Poseidon: Mitigating Interest Flooding DDoS Attacks in Named Data Networking

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***Abstract*—Content-Centric Networking (CCN) is an emerging networking paradigm being considered as a possible replacement for the current IP-based host-centric Internet infrastructure. CCN focuses on content distribution, which is arguably not well served by IP. Named-Data Networking (NDN) is an example of CCN. NDN is also an active research project under the NSF Future Internet Architectures (FIA) program. FIA emphasizes security and privacy from the outset and by design. To be a viable Internet architecture, NDN must be resilient against current and emerging threats.**

This paper focuses on distributed denial-of-service (DDoS) attacks; in particular we address *interest flooding*, an attack that exploits key architectural features of NDN. We show that an adversary with limited resources can implement such attack, having a significant impact on network performance. We then introduce Poseidon: a framework for detecting and mitigating interest flooding attacks. Finally, we report on results of extensive simulations assessing proposed countermeasure.

I. INTRODUCTION

The Internet is an amazing success story, connecting hundreds of millions of users. The way people access and utilize it has changed radically since the 1970-s when its architecture was conceived. Today, the Internet has to accommodate new services, new usage models and new access technologies. Users are increasingly mobile, constantly accessing – and contributing to – remote information using a variety of devices such as laptops and smartphones. Ever-increasing mobility, device heterogeneity, as well as massive amounts of user-generated content and social networking are exposing the limits of the current Internet architecture.

To this end, there are some recent research efforts [23], [33], [22], [24], [7] with the long-term goal of designing and deploying a next-generation Internet architecture. One such new architecture is Named Data Networking (NDN). It is based on the principle of Content-Centric Networking, where content – rather than hosts – occupies the central role in the communication architecture. NDN is one of the five NSF-sponsored Future Internet Architectures (FIA) [12]; like the rest, it is an on-going research effort. NDN is primarily oriented towards efficient large-scale content distribution. Rather than establishing direct IP connections with a host serving content, NDN consumers directly request (i.e., express *interest* in) pieces of content by name; the network is in charge of finding the closest copy of the content, and of retrieving it as efficiently as possible. This decoupling of content and location allows NDN to efficiently implement multicast, content replication and fault tolerance. One of the key goals of the NDN project is *"security by design"*. In contrast to today's Internet, where security problems were (and are still being) identified along the way, the NSF FIA program (for all of its projects) stresses both awareness of issues and support for features and countermeasures from the outset. To this end, this paper investigates distributed denial of service (DDoS) attacks in NDN. DDoS attacks are considered to pose serious threats to the current Internet. NDN is not immune to them and might actually offer avenues for new DDoS attacks.

In NDN, each content consumer's request (called an "interest") causes NDN routers to store a small amount of transient state, which is flushed as the content is routed back to the consumer. This has been pointed out in previous work as a plausible attack vector – under the name of interest flooding attack [13], [31].

Motivated by the importance of addressing security in the early stages of a potential new Internet architecture, we focus on DDoS over NDN, specifically, using interest flooding attack. We believe that interest flooding attack and countermeasures deserve an in-depth investigation before NDN can be considered ready for large-scale deployment. While some preliminary results of this research appeared in [8], in the current paper we show, via extensive simulations, that interest flooding attacks are not just theoretical. It is, in fact, relatively easy to perform interest flooding with rather limited resources. We simulate interest flooding over a realistic topology [15]: the AT&T network. We focus on reactive countermeasures and propose techniques for early detection of interest flooding. (This was left as an open problem in [13].) We then describe the design and implementation of Poseidon – a framework for local and distributed interest flooding attack mitigation. Finally, we report on the effectiveness of proposed methods.

Organization. We present NDN in Section II and interest flooding in Section III. Section IV details our simulation

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environment and Section V evaluates the impact of interest flooding attack in our setup. Section VI presents our countermeasure, evaluated in Section VII. Finally, Section VIII overviews related work and Section IX concludes the paper.

II. NDN OVERVIEW

NDN supports two types of messages: *interests* and *content* [5]. A content message includes a name, a payload and a digital signature computed by the content producer. Names are composed of one or more components, which have a hierarchical structure. In NDN notation, "/" separates name components, e.g., `/cnn/politics /frontpage`. Content is delivered to consumers only upon explicit request. Each request corresponds to an *interest* message. Unlike content, interests are not signed. An interest message includes a name of requested content. In case of multiple content under a given name, optional control information can be carried within the interest to restrict desired content. Content signatures provide data origin authentication.

