Addressing SMTP-based Mass-Mailing Activity Within Enterprise Networks

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Abstract

Malicious mass-mailing activity on the Internet is a serious and continuing threat that includes mass-mailing worms, spam, and phishing. A mechanism commonly used to deliver such malicious mass mail is an SMTP-engine, which turns an infected system into a malicious mail server. We present a technique that enables, within a single mailing attempt in many popular network environments, detection and containment of (even zero-day) SMTP-engine based mass-mailing activity. Contrary to other mass-mailing detection techniques our approach is content independent and requires no attachment processing, network traffic correlation, statistical measures, or system behavioral analysis. It relies instead on the observation of DNS MX queries within the enterprise network. This stateless detection technique requires minimal computational resources making it ideally suited for real-time wire-speed deployment.

1 Introduction

Internet users are inundated by a steady stream of emails infected with malicious code, unwanted product advertisements, and requests for personal information from criminals masquerading as legitimate entities to enable the commission of fraudulent activity. The use of gateway anti-virus (and per client) software and spam filters offers some measure of protection. However, these perimeter defences often fail to detect *zero-day* worms and viruses, often quarantine legitimate emails misidentified as spam, and do not address perhaps the most prevalent infection method: users unwittingly opening malicious attachments. A strong argument can be made that the best chance to detect and quarantine malicious email occurs before it is sent outside of the enterprise network.

To date, the use of mass-mailing worms has been the fastest way to propagate malicious mail.[*] For example, the MyDoom mass-mailing worm at its peak was responsible for one in every twelve Internet email messages [6]. The majority of mass-mailing worms employ the same infection delivery mechanism: a *Simple Mail Transfer Protocol engine (SMTP-engine)*, which turns an infected system into a malicious mail server. As mail server filtering techniques become more effective, spammers and phishers are resorting to hijacking ordinary PCs (thereafter *zombies*) and using built in SMTP-engines or mail proxy programs to send malicious mail without the owner's knowledge [3, 12]. In fact, it has been estimated that 80% of spam is sent by spam zombies [12].

In this paper, we exploit the interaction between SMTP-engines and DNS servers to provide a new method to detect malicious mass-mailing activity within an enterprise network. In short, SMTP-engine infected clients typically request Mail Exchanger (MX) records from a DNS server (either their local DNS server or DNS servers outside the network boundary) in order to locate the mail servers that can deliver the malicious mail to their intended victims. While some legitimate client systems run their own email servers locally, most enterprise environments use perimeter mail servers to send and receive email.[†] In this scenario, only the corporate mail servers within the enterprise network are generally expected to

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[*] We define malicious mail as unwanted email unwittingly sent by a compromised system whether or not it contains malicious code (i.e. including spam).

[†] This allows for gateway anti-virus software at the network perimeter and lower cost (e.g. maintenance, support, policy enforcement) corporate email.

query DNS servers for MX records (see further discussion, including exceptions in Section 4.2).

Our Contributions. We present a technique, implemented and tested with a software prototype, to detect and quarantine SMTP-engine mass-mailing based solely on the observation of a DNS MX record request from client systems. No modeling or statistical measurement of user or network behavior is required. Furthermore, it does not rely on attachment scanning, allowing detection of malicious text-based emails with hypertext embedded links to malicious websites.[‡] To validate these claims, we performed tests in an isolated test network with a live mass-mailing worm.

Our anomaly-based approach is appealing for a number of reasons:

1. *Speed*: in certain network environments the possibility to detect and contain an SMTP-engine before a single malicious email message can be sent.
2. *Detection and containment of zero-day mass-mailing worms*: possible because the approach does not rely on existing worm signatures.
3. *Impact to quarantined system*: once identified as a malicious mass-mailer, only SMTP activity (port 25) will be blocked on the system allowing all other user activity to proceed unhindered.
4. *Low-false positive rate*: empirical analysis (see Section 4.2) suggests that client MX record requests are rare for most users.[§]
5. *Ease of deployment*: the approach is network-based, runs on commodity hardware, and relies on the observation of a protocol found in all networks (i.e. DNS).

Organization. Section 2 discusses related work. Section 3 outlines the basic approach. Section 4 presents an empirical analysis of client MX record request activity. Section 5 discusses our prototype and its performance in an isolated worm test network. Section 6 contrasts our technique with others. We conclude in Section 7.

