Packed to the Brim: Investigating the Impact of Highly Responsive Prefixes on Internet-wide Measurement Campaigns

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Motivation

Port scans are an important building block for Internet research

- Rough overview of service deployments on IANA standardized ports
- Target acquisition for application layer scans
- Target selection in security use cases
  - e.g., Censys, Shodan, and Rapid7 use port scans as a baseline

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Systematic distortions from port scans will affect results in all use cases

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Step 3

- Evaluate application-layer results

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  - Different deployment strategies by ASes: HRPs only on specific ports or on all ports

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  - Between 20 %-75 % of responsive addresses are impacted
  - Different deployment strategies by ASes: HRPs only on specific ports or on all ports
- RQ3: What impact does this have on application-layer scans?
  - Lower success rate for targets within HRPs
  - Lower information gain per scanned target

Related Work

- No in-depth analysis in IPv4; but indicators
  - All addresses within a prefix appear to be responsive; Izhikevich et al.[1]
    - Evaluation of application layer services on non-standard ports

[1] L. Izhikevich et al. 2021. LZR: Identifying Unexpected Internet Services. In Proc. USENIXSecuritySymposium [2]

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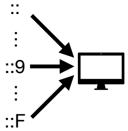
- Aliased prefixes in IPv6 hitlists; Gasser et al.[2]
  - All addresses handled by a single host
  - Induces bias in hitlist



Aliased Prefix

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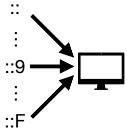
  - All addresses handled by a single host
  - Induces bias in hitlist
- Fully responsive prefixes; Zirngibl et al.[3]
  - Need for a broader definition
  - CDN prefixes appear to be fully responsive in IPv6
  - Different considerations apply for aliased vs fully responsive prefixes



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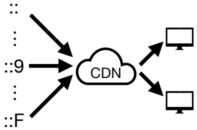

Fully Responsive Prefix

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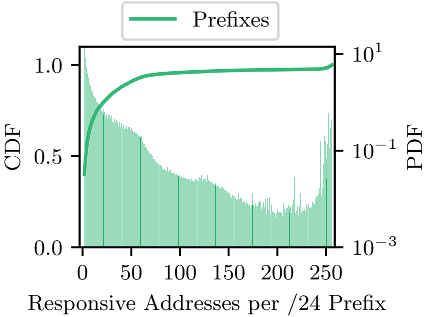
[3] J. Zirngibl et al. 2022. 2022. Rusty Clusters? Dusting an IPv6 Research Foundation. In Proc. ACM Int. Measurement Conference [3]

Research Questions

- RQ1: Are there distortions in port scans?
- RQ2: To what extent do highly responsive prefixes impact port scans?
- RQ3: What impact does this have on application-layer scans?

Are there distortions in port scans?

TCP/443 Port Scan Results



- 91 % of prefixes have less than 50 responsive addresses

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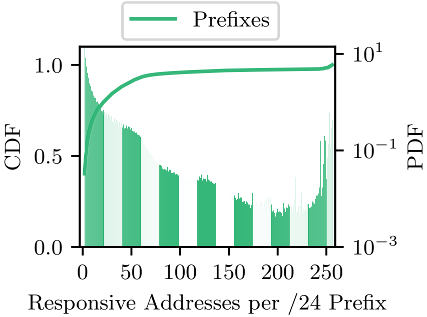
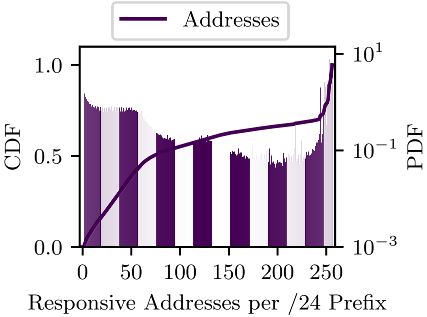
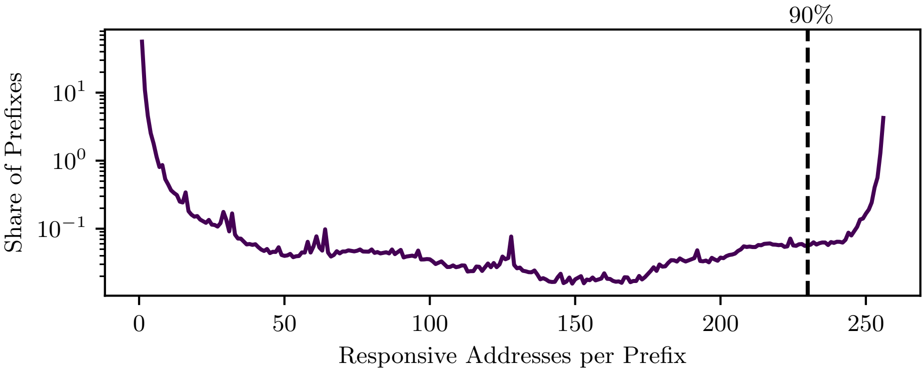