NDN routers forward interests towards the content producer responsible for the requested name, using name prefixes for routing. Each NDN router maintains a Pending Interest Table (PIT) – a lookup table containing outstanding [*interest*,*arrival-interfaces*] entries. When an NDN router receives an interest, it first looks up its PIT to determine whether another interest for the same name is currently outstanding. There are three possible outcomes: (1) If the same name is already in the router's PIT and the arrival interface of the present interest is already in the set of *arrival-interfaces* of the corresponding PIT entry, the interest is discarded. (2) If a PIT entry for the same name exists, yet the arrival interface is new, the router updates the PIT entry by adding a new interface to the set. The interest is not forwarded further. (3) Otherwise, the router creates a new PIT entry and forwards the present interest.

Upon receipt of the interest, the producer injects content into the network, thus *satisfying* the interest. The requested content is then forwarded towards the consumer, traversing – in reverse – the path of the corresponding interest. Each router on the path deletes the PIT entry corresponding to the satisfied interest. In addition, each router may cache a copy of forwarded content in its local Content Store (CS). A router that receives an interest for already-cached content does not forward the interest further; it simply returns cached content and retains no state about the interest.

Not all interests result in content being returned. If an interest encounters either a router that cannot forward it further, or a content producer that has no such content, no error packets are generated. PIT entries for unsatisfied interests in intervening routers are removed after a predefined *expiration* time. The consumer can choose whether to regenerate the same interest after a timeout.

III. INTEREST FLOODING

It is easy to see that an adversary can take advantage of CS and PIT – two features unique to NDN – to mount DoS/DDoS attacks specific to NDN. We focus on attacks that exploit the PIT, in particular, rapid generation of large numbers of interests that saturate the victim router's PIT. Once the PIT is completely full, all subsequent incoming (un-collapsible) interests are dropped. Flooding an NDN router with interests saturates its PIT if the rate of incoming interests is higher than the rate at which entries are removed from the PIT, either due to returning content or expiration. This is the goal of interest flooding attacks.

There are several analogies between well-known SYN flooding [32] and interest flooding. In a SYN flooding attack, the adversary's goal is to consume resources on the victim host by initiating a large number of TCP connections. This requires the victim to keep state for each connection for a relatively long time. The main difference between SYN flooding and interest flooding attacks is the victim: the primary victims of interest flooding are routers. End-hosts are secondary victims.

As observed in [13], there are at least three ways to mount this attack. The adversary can issue closely-spaced interests for: (1) existing static content; (2) dynamically-generated content; or (3) non-existent content. In the rest of this paper, we refer to interests for non existing content as *fake interests*.

In strategy (1), the adversary requests distinct content to avoid interest collapsing. If the flooding rate is sufficiently high, the producer (or, possibly, a router past the victim) will start dropping packets. This causes interests to linger in the victim's PIT until they expire, Depending on the victim's ability to satisfy interests quickly (and flush them from the PIT), this strategy may be very expensive. Also, router caches might lower the impact of this attack, satisfying adversary's requests *before* they reach the victim.

Strategy (2) is similar to (1), except that content is never returned from caches. Also, (2) may impose more load on the producer, due to the increased number of requests for content that can not be precomputed. This could cause higher round-trip latency and higher rate of dropped packets, which forces adversary's interests to remain in the victim's PIT longer.

Strategy (3) allows the adversary to create entries in the victim's PIT for which no content will ever be returned. This has several consequences: i) Adversarial interests referring to non-existent content are stored in the victim's PIT until they expire. ii) The maximum rate of adversarial interests does not depend on the bandwidth allocated by the victim to content packets, or on the adversary's ability to receive content. iii) Adversarial interests cannot be satisfied by router caches, since they request non-existing content. iv) If constructed properly (for example, a with random component at the end of each name) adversarial interests are never collapsed. These effects allow the adversary to efficiently fill up the victim router's PIT, which makes this attack more dangerous than (1) or (2). Therefore, in the rest of this paper, we focus on (3) – interest flooding via fake interests.

It is straightforward to construct interests that are routed through the victim. Let R be the router advertising namespace `/nsf/fia/`. If the adversary issues interests for `/nsf/fia/`*rnd* (where "*rnd*" is a random string), they are forwarded through R.

IV. EVALUATION ENVIRONMENT

We use simulations to quantify effects of both attacks and countermeasures. In particular, we run CCNx over NS-3 [25] via DCE. CCNx [4] is the official implementation of NDN, originally developed by PARC, and released as open-source project in 2009. Even though CCNx codebase is still in early stage of development, it provides all basic functionalities of NDN. CCNx currently runs as an overlay on top of IP. Direct Code Execution [11] (DCE) is a framework developed by INRIA to allow regular applications to access a network environment simulated using NS-3. DCE allows us to test the latest CCNx, without reimplementing it for NS-3.