2 Related Work

Zou et al. [22] developed a mass-mailing worm model by profiling the user behavior of email checking times and email attachment opening probabilities. They analyzed the impact of *selective immunization defense*, that entails making the most connected email users' systems immune to an email worm. Their results reveal that although a power law topology enables a worm to spread more quickly, it also allows for faster containment. Their work provides an email worm model that incorporates user behavior and offers some insight into worm propagation on a number of network topologies. The same authors propose [21] a multi-step feedback email defence mechanism to detect malicious email within an enterprise network; and suggest the use of a *honeypot* to detect outgoing viruses.

Sidiroglou et al. [17] propose an architecture to detect zero-day worms and viruses, which intercepts and scans every email for dangerous attachments. They employ virtual machine clusters, host-based intrusion detection, and email-worm vaccine aware Mail Transfer Agents.

Hu et al. [10] present an application of the PAIDS *(ProActive Intrusion Detection System)* detection paradigm using a prototype system called BESIDES which detects mass-mailing viruses. PAIDS employs two general techniques: comparing a system's behavior against its security policy (*behavior skewing*) and isolating illegal system behaviors in a virtual environment (*cordoning*). Their prototype detected a number of real mass-mailing worms with a low false positive rate. However, their implementation is deployed at SMTP servers which would fail to detect SMTP-engine activity. SMTP-engines bypass network mail servers (and even in some cases local DNS servers) making network-based detection techniques necessary.

Gupta et al. [9] use *specification-based* anomaly detection to detect email viruses. Their approach looks for increases in mail traffic from clients to mail servers over a threshold determined during a training period. Specifically, the statistics of send and deliver transitions in a state machine are maintained for both individual clients and the entire collection of clients within the network. Using a series of simulated experiments they detected stealthy (e.g. polymorphic) viruses with a low false positive rate.

Our technique is motivated in part by previous work specifically related to DNS activity and mass-mailing worm detection. Wong et al. [19] performed an empirical study on mass-mailing worm behavior using network traffic traces from a college campus. The characteristics of two mass-mailing worms with respect to DNS activity and TCP traffic flows were studied. They found that changes in network activity from infected hosts allowed for interesting detection possibilities. They propose that a more in-depth investigation of monitoring and containing mass-mailing worms using DNS servers should be performed as it holds promise as a way to slow down propagation. One important observation was that defences designed for monitoring SMTP servers will not work well for mass-mailing worms as they have their own SMTP-

[‡] These websites infect a system by sending malicious code through website content retrieved by the client system.

[§] In a university network of about 300 users over one week, we found only 5 anomalous MX record queries from client systems. While in most corporate environments the deployed software application baseline differs substantially from a university network, the greater software diversity in the latter makes it a good test environment.

engines.

Ishibashi et al. [11] employ a technique that uses a Bayesian inference method to calculate and assign a value to the suspiciousness of specific domain name queries from individual hosts. This method assumes that there is partial prior information about the normal characteristic domain name queries from the network. Signatures are manually derived from the query content of suspected worm infected hosts. Hosts that send domain requests that match the signature query content are assumed to be infected with a mass-mailing worm. Their technique is not suitable for detecting zero-day worms in real-time as it requires both manual analysis and a predetermined signature to identify suspected worm activity.

Whyte et al. [18] used DNS activity to detect the presence of scanning worms within an enterprise network. The observation of connections outside the network not preceded by a DNS query was considered anomalous and a strong indicator of scanning worm activity. They hypothesized that MX queries from client systems could indicate mass-mailing worm infection, but recognized that the detection and containment of mass-mailing worms would require the collection of different network data (i.e. a data set with substantial mail activity) and a different approach that was out of scope with the scanning worm detection technique. In contrast to their work we: (1) implement a new detection paradigm, (2) construct a prototype that processes DNS MX records and performs containment as opposed to pure detection, and (3) analyze a much larger network trace that includes SMTP activity.

Finally, closely related work on this subject was performed by Musashi et al. [15, 14, 13]. In independent work from [18], they also recognized that MX query activity from client systems could indicate mass-mailing worm infection, and developed an *indirect virus detection system* (MXRPDS) that detects mass-mailing worm infection by monitoring DNS server and PC terminal interaction. In their implementation, they poll the DNS server syslog file every 10 seconds to determine client queries of A, MX and PTR records. Any client that accesses the DNS server for MX and A records without PTR records is considered to be infected with a mass-mailing worm. Clients that request a mixture of MX, A, and PTR records are considered to be spam relays. Their DNS host-based approach has a number of disadvantages compared to our network-based implementation. Specifically, a host-based approach does not address a common technique employed by SMTP-engines to obtain MX records by querying both local and remote DNS servers. Parsing of a local DNS's syslog file will not detect remote DNS accesses and introduces significant false negatives. Additionally, processing the DNS syslog every 10 seconds allows a newly infected system to remain active during this time sending potentially hundreds of malicious emails. Finally, they propose no way to quarantine the infected systems once detected.

