

# Honey Onions: Exposing Snooping Tor HSDir Relays

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**Abstract**—Tor is a widely used anonymity network that protects users’ privacy and identity from corporations, agencies and governments. However, Tor remains a practical system with a variety of limitations which can be subverted [1]. In particular, Tor’s security relies on the fact that a substantial number of its nodes do not misbehave.

Previous work showed the existence of malicious participating Tor relays. For example, there are some Exit nodes that actively interfere with users’ traffic and carry out man-in-the-middle attacks. In this work we expose another category of misbehaving Tor relays (HSDirs), that are integral to the functioning of the hidden services and the dark web. The HSDirs act as the DNS directory for the dark web. Because of their nature, detecting their malicious intent and behavior is much harder. We introduce, the concept of honey onions (honions), a framework to detect misbehaving Tor relays with HSDir capability. By setting up and deploying a large scale honion over Tor for more than 72 days, we are able to obtain lower bounds on misbehavior among HSDirs.

We propose algorithms to both estimate the number of snooping HSDirs and identify them, using optimization and feasibility techniques. Our experimental results indicate that during the period of our work at least 110 such nodes were snooping information about hidden services they host. We reveal that more than half of them were hosted on cloud infrastructure and delayed the use of the learned information to prevent easy traceback. Furthermore, we provide the most likely geolocation map of the identified snooping Tor HSDirs.

## I. HONION GENERATION & DETECTION

In this work, we introduce the concept of *honey onions* (honions), a framework to expose when a Tor relay with HSDir capability has been modified to snoop into the hidden services that it currently hosts. We developed several tools, to automate the process of generating and deploying honions in a way that they cover a significant fraction of HSDirs. A key constraint in this process was to minimize the number of deployed honions. This derives primarily from our desire to not impact the Tor statistics about hidden services; specially given the recent surge anomaly (Figure 1). By considering the number of HSDirs (approximately 3000), we could infer that to cover all HSDirs with 0.95 probability, we need to generate around 1500 honions. We decided on three schedules to allow us to detect different snooping behaviors. Namely, daily, weekly and monthly. The daily schedule allows us to detect malicious HSDirs who visit honions shortly after hosting them. The weekly and monthly schedules enables us to detect more sophisticated snoopers who delay their visits to avoid identification.

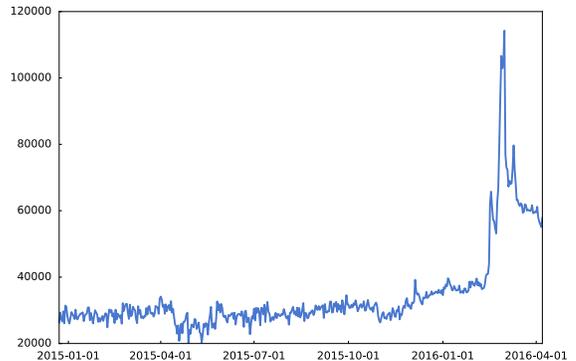


Fig. 1: Recent unexplained surge in the number of Hidden Services.

**HONion back end servers:** Each honion corresponds to a process that is running locally. The server behind hidden services, should not be running on a public IP address, to avoid de-anonymization. We also log all the requests that are made to the server programs and the time of each visit. Recording the content of the requests allows us to investigate the snoopers’ behavior and intent.

**HONions generation and deployment schedule:** To keep the total number of honions small, we decided on three schedules for their generation and placement, *daily*, *weekly*, and *monthly*. The three schedules allow us to detect the malicious HSDirs who visit the honions shortly (less than 24 hours) after hosting them. Since the HSDirs for hidden services change periodically, more sophisticated snoopers may wait for a longer duration of time, so they can evade detection and frame other HSDirs.

**Identifying snooping HSDirs:** Based on the visited hidden service, the time of the visit, and the HSDir that have been hosting the specific onion address prior to the visit, we can mark the potential malicious and misbehaving HSDirs. Then, we add the candidates to a bipartite graph, which consists of edges between HSDirs and the visited honions. The analysis of this graph allows us to infer a lower bound on the number of malicious HSDirs as well as specific snoopers. Figure 2 depicts the architecture of the system.