We emphasize that running simulations of NDN as an overlay (over IP) reflects the status of the current CCNx implementation. In fact, even in the official NDN testbed [23], links between routers are essentially Generic Routing Encapsulation (GRE) tunnels carrying UDP packets.

Our experiments are performed over the AT&T network topology shown in Figure 1. We use Rx, Cx, Px, and Ax to denote the x-th router, consumer, producer, and adversary-controlled node, respectively. Continuous lines in Figure 1 indicate connections between routers; dashed lines denote connections between consumers and routers; dotted lines represent connections between producers and routers. Our setup includes 16 (honest) consumers and 2 producers.

We first analyze the topology without any adversarial traffic. This provides us with a baseline. Each consumer issues interests for content produced by P0 and P1. Interests retrieve distinct pieces of non-existent content; therefore, routers cannot collapse them or satisfy them via cached content. Consumers send a short burst of 30 interests, spaced by 2 ms, at time $t = 1$ s of the simulation. Starting from $t = 1.2$ s, consumers switch to a rate of one interest every 10.7 ms. In our configurations, such interest spacing allows routers to forward interests roughly at the same rate at which they receive content packets. We set routers' PIT size to 120 KB, while the interest expiration time was set to the default timeout of 4 s.

We report the average of the various runs in Figure 2. In particular, Figure 2(a) shows the total number of contents (y-axis) received by the different routers (x-axis), while Figure 2(b) shows PIT usage (y-axis) as a function of simulation time (x-axis). The maximum value on the y-axis for 2(b) corresponds to the total space available in the PITs (120 KB). Also, the two vertical lines (at 1 s and 26 s) indicate the instant when consumers start and stop sending interests. (The same notation is used in all graphs that refer to PIT usage reported in this paper.)

V. ATTACK EFFECTIVENESS

We assume that the adversary is able to corrupt a portion of the consumers, through which it implements the attack – i.e., issues fake interests. However the adversary is not allowed to control routers. We believe that this restriction is realistic and well represents the current scenario of DDoS attacks (e.g., [17]). While we do not exclude that attacks might come from internal routers, we leave the investigation of this as future work.

In our simulations we observe that successful instantiation of interest flooding requires very small amount of bandwidth. The adversary controls the nodes connected through a red solid line in Figure 1. The three adversarial nodes (A0, A1, A2) send interests for non-existent content for the namespace registered by P0 – i.e., all fake interests are routed to P0. Similar to honest nodes, the adversary starts sending interests at $t = 1$ s. Fake interests are generated every 1.337 ms. Behavior of honest consumers is unchanged from the base scenario.

Attack results are plotted in Figure 3 for some representative nodes in both topologies. In particular, Figure 3(a) shows the ratio of content packets forwarded during the attack with respect to the same network with no malicious traffic. Figure 3(b) shows PIT usage.

Figure 3(a) demonstrates that the attack has significant impact on the network: several routers forward 20% of the original traffic.

It is important to note that consumers are spread all over the network and the number of adversaries is quite small (three for both topologies). However, attack impact is significant: fraction of packets forwarded by routers varies between 25% and 80% with respect to the base-line scenario. Differences in the effectiveness of the attack for different routers can be explained by their distance from the adversary-producer paths. We emphasize that reduced bandwidth available to consumers can only be attributed to high PIT usage, as shown in Figure 3(b). It is easy to see that the fraction of traffic forwarded by routers drops significantly once PITs fill up. As confirmed by Figure 3(b), R3 (closest to P0) is the first to succumb (reaching its PIT limit). This can be attributed to the central role R3 occupies in the topology.

VI. OUR COUNTERMEASURE: POSEIDON

We now discuss countermeasures for IFA. We focus on countermeasures that consist in a detection and a reaction phase. Detection can be local or distributed (collaborative). In the former, routers rely only on local metrics (e.g., PIT usage, rate of unsatisfied interests, amount of bandwidth used to forward content) to identify an attack. In the latter, nearby routers collaborate to determine whether an attack is in progress and how to mitigate it.

In case of successful interest flooding attack, the victim router can easily identify an attack by observing whether its PIT is full or whether the bandwidth allocated to forwarding of content is very small. However, it may not be possible for a router on the path to the victim to detect an attack in progress. Collaborative detection mechanisms allow routers to exchange information about their state, with the goal of detecting an attack in progress as soon – and as close to the adversary – as possible. With collaborative detection, routers not only exchange information about the *existence* of an attack, but also the (locally detected) properties of such attack: strategies can take into account feedback from multiple routers.