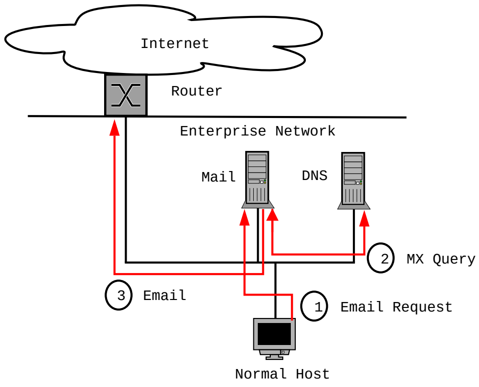


Figure 1. Normal Email Delivery.

Regarding a discussion of alternate proposals to address malicious mass-mailing activity, see Section 6.

3 Review of Normal vs. Malicious Email Delivery

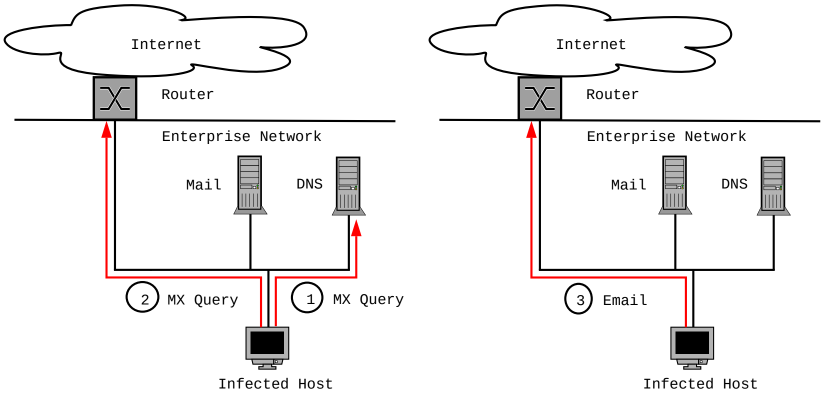
In this section, we contrast normal email delivery with email sent from a host with an SMTP-engine. Our technique is based on this simple observation. We assume an enterprise or corporate environment.

3.1 Normal Email Delivery

Generally, to generate an email message a user accesses local email client software responsible for sending the email to the mail server specified in its configuration file. Then, the mail server sends and delivers email on behalf of the users within its domain.

In order to determine the IP addresses of the mail servers responsible for delivering mail to the intended recipients, DNS MX queries are made. An MX record identifies the mail server responsible for sending and delivering emails for a Fully Qualified Domain Name (FQDN). Figure 1 illustrates the steps required to send an email message.

1. *User to mail server interaction:* a user in the enterprise network uses their email client to compose an email for a recipient or list of recipients. Once completed, the email client forwards the email to its local mail server for delivery.
2. *Mail server to DNS server interaction:* mail servers are store-and-forward systems. Once a mail server receives an email, it accesses the recipient list to determine where it must be delivered.



(a) MX Record Request (b) Malicious Mail Delivery

Figure 2. SMTP-engine Malicious Mass-Mailing Delivery.

The recipient list contains addresses of the form *user@host.domain* as specified in RFC 822 [8]. The *user* field will be a unique identifier for the particular domain. The *host.domain* field contains the host's FQDN. DNS servers use the FQDN to locate the mail servers that service the respective domain. As shown in Figure 1, the local DNS server happens to have the MX record in its cache for the recipient's domain and sends the IP address of the mail server identified in the MX record to the local mail server.

3. *Mail server to mail server interaction:* using the IP address contained in the MX record, the local mail server sends the email to the intended recipient's mail server. In turn, the recipient's mail server sends the email to the local client of the user specified in the email address.

3.2 Malicious Email Delivery with an SMTP-engine

In contrast to a normal email generation, mass-mailing activity via SMTP-engines bypasses corporate mail servers when it attempts to send malicious mail. Malicious mass-mailing software can either interrogate the host system to harvest email addresses (e.g. mass-mailing worm) or be supplied with a recipient list (e.g. spam) to send the malicious messages. In either case, here the SMTP-engine of the infected system is responsible for sending the malicious mail messages directly. In order to determine the mail server that services a particular recipient, the infected system, not the local mail server, queries a DNS server for an MX record associated with the email recipient's FQDN. Figure 2 illustrates the steps an infected host with an SMTP-engine performs to send an email message.