**HONion Visit Graph Formation:** In the following we first introduce a formal model and notation for the Honey Onions

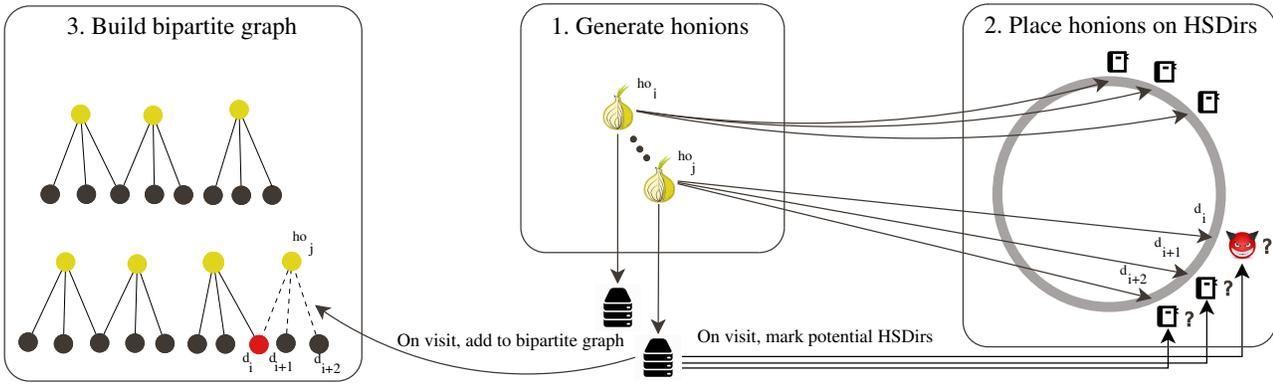


Fig. 2: Flow diagram of the honion system.

system. First,  $HO$  denotes the set of honey onions generated by the system that were visited, and  $HSD$  the set of Tor relays with the  $HSDir$  flag (so far referred to as HSDir relays). The visits of honions allow us to build a graph  $G = (V, E)$  whose vertices are the union of  $HO$  and  $HSD$  and edges connect a honion  $ho_j$  and HSDir  $d_i$  iff  $ho_j$  was placed on  $d_i$  and subsequently experienced a visit.  $G$  is by construction a bipartite graph. We also note that each honion periodically changes descriptors and therefore HSDirs (approximately once a day). However, a HSDir currently a honion  $ho$  cannot explain visits during past days. Therefore, each time a honion changes HSDirs we clone its vertex  $ho$  to  $ho'$  and only add edges between  $ho'$  and the HSDirs who know about its existence when the visit happened.

**Estimation & Set Cover:** Since each honion is simultaneously placed on multiple HSDirs, the problem of identifying which ones are malicious is not trivial. We first formulate the problem of deriving a lower-bound on their number by finding the smallest subset  $S$  of  $HSD$  that can explain all the visits. The size  $s$  of the minimal set tells us that there cannot be less than  $s$  malicious HSDirs who would explain the visits.

$$\begin{aligned}
 HSD &= \{d_i : \text{Tor relays with } HSDir \text{ flag}\} \\
 HO &= \{ho_j : \text{Honey Onion that was visited}\} \\
 V &= HSD \cup HO \\
 E &= \{(ho_j, d_i) \in HO \times HSD \mid ho_j \text{ was placed on } d_i \\
 &\quad \text{and subsequently visited}\}
 \end{aligned}$$

$$\operatorname{argmin}_{S \subseteq HSD} |S : \forall (ho_j, d_i) \in E \exists d'_i \in S \wedge (ho_j, d'_i) \in E| \quad (1)$$

Finding the smallest set  $S$  as defined by Equation 1, is not trivial as one can easily see that it is equivalent to the hitting set problem, which is well known to be NP-Complete. However, it can also be formulated as an Integer Linear Program. Let  $x_{1 \leq j \leq |HSD|}$  be binary variables taking values 0 or 1. Solving Equation 1, consists of finding integer assignments to the  $x_j$  such that:

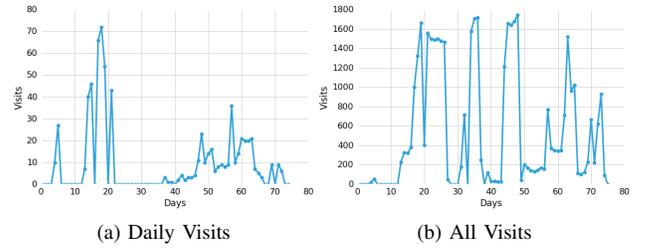


Fig. 3: Plot of the visits to the honions.