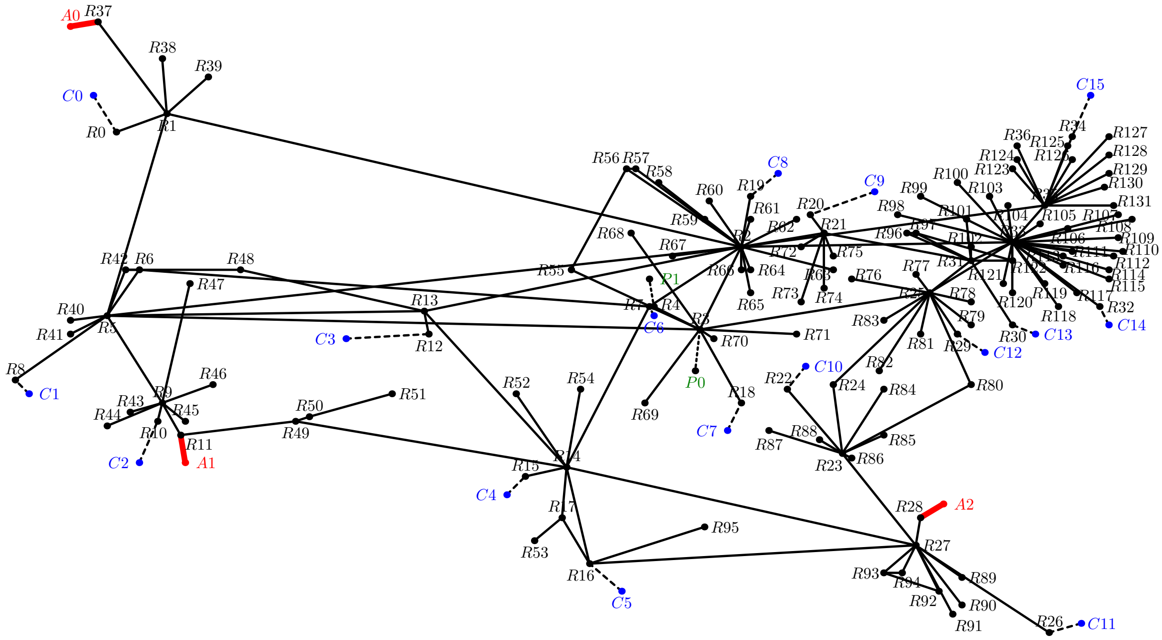
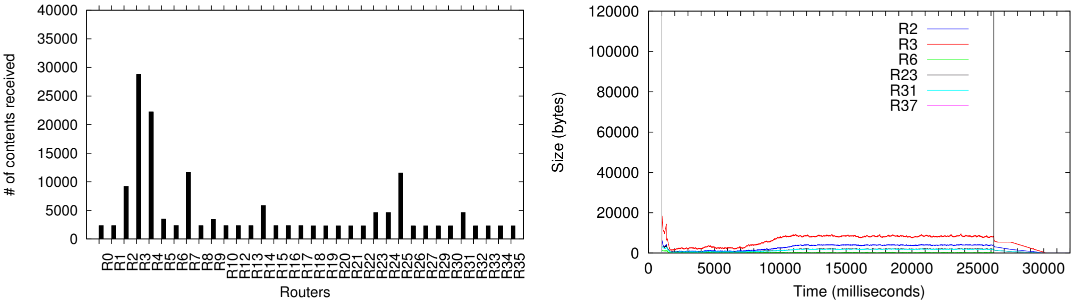


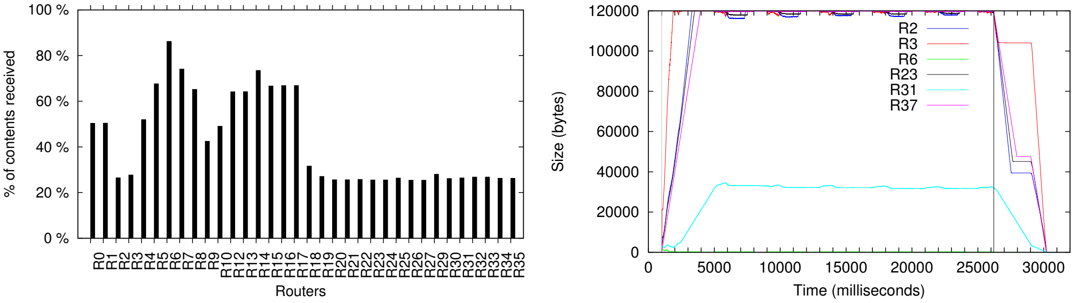
Fig. 1. AT&T topology



(a) Throughput (abs. values)

(b) PIT usage

Fig. 2. Baseline behavior (no attack)



(a) Throughput (%)

(b) PIT usage

Fig. 3. Interest Flooding Attack (IFA): impact over baseline

In this paper, we consider a particular collaborative approach – known as push-back [13] – to counter interest flooding. We call our implementation *Poseidon*, and we discuss it in the rest of the paper. Poseidon is a set of algorithms that run on routers, with the goal of identifying traffic anomalies (especially, interest flooding) and mitigate their effects. Poseidon continuously monitors per-interface rates of unsatisfied interests with respect to overall traffic. If these rates change significantly between two consecutive time intervals, it sets a filter on the offending interface(s) (which reduces the number of incoming interests). Additionally, Poseidon can issue a push-back "alert" message to the same interfaces, to signal that an interest flooding attack is in progress.