1. *Infected host to local DNS server interaction:* an internal system in the network is infected with malicious mass-mailing software that includes an SMTP-engine. To send mail, the infected system must forward MX queries to a DNS server. As shown in Figure 2(a), 1, the query is sent to the local DNS server which happens to have in its cache the MX record for the recipient's domain and sends the MX record to the infected system.
2. *Infected host to external DNS server interaction:* alternately, the infected system can query an external DNS server (i.e. Figure 2(a), 2) for an MX record.[¶]
3. *Infected host to mail server interaction:* the infected system sends the malicious email to the mail server responsible for the recipient specified in the email address. The local mail server is bypassed completely.

4 Basic Approach and MX Record Activity Analysis

Detection Approach - High Level Overview. Malicious mass-mailing software that use SMTP-engines bypass local mail servers but must still rely on DNS servers to locate the respective mail servers of their intended victims. Client-based MX requests are a violation of typical DNS behavior in the network.

To detect SMTP-engine malicious mass-mailing activity we simply observe all locally generated MX queries that originate from systems other than the (known) network mail servers. These systems are regarded as potentially infected and after a certain number (configurable within our prototype) of MX queries are observed, they

[¶] For instance, during the SoBig.F outbreak, Verisign discovered DNS MX lookups from tens of thousands of systems to its root DNS server [4].

Table 1. One-week Survey of DNS Record Activity.

Record Type	Number of Records
PTR	194 140
AAAA	99 019
SOA	17 800
A	2 074 620
CNAME	72
MX	211 697
NS	4 056

are quarantined from the network. Quarantining a system involves restricting it from directly performing any SMTP (i.e. port 25) network activity. Note that this differs from blocking port 25 activity of all (non-server) systems, which is discussed in Section 6.1.

Our detection technique relies on the hypothesis that MX query activity from ordinary client systems is distinguishable from those that perform mass-mailing. To confirm this hypothesis we monitored the internal client accesses of two DNS servers (a primary and secondary DNS server) for a medium sized departmental network within our university.

4.1 Network MX Record Activity Analysis

To understand the prevalence and behavior of MX record activity within a network of diverse clients, we observed a network that services a population of approximately 300 client systems used by faculty, administrative staff, and students. These systems contain a variety of operating systems that include Windows platforms, Linux, BSD, and SunOS. We monitored all internal (within the department network) and external accesses (outside of the department network including the Internet) of both DNS servers over a one week period. Table 1 shows the total DNS record activity for both DNS servers.

DNS A (authoritative) records are the most active type of DNS records observed. This is expected as DNS A records provide the mapping between the numeric IP address of a system and its FQDN. DNS A records are required for most routine connection requests between remote systems (e.g. HTTP). MX record activity is the second most requested DNS resource record.

4.2 Client MX Record Activity Analysis

MX record requests from external systems and internal mail servers are a normal occurrence. We analyzed the MX query activity within our network to determine if any client systems (i.e. not authorized mail servers) performed any MX queries. Table 2 shows that of the approximately 300 internal systems serviced by the two DNS servers, only five clients made MX record requests during the one week analysis period. Two of these (10.0.0.68 and 10.0.0.42)[‖] made a total of 1705 MX record requests to 133 unique FQDNs. System 10.0.0.68 is owned by a network administrator who, as part of a strategy to combat spam, was testing *SpamAssassin* [1]. We confirmed that the MX request activity in question from this system was performed as part of this software testing. System 10.0.0.42 was owned by a user. A quick inspection of the system configuration determined that this activity was the result of a mis-configured *cronjob* requesting nonexistent MX records (i.e. *localhost.localdomain*) from the DNS server.

The remaining three (10.0.0.36, 10.0.0.51, and 10.0.0.83) systems were responsible for a total of 5 MX record requests over the one-week test period. As the IP addresses that corresponded to these three systems were assigned via *DHCP*, the necessary logs to perform user attribution for these IP addresses do not exist. Therefore, an analysis of the cause of these MX queries was not possible. Given the low number of *unexplained* MX queries (i.e. 5) we conjecture that these are likely caused by isolated MX lookups (e.g. perhaps evidence of mail relaying through 3rd party mail servers). The conclusion we draw from this analysis is that most client systems within this network do not perform MX queries even though it is a heterogeneous software environment (e.g. university network). If we assume this network is representative, our technique is generally viable as there are very few false positives.

However, there may be instances in which a user at a client system needs to legitimately access SMTP services directly and request MX records (e.g. a mobile user with a laptop wanting to relay mail through their own *home* mail servers). We believe this activity is discernible from mass-mailing activity and can easily be accommodated by any containment approach.