$$\begin{aligned}
 \min_{(x_1, \dots, x_{|HSD|})} & \sum_{j=1}^{|HSD|} x_j \\
 \text{subject to } \forall ho_i \in HO & \sum_{j: (ho_i, d_j) \in E} x_j \geq 1
 \end{aligned}$$

## II. RESULTS & DISCUSSION

We started the daily honions on Feb 12, 2016; the weekly and monthly experiments on February 21, 2016, which lasted until April 24, 2016. During this period there were three spikes in the number of hidden services, with one spike more than tripling the average number of hidden services (Figure 1). There are some theories suggesting that this was due to botnets, ransomware, or the success of the anonymous chat service, called Ricochet. However, none of these explanations can definitely justify the current number of hidden services. Our daily honions spotted snooping behavior before the spike in the hidden services, this gives us a level of confidence that the snoopings are not only a result of the anomaly (Figure 3). Rather, there are entities that actively investigate hidden services.

**Snooping HSDirs Nature and Location:** In total we detected at least 110 malicious HSDir using the ILP algorithm, and more than 40000 visits. More than 70% of these HSDirs are hosted on Cloud infrastructure. Around 25% are exit nodes as compared to the average, 15% of all relays in 2016, that have both the HSDir and the Exit flags. This can be interesting for further investigation, since it is known that some Exit nodes are malicious and actively interfere with users' traffic and perform active MITM attacks [2]. Furthermore, 20% of the misbehaving HSDirs are, both exit nodes and are hosted



Fig. 4: The global map of detected misbehaving HSDirs and their most likely geographic origin.

on Cloud systems, with data centers in Europe and Northern America. The top 5 countries are, USA, Germany, France, UK, and Netherlands. Figure 4 depicts the spread and the most likely geolocation of the malicious HSDirs.

**HSDirs Behavior and Intensity of the Visits:** Most of the visits were just querying the root path of the server and were automated. However, we identified less than 20 possible manual probing, because of a query for `favicon.ico`, the little icon that is shown in the browser, which the Tor browser requests. Some snoopers kept probing for more information even when we returned an empty page. For example, we had queries for `description.json`, which is a proposal to all HTTP servers inside Tor network to allow hidden services search engines such as Ahmia, to index websites. One of the snooping HSDirs (`5.*.*:9011`) was actively querying the server every 1 hour asking for a server-status page of Apache. It is part of the functionality provided by `mod_status` in Apache, which provides information on server activity and performance. Additionally, we detected other attack vectors, such as SQL injection, targeting the `information_schema.tables`, username enumeration in Drupal, cross-site scripting (XSS), path traversal (looking for `boot.ini` and `/etc/passwd`), targeting Ruby on Rails framework (`rails/info/properties`), and PHP Easter Eggs (`?=PHP*-*_*-*_*`).

### III. CONCLUSION & FUTURE WORK

In this work, we introduced honey onions (HONions), a framework for methodically estimating and identifying Tor HSDir nodes that are snooping on hidden services they are

hosting. We propose algorithms to both estimate the number of snooping HSDirs and identify them. Our experimental results indicate that during the period of the study (72 days) at least 110 such nodes were snooping information about hidden services they host. Furthermore, we observe that not all snooping HSDirs operate with the same level of sophistication and intensity. For example the less sophisticated snoopers visit the honeys shortly after hosting them (less than 24 hours), while the more sophisticated snooping HSDirs delay their visits to avoid detection and frame their neighboring relays. We believe that behavior of the snoopers can be modeled and studied in more detail using a game theoretic framework. Additionally, we reveal that more than half of them were hosted on cloud infrastructure making it difficult to detect malicious Tor nodes. Specially some cloud providers such as Vultr, even accepts payments in the form of bitcoins, which prevents the traceback and identification of misbehaving entities. It is noteworthy that the current proposals [3] for the next generation of hidden services would improve their privacy and security.

### REFERENCES

- [1] A. Sanatinia and G. Noubir, "Onionbots: Subverting privacy infrastructure for cyber attacks," in *The Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN)*, 2015.
- [2] P. Winter, R. Köwer, M. Mulazzani, M. Huber, S. Schrittwieser, S. Lindskog, and E. Weippl, "Spoiled onions: Exposing malicious tor exit relays," in *Privacy Enhancing Technologies: 14th International Symposium (PETS), Proceedings*, 2014.
- [3] N. Mathewson, "Next-generation hidden services in tor," <https://gitweb.torproject.org/torspec.git/tree/proposals/224-rend-spec-ng.txt>.