Poseidon keeps several statistics on expired interests. In particular, for each of them it records namespace and incoming/outgoing interfaces information. Relatively common network phenomenon (e.g., packet loss) and regular applications behavior usually account for only a (relatively) small amount of expiring interests in routers' PITs.

In the next sections we introduce the detection and reaction phases of Poseidon. Notation used is shown in Table I.

R	set of all routers in the network running Poseidon
r_i	i-th router, $1 \leq i \leq \|\mathsf{R}\|$
r_i^j	j-th interface on router r_i
t_k	k-th time interval
$\omega(r_i^j, t_k)$ content	rate between incoming interest and outgoing for a given interface r_i^j
$\rho(r_i^j, t_k)$ r_i^j,	PIT space used by interests arrived on interface measured at the end of interval t_k
$\Omega(r_i^j)$	interest flooding detection threshold for $\omega(r_i^j, t_k)$
$\mathrm{P}(r_i^j)$	interest flooding detection threshold for $\rho(r_i^j, t_k)$

TABLE I
NOTATION.

A. Detection Phase

Attacks are detected using two parameters: $\omega(r_i^j, t_k)$, and $\rho(r_i^j, t_k)$. The former represents the number of incoming interests divided by the number of outgoing content packets, observed by a router r_i on its interface r_i^j within time interval t_k:

$$\omega(r_i^j, t_k) = \frac{(\#\text{ of interests from } r_i^j \text{ at interval } t_k)}{(\#\text{ of content packets to } r_i^j \text{ at interval } t_k)}.$$

$\rho(r_i^j, t_k)$ indicates the number of bytes used to store interests in PIT, coming from interface r_i^j within time interval t_k.

Poseidon detects an attack when both $\omega(r_i^j, t_k)$ and $\rho(r_i^j, t_k)$ exceed their respective thresholds $\Omega(r_i^j)$ and $\mathrm{P}(r_i^j)$. The detection algorithm is executed at fixed time intervals – typically every 60 ms – and in the presence of particular events, (i.e., push-back messages, as detailed below).

The parameter $\omega(r_i^j, t_k)$ is a good representation of the ability of routers to satisfy incoming interests in a particular time interval. (This is also confirmed by our experiments, detailed in Section VII.) In particular, $\omega(r_i^j, t_k) > 1$ indicates that the number of content packets forwarded to r_i^j is smaller than the number of interests coming from the same interface. However, a small bursts of (either regular or non-satisfiable) interests may not be caused by an attack. Hence, taking into account only $\omega(r_i^j, t_k)$ (i.e., not considering $\rho(r_i^j, t_k)$) may cause the detection algorithm to report a large number of false positives. Applying countermeasures may, in this case, produce negative effects to the overall network performance.

We argue that neither increasing $\Omega(r_i^j)$, nor computing $\omega(r_i^j, t_k)$ over longer intervals, produces the indented effects. In fact, in the first case the bound must be set high enough to avoid classification of short burst of interests as attacks; however this could inevitably lead to late- or mis-detection of actual attacks. Increasing the size of the interval over which $\Omega(r_i^j)$ is computed may reduce the sensitivity of Poseidon to short burst of interests. An interval length similar or longer than the average round-trip time of interest/content packet, in fact, may allow (part of) the content requested by the burst to be forwarded back, reducing $\omega(r_i^j, t_k)$ to a value closer to 1. However this could significantly increase the detection time.

Instead, to improve detection accuracy (distinguishing naturally occurring burst of interests from attacks), Poseidon takes into account also $\rho(r_i^j, t_k)$. This value measures the PIT space used by interests coming from a particular interface. This allows Poseidon to maintain the number of false positives low – when compared to considering solely $\omega(r_i^j, t_k)$ – while allowing it to detect low-rate interest flooding. In a low-rate interest flooding attack the adversary limits the rate of fake interests to keep $\omega(r_i^j, t_k)$ below its thresholds. Monitoring the content of the PIT allows Poseidon to observe the *effects* of the attack, rather than just its *causes*, allowing for early detection.