[‖] IP addresses have been anonymized.

Table 2. MX Record Lookups.

IP Address	MX Requests	Unique MX Requests	Reason
10.0.0.68	1691	132	System admin SpamAssassin test system.
10.0.0.42	14	1	Mis-configured cron job sending mail to *localhost.localdomain*.
10.0.0.36	3	3	DHCP system - unexplained.
10.0.0.51	1	1	DHCP system - unexplained.
10.0.0.83	1	1	DHCP system - unexplained.

5 Prototype and Analysis

In this section, we describe our software prototype detection and proof-of-concept containment system. We also discuss its performance in detecting and containing a *live* mass-mailing worm within an isolated test network.

5.1 Prototype

To validate our SMTP-engine detection and containment technique, we developed and tested a fully functional software prototype. The software was installed on a commodity PC with a Linux operating system. The prototype processes network data in *real-time* and performs two distinct functions: (1) detection of SMTP-engine mass mailing activity, and (2) containment of systems that exhibit SMTP-engine mass-mailing activity. We now discuss these two functions in turn.

Detect. The only network data feature extraction required by the prototype to detect SMTP-engine mass-mailing activity is DNS MX queries. If any client system performs a DNS MX query (local or external) this is considered potential malicious mass-mailing activity. MX queries originating from authorized mail servers (or other systems authorized to use SMTP) are exempt from the detection algorithm through the use of a *whitelist*.

Contain. Once potential SMTP-engine mass-mailing activity is detected, the prototype uses *IPTables* [2] to stop all SMTP activity from the client. IPTables software is included within the Linux kernel and provides a generic specification of rule sets that allows for stateful packet filtering. When a client system, not enumerated within the whitelist, exceeds the number of allowed MX queries, a rule is added to IPTables that restricts port 25 (SMTP) activity (both outgoing and incoming) from that client's source address.

Configuration Discussion. False positives are an important concern. A balance must be struck between rapid detection and impact to users due to unwarranted containment. Our prototype can be configured to restrict SMTP activity after the observation of any number (e.g. 1 or more) of MX queries within a given time interval. This flexibility enables the reduction of false positives (see Section 5.3), and the ability to allow mail relaying in the network if permitted (see discussion in Section 6.1).

Regardless, in our current implementation even if a false positive occurs a *contained* client system is only restricted from performing SMTP activity. The client is allowed unhindered access to all other network services. However, it could be argued that if we suspect a client system contains a malicious SMTP-engine, it may contain other active infection vectors (e.g. network share traversal, scanning). In this case, it may be a prudent containment decision to generate the necessary IPTables rules to restrict all network access from the client.

A further consideration for the prototype is network placement. The two most important placement considerations are (cf. Fig. 2(a)): (1) enabling detection of all MX query activity (i.e. remote and local), and (2) the ability to restrict the network access of infected systems. Most SMTP-engines are configured to query the local DNS server for MX records first. In the event the local DNS server cannot be accessed, some SMTP-engines contain a list of remote DNS servers to query. The prototype should be placed where it can monitor all MX activity on the network (e.g. to also detect the use of external DNS servers). Furthermore, in order to restrict the SMTP activity of infected systems, the containment device must be placed at all egress points on the network.

5.2 Live Worm Network Testing

To conduct our prototype evaluation, we tested it against a *live* worm within an isolated network test environment. The network was used to: (1) observe the behavior of SMTP-engine mass-mailing systems, and (2) test the effectiveness of our prototype. The isolated worm test network is attached to a fully functional research network that in turn connects to a university department network. All of these networks (with the exception of the isolated worm test network) share part of our university's Class B IPv4 Internet address space.

To prevent inadvertent infection of systems during testing, we placed a firewall between the isolated worm test network and the research network. The firewall rules allowed only DNS traffic to enter or leave the isolated worm test network. Additionally, we physically (and logically) isolated all the worm test network IP addresses on a separate switch using a VLAN with non-routeable IP addresses (i.e. 192.168.1.0/24 [16]). To confirm the validity of our approach we infected a system within the worm test network with the NetSky.Q.mm mass-mailing worm [5] and observed its behavior for 10 minutes. Table 3 shows the network activity from the infected system. Within 10 minutes the system generated 194 MX queries to our local DNS server looking to resolve 37 unique mail server FQDNs. Additionally, after an initial burst of MX query activity, the infected system attempted to contact 44 external mail servers via SMTP.