- 91 % of prefixes have less than 50 responsive addresses
- $>$ 30% of addresses are in highly responsive prefixes

HRP Definition



- Evaluation of reachable host per prefix across all analyzed ports

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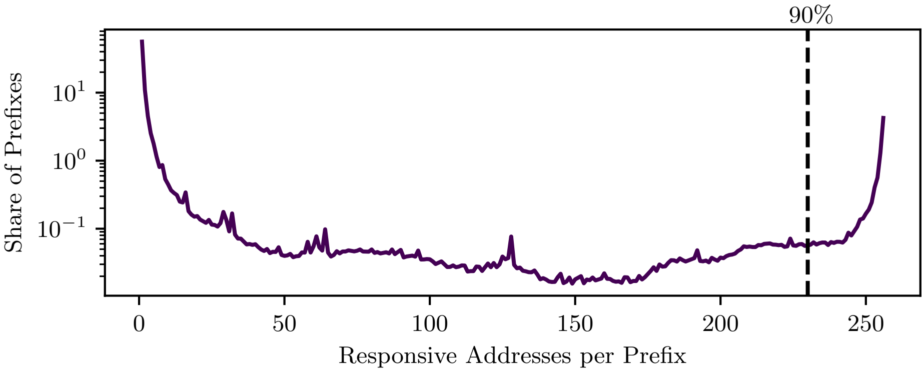

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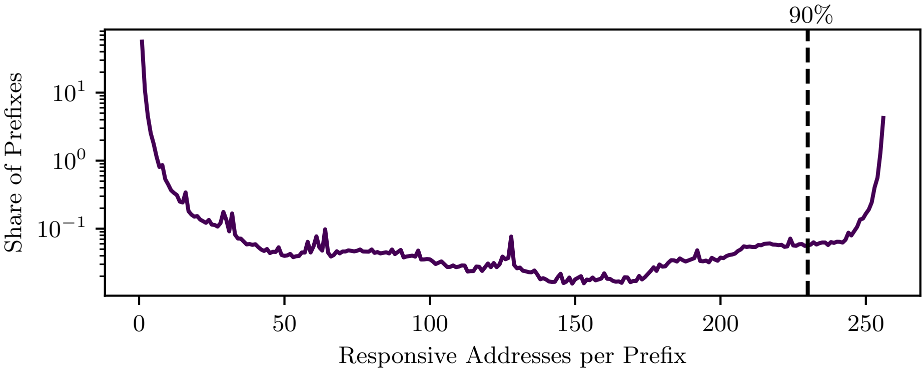

- Evaluation of reachable host per prefix across all analyzed ports
- Extreme ends of distribution strongly influence overall result
- HRPs are all prefixes with more than 90% responsive hosts

Datasets

Port Scan Datasets

- Weekly TCP/443 port scans from 2021 until end of 2022

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Application Layer Data

- TLS application layer results

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- TLS application layer results
- Rapid7 TLS and HTTP results