To sum up, different parameters monitored by Poseidon act as weights and counterweights for interest flooding detection. When a router is unable to satisfy incoming interests over a relatively short period, $\rho(r_i^j, t_k)$ may exceed the detection threshold but $\omega(r_i^j, t_k)$ will not; when the router receives a short bursts of interests, $\omega(r_i^j, t_k)$ may become larger than $\Omega(r_i^j)$ but the PIT usage will likely be within normal values. To stay undetected, an adversary willing to perform interest flooding must therefore: (1) reduce the rate at which it sends interests, which limits the effects of the attack; and/or (2) restrict the attack to short burst, which makes the attack ineffective.

Thresholds $\Omega(r_i^j)$ and $\mathrm{P}(r_i^j)$ are not constant and may change over time to accommodate different conditions of the network. As an example, push-back messages described below provide input for determining more appropriate values for these thresholds.

B. Reaction Phase

Once an interest flooding attack from interface r_i^j of router r_i has been identified, Poseidon limits the rate of incoming interests from that interface. The original rate is restored once all detection parameters fall again below their corresponding thresholds.

With collaborative countermeasures, once a router detects adversarial traffic from a set of interfaces it limits their rate and issues an alert message on each of them. An alert message is an unsolicited content packet which belongs to a reserved namespace ("`/pushback/alerts/`" in our implementation), used to convey information about interest flooding attack in progress. There are two reasons for using content packets rather than interests for carrying push-back information: (1) during an attack, the PIT of the next hop connected to the offending interface may be full, and therefore the alert message may be discarded; and (2) content packets are signed, while interests are not. This allows routers to determine whether an alert message is legitimate.

Routers running Poseidon do not process alert messages as regular content: alerts are not checked against PIT content and are not forwarded any further. The payload of an alert packet contains: the timestamp corresponding to the alert generation time; the new (reduced) rate at which offending interests will be accepted on the incoming interface; and detailed information about the attack – such as the namespace(s) used in malicious interests.

Router r_i receiving a packet msg processes it as detailed in Algorithm 1. A persistent interest flooding attack on router r_i causes it to send multiple alert messages towards the source(s) of the attack. Such sources will decrease their thresholds $\Omega(r_i^j)$ and $\mathrm{P}(r_i^j)$ until they detect the attack and implement rate-limiting on the malicious interests. If no attack is reported for a predefined amount of time, thresholds are restored to their original values.

This push-back mechanism allows routers that are not the target of the attack, but are unwittingly forwarding malicious interests, to detect interest flooding early. In particular, alert messages allow routers to detect interest flooding even when they are far away from the intended victim – i.e., close to nodes controlled by the adversary, where countermeasures are most effective.

VII. EVALUATION

In this section we report on experimental evaluation of countermeasures presented in Section VI. Our countermeasures are tested over the same topology used in previous experiments and detailed in Figure 1. Each router implements detection techniques discussed in Section VI-A and countermeasures from Section VI-B. As for the parameters used in our experiments, we considered these initial values: for each router r_i, interface r_i^j, $\Omega(r_i^j) = 3$ and $\mathrm{P}(r_i^j) = 1/8$ of the PIT size. Furthermore, we set scaling factor $s = 2$ and $wait\_time$ to 60 ms. The Decrease function divides the threshold in input by s at each invocation. Similarly, the Increase function increases its input by 1/8 of the current value. Consumers request the same content at the same rate as in the previous simulations. Similarly, the nodes controlled by the adversary implement interest flooding as in the simulation in Section V.

Local Countermeasures. Figure 4(a) shows the result of local countermeasures. Values shown represent the average of 20 executions. Figure 5 reports the ratio of content packets received with respect to the scenario with no adversary. (For comparison purposes, in the same figure we also report the corresponding value with no countermeasures in place.)

Algorithm 1: MessageProcessing

```
input : Incoming packet $msg$ from $r_i^j$; $wait\_time$;
        $\Omega(r_i^j)$; $\mathrm{P}(r_i^j)$; Scaling factor $s$; Alert message $m$
        from interface $r_i^j$
if $msg$ is ContentObject then
    process $msg$ as ContentObject and return
end if
if $msg$ is AlertMessage then
    if Verify($msg.signature$) and IsFresh($msg$) and
    time from last Alert received from $r_i^j >$ wait_time
    then
        // Push-back reaction
        Decrease($\Omega(r_i^j), s$)
        Decrease($\mathrm{P}(r_i^j), s$)
    else
        drop $msg$ and return
    end if
end if
if $msg$ is Interest then
    if $\omega(r_i^j, t_k) > \Omega(r_i^j)$ and $\rho(r_i^j, t_k) > \mathrm{P}(r_i^j)$ then
        drop $msg$
        if time from last Alert sent on interface $r_i^j >$
        wait_time then
            send Alert to $r_i^j$
        end if
    else
        process $msg$ as Interest
    end if
end if
```