Once the 10 minute observation period ended, we removed the worm infection from the system using antivirus software. The prototype was then placed in-line before the firewall. The client system was reinfected with the mass-mailing worm and the network traffic was observed. Our prototype detected the first MX query and blocked all SMTP traffic from the infected host. Audit logs from both the firewall and our prototype confirm that no subsequent SMTP traffic from the infected system passed through the in-line prototype.

5.3 Discussion of False Positives and Negatives

The following two sections discuss the impact and causes of false positives and negatives on our detection technique.

False Positives. In our analysis of MX query activity in Section 4.2, we discovered that over a one-week period only 5 unexplained MX queries were made by client systems. Although this suggests that no widely installed client application requires MX records to access external mail servers, these queries would still be a source of false positives. Using our current configuration, our prototype would have erroneously contained three systems during the observation period.

However, the prototype could be set to restrict access after the observation of more than a single MX query within a specified time window (see Section 5.1). For instance, during the same one-week observation period if we had set the prototype to contain a client system after the observation of two or more MX queries within a 20 minute time period then no false positives would have occurred. If any client requires the use of its own SMTP server, then two options exist. First, its IP address could be added to the whitelist to exempt it from detection and containment. Second, the prototype could be configured to allow clients a certain number of MX queries within a given time interval before quarantine occurs.

False Negatives. The prototype permits client MX record request activity within the enterprise network through the use of a whitelist. For instance, in the department network we observed in Section 4.2 the whitelist would consist of four entries (i.e. three authorized mail servers and the SpamAssassin test system). If a system on the whitelist becomes infected with a mass-mailing SMTP-engine, its malicious mailing activity will not be detected.

5.4 Limitations and Circumvention

Limitations. Instead of using SMTP-engines to send email, compromised systems could use the resident email client software. In this case, the corporate mail server would perform the MX queries on behalf of the system and this would not be detected by our technique. However, an attacker using this strategy would not benefit from the advantages of using SMTP-engines.

SMTP-engines allow mass-mailing worms to circumvent corporate mail servers and send infected emails directly from the victim system. Furthermore, there is no requirement for the worm to have the capability to detect and then use disparate email clients on victim systems. This ensures that emails can be generated and sent regardless of the email client software used by the victim, thus increasing the worm's propagation rate.

Additionally, the use of an SMTP-engine obviates the need for the worm to interact with the victim system's email client resulting in fewer signs of an active infection. For example, no copies of the infected emails will appear in the sent items folder of the infected system's email client.

Circumvention. If an infected system contained a list of IP addresses for the mail servers it wanted to send mail to, then no MX queries would be required. However, this would limit the infected system to sending mail to predetermined domains. While this may be a questionable strategy for opportunistic mass-mailing worms, it may be acceptable when sending spam where a recipient's list may be available. In this scenario, although the attacker would still need to perform MX queries, these could be made offline and thus undetectable by our technique.

Another way to avoid detection would be to have the infected systems contact a system outside of the enterprise network to perform DNS queries on their behalf. Communications to this *covert proxy DNS* server could be tunneled through the network using an arbitrary non-filtered port. Our implementation of the technique currently can not detect DNS activity tunneled through the arbitrary ports (i.e. ports other than port 53).

6 Comparison with Alternate Approaches

In this section, we compare our technique to several existing techniques that attempt to prevent malicious

Table 3. NetSky.Q.MM Network Activity (10 minute period).

Activity	Unique Requests	Total Requests
MX Record Queries	37	194
A Record Queries	24	24
SMTP connections	44	322

mass-mailing.

6.1 Port 25 Blocking

Many enterprises and ISPs have instituted port 25 blocking at the network boundary to stop malicious SMTP-engine mass-mailing activity. This prohibits users running SMTP services locally. Mail relaying to 3rd party mail servers is typically allowed only through the ISP's mail servers. Indiscriminate port 25 blocking and the mandating of mail relaying activity to specific mail servers has proved to be both an unpopular and questionable strategy, with disadvantages including:

1. *Detection of infected systems*: port blocking alone will not identify malicious mass-mailers.
2. *Impact to user privacy*: mandatory mail relaying through an ISP's mail servers closely ties the user's identity to the ISP's network.
3. *Impact to user choice*: mandating how mail should be forwarded breaks a fundamental design principle of the Internet (i.e. flexibility) and takes away user options.
4. *Circumvention*: mass-mailers have begun to evade port blocking by setting up servers to use arbitrary ports (i.e. other than port 25) to relay mail from mass-mailing zombies.

