Notos: Building a Dynamic Reputation System for DNS

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Problems with Static Blacklisting

- Malware families utilize large number of domains for discovering the “up-to-date” C&C address
  - Examples are the Sinowal, Bobax and Conficker bots families that generate tens of thousands new C&C domains every day
  - IP-based (dynamic or not) blocking technologies cannot keep up with the number of IP addresses that the C&C domains typically use
  - DNSBL based technologies cannot keep up with the volume of new domain names the botnet uses every day

- Detecting and blocking such type of agile botnets cannot be achieve with the current state-of-the-art
Outline

• Notos
  – Notations, Passive DNS trends, and anchor-zones
  – Network based profile modeling
  – Network and zone based profiles clustering
  – Reputation function
  – System implementation
  – Results

• Conclusions and Future Work
• Network and zone based features that capture the characteristics of resource provisioning, usages, and management by domains.
  – Learn the models of legitimate and malicious domains

• Classify new domains with a very low FP% (0.3846%) and high TP% (96.8%).
  – Days or even weeks before they appear on static blacklists.
Notation & Terminology

- Resource Record (RR)
  - www.example.com 192.0.32.10
- 2nd level domain (2LD) and 3rd level domain (3LD)
  - For the domain name www.example.com: 2LD is the example.com and 3LD is the www.example.com
- Related Historic IPs (RHIPs)
  - All “routable” IPs that historically have been mapped with the domain name in the RR, or any domain name under the 2LD and 3LD
- Related Historic Domains (RHDNs)
  - All fully qualified domain names (FQDN) that historically have been linked with the IP in the RR, its corresponding CIDR and AS
Passive DNS data

• Successful DNS resolutions that can be observed in a given network
• Data set has traffic from 2 ISP sensors - one in west coast and one in east coast, also data from SIE
• We observe that different classes of zones demonstrate different passive DNS behaviors
• The number of new domain names and IPs we observe every day is in the range of 150,000 to 200,000
Passive DNS trends

Anchor classes in pDNS: Akamai, CDN, Popular, DYNDNS and Common
Features

Notos computes three feature vectors for a RR, based on its RHIPs, RHDNs and Evidence data. The analysis of these feature vectors is forwarded to the reputation engine.

These 3 vectors are the Network Based Feature Vector [18], Zone Based Feature Vector [17] and the Evidence Based Feature Vector [6].
Network Profile Modeling

- Train a Meta-Classifier based on the 5 anchor-classes
- The network feature vector of a domain name $d$ is translated into the network modeling output ($NM(d)$)

The $NM(d)$ is a feature vector composed from the confidence scores for each different anchor-class
Domain Clustering

The network and zone based feature vectors of a domain $d$ are used to produce the domain clustering output ($DC(d)$).

In this step we are able to **characterize** unknown domains within clusters based on already labeled domains **in close proximity**. The $DC(d)$ is a 5-feature vector characterizing the position of $d$ in the cluster.
Reputation Function

- Each domain $d$ in our dataset is transformed into three feature vectors by Notos: $NM(d)$, $DC(d)$ and $EV(d)$ (evidence profile output); these vectors assemble the reputation vector $v(d)$
- The reputation function $f(v(d))$ assigns a score to the domain name $d$ between $[0,1]$
- The reputation function is a statistical classifier (Decision Tree with Logistic Boost - after model selection)
- The reputation function is trained using labeled domain data
Operational Model of Notos

- Notos utilizes the **Off-line mode** to train classifiers, build the clusters and train the reputation function.
- In the **In-line mode**, Notos assigns reputation to new RRs observed at the monitoring point.
Results from the Reputation Function

FP% = 0.3849% and TP% = 96.8%
Results from the Reputation Function (cont’d)

# of days the detection earlier than public BLs

(a) Overall Volume of Malicious Domains

(b) Flux and Spam Domain Names Identified

(c) Malware Dropping/Trojans, Exploits and Rogue AV Domain Names Identified

(d) Botnet Domain Names Identified
Tech Transfer

• Damballa is actively evaluating Notos
• ISPs are interested in having us extend this line of research
• DNS vendors and other network operators
  – Have been spending millions of $ and years trying to build similar system, but fail to match Notos’ capability/performance
  – Trying to get Notos technologies
Conclusions and Future Work

• Conclusions:
  – Combining network, zone, and evidence features provides the ability to dynamically associate unknown domains to known domains/networks
  • Benefits: with limited labeled domains we can identify new malicious ones, much sooner than BLs

• Future Work:
  – Targeted detection: use an additional clustering step based on association with specific fraudulent domain name class (RBN, Zeus, etc.) to enable targeted detection
  – Combine Notos with Spam/Flux detection systems