Our results show that the rate-based (local) countermeasure – while simple – is very effective (see Figure 5): under attack, the performances with the countermeasures increases by some 50% for most routers (e.g., see R30), when compared to the situation with the attack and no countermeasures. The impact of the adversary is now more limited: the attack only reduces the traffic by *some* 50% for most. In contrast, without any countermeasure the adversary was able to reduce content traffic by about 80%. Figure 4(a) report PIT usage over the same experiments, for some representative routers. Our results also show that this countermeasure significantly reduces the PIT usage in presence of an adversary. The effects of the rate-based approach are evident at $t = 6$ s, when fake interests corresponding to the initial phase of the attack – those that triggered the detection – expire. This shows that the detection time for the attack is around one second.

Distributed Countermeasures. Figure 5 show the ratio of content packets received under attack with the the push-back countermeasure in place. To simplify comparison, we report the results of the simulations of the attack without countermeasures and with the previous (local) countermeasure. The push-back mechanism offers visibly better performance compared to the rate-based countermeasure: for several routers the improvement with respect to the local countermeasure is over 300%.

A similar conclusion applies also to the PIT usage – which is another measure for attach effectiveness. In fact, it is possible to observe a significant benefits of push-back comparing Figure 4(a) to Figure 4(b), e.g. for the PIT of router R31.

So far we have considered cumulative results for throughput; however, it is interesting to analyze also how the content packets throughput varies over time in different scenarios.

Figure 6 shows the effect of our push-back countermeasure on a router (R4), which we deem notable in our topology. This figure clearly illustrates that using the distributed (push-back) countermeasure, routers are able to provide roughly the same throughput measured without interest flooding.

An interesting phenomenon highlighted by Figure 6(b) is the cyclical behavior of the amount of bandwidth available to content. This pattern can be explained as follows. As soon as the PITs of these routers are filled up with fake interests, no legitimate interests are forwarded and therefore no content is routed back. After four seconds – i.e., in our setting, the lifetime of an unsatisfied interest – fake interests are removed from the PITs allowing routers to forward new (legitimate) requests for content. When this happens, the adversary is quickly able to fill up PITs again. This process continues indefinitely for the whole duration of the attack.

VIII. RELATED WORK

There is lots of previous work on DoS/DDoS attacks on the current Internet infrastructure. Current literature addresses both attacks and countermeasures on the routing infrastructure [16], packet flooding [19], reflection attacks [26], DNS cache poisoning [27] and SYN flooding attacks [32]. Proposed countermeasures are based on various strategies and heuristics, including: anomaly detection [3], packet filtering [30], IP trace back [21], [29], ISP collaborative defenses [6] and user-collaborative defenses [14]. The authors of [13] present a spectrum of possible DoS/DDoS attacks in NDN. They classify those attacks in interest flooding and content/cache poisoning, and provide a high-level overview of possible countermeasures. However, the paper does not analyze specific attacks or evaluate countermeasures.

NDN caching performance optimization has been recently investigated with respect to various metrics including energy impact [18], [28], [20]. The work of Xie, et al. [34] address cache robustness in NDN. This work introduces CacheShield, a proactive mechanism that helps routers to prevent caching unpopular content and therefore maximizing the use of cache for popular one. To address the same attack, Conti et al [9] introduce a lightweight reactive mechanism for detecting cache pollution attacks.

Afanasyev et al. independently address interest flooding in [1]. Their work confirms the feasibility of interest flooding attack, and the need for an effective countermeasure. Interestingly, this work can be considered complementary to ours, both in terms of attack evaluation and countermeasures. In fact, while our experiments rely on the official NDN implementation [4], the work in [1] used NDNsim [2]. Although both approaches provide valuable insights into the attack, we argue that using the actual NDN code may result in a more accurate assessment.

A slightly different approach has been proposed by Dai et al. in [10]. Their technique relies on the collaboration between routers and producers in charge of the namespaces to which fake interests are directed.

In [31], Wählisch et al. independently investigate how data-driven state can be used to implement various DoS/DDoS attacks. Relevant to our work, their analysis includes: resource exhaustion, which is analogous to our interest flooding attack; mobile blockade, in which a wireless node issues a large number of interests and then disconnects from the network, causing the returned content to consume a large portion of the shared network bandwidth; and state decorrelation attacks, in which an adversary issues updates of local content or cache appearances at a frequency that exceeds the content request routing convergence. Attacks are tested on two physical (i.e., not simulated) topologies comprised of three and five NDN routers.