Wholesale port 25 blocking is a quixotic solution: it addresses the problem of stopping malicious SMTP-engine mass-mailing activity, at the expense of denying all legitimate client-based SMTP activities. In contrast, our prototype can contain SMTP traffic from a client system after any number of MX query attempts within a configurable time interval.

During our testing (see Section 5.2) we configured our prototype to restrict SMTP activity once it detected the first MX query attempt from a client system. This rule effectively restricts MX queries to the exclusive domain of the network mail servers specified in the whitelist during initialization. This decision was directly supported by our analysis of client MX query activity presented in Section 4.2. In other network environments it may be an appropriate strategy to contain a client system after observing some number of MX queries (e.g. ≥ 2) within an arbitrary time interval. For instance, this strategy would be recommended for networks where it is common practice to allow users to relay mail to 3rd party mail servers. In this case, the prototype could be set to contain a client system after observing MX record activity greater than that required to resolve the FQDNs of a finite number of 3rd party mail servers. Although our approach can be as restrictive as port 25 blocking (e.g. quarantine after a single MX query is observed), it offers a means to allow a configurable amount of client-based mailing.

6.2 Preventing Email Address Forgery

Sender Policy Framework (SPF) [20] is designed to reduce email address forgery. Domain owners publish SPF records that specify the systems authorized to send mail for that domain. The recipient of an email performs a check to determine if the sending MTA is listed in the SPF record for the domain specified in the sender's email address. If not, it is flagged as suspicious (e.g. potential spam) or simply rejected. SPF breaks simple mail forwarding, which preserves the from address within an email header as it travels through different mail servers. In order to be verified by SPF, mail forwarding must be replaced by some form of re-mailing (i.e. the sender field is changed to reflect the address of the last mail server hop).

An alternate proposal to address email address forgery is DomainKeys [7]. Unlike SPF, it is designed to verify both the domain of the sender and the contents of the message. The integrity of the message is ensured by the use of a digital signature over a SHA-1 hash of the mail message (selected header fields and body), by the sending mail server's private key. To verify the message, the receiving mail server performs a DNS lookup for a record that contains the sending domain's public key. Signature verification is assumed to imply that the email came from the claimed domain and it has not been modified in transit. A mail server receiving an unsigned mail message may flag it as suspicious or simply choose to reject it. Potential issues arise from the fact the entire email message (including header) is hashed. Mail message headers are often legitimately altered by mail list servers, spam filters, and even ordinary mail servers, causing signature verification to fail. Additionally, this approach entails both computational and administrative overhead as a result of the cryptographic services.

Both SPF and DomainKeys are designed to detect spoofed email as it is received at network mail servers. However, SMTP-engines bypass corporate mail servers completely. These techniques would be ineffective in preventing the origination of mass-mailing from unauthorized SMTP-engines; such mail would be stopped at the receiving end only after it has been sent. In contrast, our approach stops such mail at the sending end. Furthermore, mail that fails SPF or DomainKeys checks may not be rejected in favor of using the failure result as an input flag to a client spam filter. It is common practice for spam filters to archive mail identified as spam in a *spam directory* for user review. In this case, the malicious mail under discussion may still consume bandwidth, network server processing, disk space, and the user's time. Our approach can be used in conjunction with these techniques to enable both the verification of incoming mail and the eradication of mass-mailing from SMTP-engines before mail is ever sent.

7 Concluding Remarks

While promising current techniques to address malicious mass-mailing activity (e.g. SPF [20], DomainKeys [7]) offer a way to identify forged mail as it is received by network mail servers, they are not designed to detect or stop malicious mass-mailing that bypasses authorized mail servers (e.g. SMTP-engines) before it leaves the enterprise network. Our approach could be applied as a complementary technique to rapidly and accurately detect and contain malicious SMTP-engine mail propagation within an enterprise network (i.e. stopped at the sending end before traversal of the Internet).

A further benefit of our technique over existing mass-mailing detection techniques is that it is email *content independent*. The detection technique being based on indirect network behaviors (i.e. MX record queries) allows us to detect mass-mailing activity from client systems regardless of whether it is stealthy (e.g. slow spreading), polymorphic, attachment-based, or spread by embedded URLs in text messages.

Although our approach can be as restrictive as port 25 blocking for all clients in the network (i.e. quarantine occurs after a single MX query), it is flexible enough to allow a number of MX queries to occur from a client system before quarantine occurs. For instance, this may allow legitimate users to relay mail through 3rd party mail servers of their choice. We believe that, in general, wholesale port blocking should only be used as an effective *stop-gap* measure until a more considered countermeasure is developed; policies like port blocking typically do not address the root problem, in this case the identification and quarantining of only malicious mass-mailing systems. Additionally, our technique could be used in conjunction with proposals to address mail forgery (i.e. SPF and Domain Keys) to offer a more comprehensive strategy to stop malicious mass-mailing.

