internet through January 1st to March 31st, 2009. The following interesting results are found: (1) we observed 10, 2, and 8 incidents in the entropy change in the total-, A-, and PTR-RRs based DNS query packet traffic, respectively. In the total DNS query packet traffic entropy change, we found 4 host search (HS) activities, 5 targeted attack (TA) ones, and 1 random attack (RA) one. In the A RR based DNS query packet traffic entropy change, we found 1 hardware trouble and 1 RA activity. In the PTR based DNS query packet traffic entropy change, we discovered 7 HS activities and 1 RA one. (2) We found that the specific IP hosts had carried out the TA attack to the campus top domain name server (**tDNS**) by transmitting the NS RR based DNS query packet traffic including a root "." as a query keyword. (3)

Also, we found a new instance for the RA activity like a random SSH dictionary attack but unlike a random spam bot (RSB). This is because we observed the difference in the source IP address based entropy change and the unique rates for the source IP address in the RSB and SSH dictionary attacks were calculated to be 11% and 72%, respectively.

From these results, it is concluded that we should pay attention to the results of resource record (RR) based component analysis since we observed the considerable differences among the total, A, and PTR RRs based DNS query traffic entropies, and we could detect the NS RR based DNS query denial of service (DoS) attack and the SSH dictionary attack by only observing the DNS resolution traffic from the Internet.

We continue further study to develop spam and propagation bots detection technology.

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References

1) Barford, P. and Yegneswaran, V.: An Inside Look at Botnets, Special Workshop on Malware Detection, *Advances in Information Security*, Springer Verlag, 2006.

2) Nazario, J.: Defense and Detection Strategies against Internet Worms, I Edition; *Computer Security Series*, Artech House, 2004.

3) Kristoff, J.: Botnets, *North American Network Operators Group (NANOG32)*, Reston, Virginia (2004), http://www.nanog.org/mtg-0410/kristoff.html

4) McCarty, B.: Botnets: Big and Bigger, *IEEE Security and Privacy*, No.1, pp.87-90 (2003).

5) Wagner, A. and Plattner, B.: Entropy Based Worm and Anomaly Detection in Fast IP Networks, *Proceedings of 14th IEEE Workshop on Enabling Technologies: Infrastracture for Collaborative Enterprises (WETICE 2006)*, Linköping, Sweden, 2005, pp.172-177

6) Ludeña Romaña, D. A., Sugitani, K., and Musashi, Y.: DNS Based Security Incidents Detection in Campus Network, *International Journal of Intelligent Engineering and Systems*, Vol. 1, No.1, pp.17-21 (2008).

7) Ludeña Romaña, D. A., Kubota, S., Sugitani, K., and Musashi, Y.: Entropy Study on A and PTR Resource Record-Based DNS Query Traffic, *IPSJ Symposium Series*, Vol. 2008, No.13, pp.55-61 (2008).

8) BIND-9.2.6:
http://www.isc.org/products/BIND/

9) Ludeña Romaña, D. A., Musashi, Y., Matsuba, R., and Sugitani, K.: Detection of Bot Worm-Infected PC Terminals, *Information*, Vol. 10, No.5, pp.673-686 (2007).

10) Ludeña Romaña, D. A., Kubota, S., Sugitani, K., and Musashi, Y.: DNS Based Spam Bots Detection in a University, *Proceedings for the First International Conference on Intelligent Networks and Intelligent Systems (ICINIS2008)*, Wuhan, China, 2008, pp. 205-208 (2008).

11) Thames, J. L., Abler, R., and Keeling, D.: A distributed active response architecture for preventing SSH dictionary attacks, *Proceedings for the Southeastcon, 2008. IEEE*, Huntsville, AL, USA, 2008, pp. 84-89 (2008).