IX. CONCLUSION

In this paper we discussed interest flooding-based DDoS over NDN. We provided, to the best of our knowledge, the first experimental evaluation of the attack. Our experiments are based on the official NDN implementation codebase; we argue that this setup provides reliable results, and closely mimics the behavior of physical (non-simulated) networks.

We demonstrated that interest flooding attack is a realistic threat; in particular, we showed that an adversary with limited resources can reduce the amount of bandwidth allocated for content objects to 15-25% of the total bandwidth. We then introduced Poseidon, a new mechanism for detecting and mitigating interest flooding. Poseidon relies on both local metrics and collaborative techniques for early detection of interest flooding. We showed that the benefits of Poseidon are significant: in fact, most routers running our countermeasure are able to use more than 80% of the available bandwidth during the attack.

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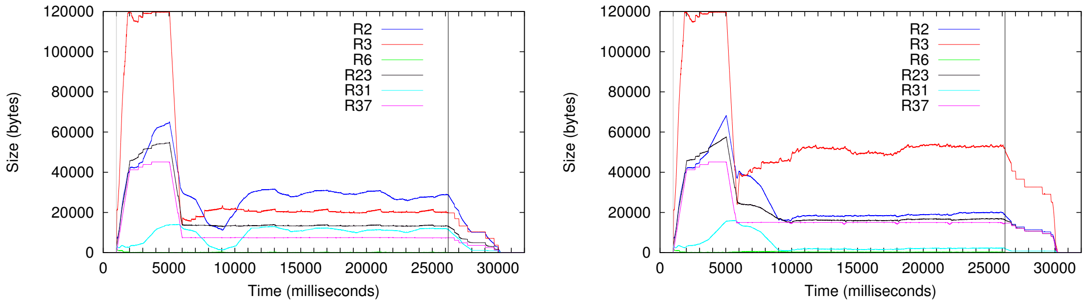


(a) Rate-based

(b) Push-back

Fig. 4. PIT usage with countermeasures

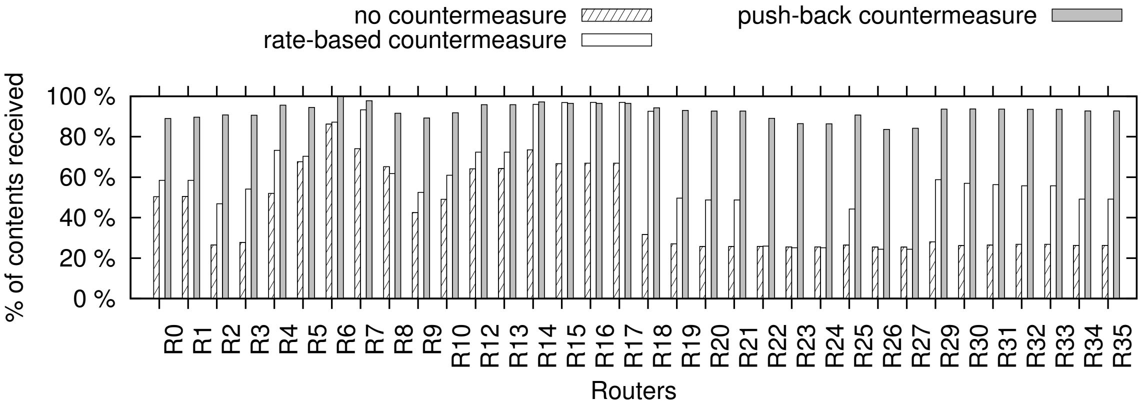
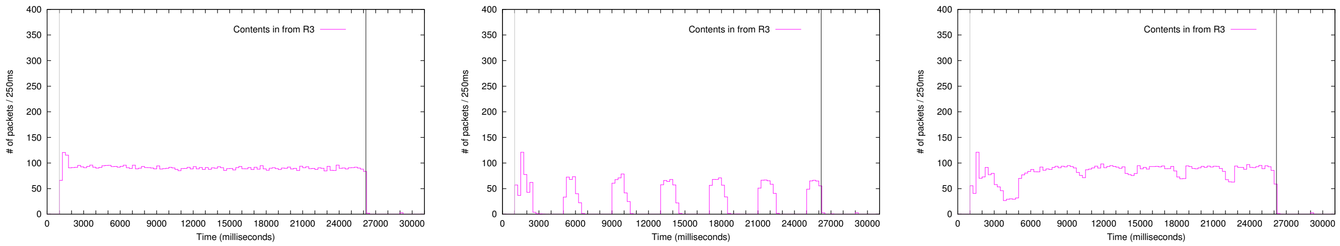


Fig. 5. Push-back: relative throughput (%)



(a) R4: baseline

(b) R4: attack

(c) R4: push-back countermeasure

Fig. 6. AT&T: content throughput (abs. values)

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