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References

[1] The Apache SpamAssassin Project. http://spam assassin.apache.org.

[2] The netfilter/iptables Project. http://www.net filter.org.

[3] W32/Dumaru.w Trojan. *McAfee Inc.* http: //vil.nai.com/vil/ content/v100977. htm; accessed on February 28, 2006.

[4] Internet Security and Intelligence Briefing. *VeriSign*, October 2003. http://www.verisign.co m/static/005572.pdf; accessed on April 20, 2006.

[5] W32.Netsky.Q@mm. July 2004. http:// security response. symantec. com/ avcenter/ venc/ data/ w32.netsky.q@ mm.html.

[6] MessageLabs Intelligence Annual Email Security Report 2004. *MessageLabs*, 2005. http://www.messagelabs.com/published content/ intelligencereports/ 2004annualsecurityreport/DA 114012.chp.html; accessed on March 02, 2006.

[7] E. Allman, J. Callas, M. Delany, M. Libbey, J. Fenton, and M. Thomas. DomainKeys Identified Mail Signatures DKIM. February 2006. http://www.ietf.org/ internet-drafts/draft-ietf-dkim-base-00.txt.

[8] D. Crocker. Standard For The Format of Internet Text Messages. RFC, August 1982. http://www.ietf.org/rfcs/rfc0822.txt; accessed May 29, 2006.

[9] A. Gupta and R. Sekar. An approach for detecting self-propagating email using anomaly detection. In *Proceedings of the Sixth International Symposium on Recent Advances in Intrusion Detection*, September 2003.

[10] R. Hu and A. Mok. Detecting unknown massive mailing viruses using proactive methods. In *Proceedings of the 7th International Symposium on Recent Advances in Intrusion Detection*, September 2004.

[11] K. Ishibashi, T. Toyono, and K. Toyono. Detecting mass-mailing worm infected hosts by mining DNS traffic data. In *SIGCOMM 05 Workshops*, August 2005.

[12] J. Leyden. Zombie PCs spew out 80% of spam. *The Register*, June 2004.

[13] Y. Musashi, R. Matsuba, and K. Sugitani. Detection of mass mailing worm-infected IP address by analysis of DNS server syslog. In *IPSJ SIG Technical Reports, Distributed System Management 32nd*, number 37, pages 31–36, 2004.

[14] Y. Musashi, R. Matsuba, and K. Sugitani. Detection of mass mailing worm-infected PC terminals. In *Proceedings for the 3rd International Conference on Emerging Telecommunications Technologies and Applications (ICETA2004)*, pages 233–237, 2004.

[15] Y. Musashi, R. Matsuba, and K. Sugitani. Detection of mass mailing worm-infected PC terminals for learners by observing DNS query access. In *27th IPSJ SIG Technical Reports, Computer Security*, number 129, pages 39–44, 2004.

[16] Y. Rekhter, B. Moskowitz, D. Karrenberg, G. de Groot, and E. Lear. Address Allocation for Private Internets. RFC, February 1996. http://www.ietf.org/rfc/rfc1918 .txt accessed on March 30, 2006.

[17] S. Sidiroglou, J. Ioannidis, A. Keromytis, and S. Stolfo. An Email Worm Vaccine Architecture. In *Proceedings of the 1st Information Security Practice and Experience Conference (ISPEC)*, April 2005.

[18] D. Whyte, E. Kranakis, and P. van Oorschot. DNS-based detection of scanning worms in an enterprise network. In *Proceedings of the 12th Annual Network and Distributed System Security Symposium*, Feb. 2005.

[19] C. Wong, S. Bielski, J. McCune, and C. Wang. A study of mass mailing worms. In *The 2nd ACM Workshop on Rapid Malcode*, Oct. 2004.

[20] M. Wong and W. Schiltt. Sender Policy Framework (SPF) for Authorizing Use of Domains in E-MAIL, version 1. June 2005. http://www.ietf.org/internet-drafts/draft-schli tt-spf-classic-02.txt.

[21] C. Zou, W. Gong, and D. Towsley. Feedback to Email Worm Defense System for Enterprise Networks. Technical report, University of Massachusetts, Amherst, TR-04-CSE-05, April 2004.

[22] C. Zou, D. Towsley, and W. Gong. Email Worm Modeling and Defense. In *Proceedings of the 13th International Conference on Computer Communications and Networks (ICCCN'04)*, October 2004.