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- TLS application layer results
- Rapid7 TLS and HTTP results
- OpenINTEL DNS data

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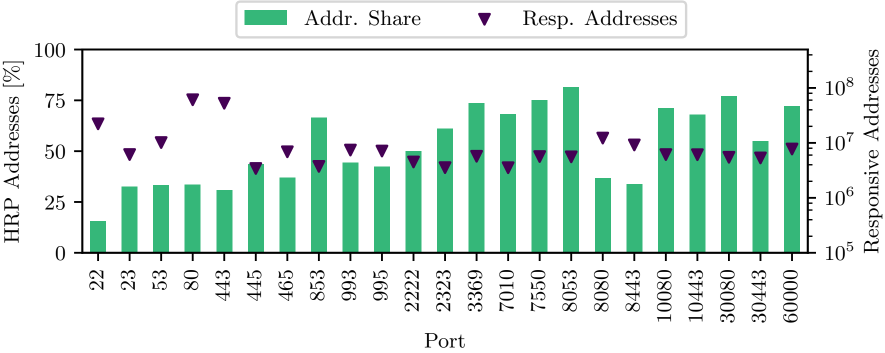
To what extent does this impact port scans?

Comparison between TCP Ports



- 30% HRP address share for IANA standard ports, port 8080 and 8443
- Other services have up to 75% HRP share

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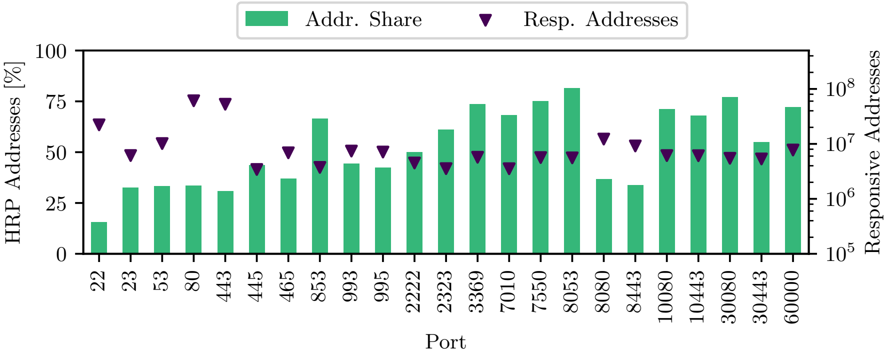

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→ Which ASes deploy HRPs?

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ASes Deploying HRPs

Top ASes by total number of HRPs

AS	Visible /24	HRP Share
AS16625 (Akamai)	22.9k	97.8%
AS20940 (Akamai)	24.7k	85.6%
AS7713 (Telin)	12.5k	52.5%
AS16509 (Amazon)	134.9k	4.4%
AS721 (DoD)	4.9k	91.3%
...		
AS13335 (Cloudflare)	3.1k	98.3%

- Four CDN/Cloud provider ASes, three ISPs, two DoD ASes, and one academic network
- Top five cover 64 % of all HRPs

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ASes Deploying HRPs

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- Four CDN/Cloud provider ASes, three ISPs, two DoD ASes, and one academic network
- Top five cover 64 % of all HRPs
- Some CDNs deploy HRPs on all visible ports

→ Different deployment reasons and strategies

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TLS Data

We use:

- TLS handshake results for port 443 from our local measurement campaign
- Certificate data by Rapid7
  - Only data for targets with certificates

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- How many TLS services are active inside HRPs?
- What information gain can be expected when scanning HRPs?

What impact does this have on application-layer scans?

TLS Hosts in HRPs

- 84% of TCP/443 HRPs contain TLS responsive hosts
- Lower share of HRPs on other ports

		App. Layer Success
Port	# HRPs	# HRPs
443	64 435	54 203
8443	13 048	3287
25	33 294	3493
110	11 394	2553
853	8352	565

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- Mail ports have large share of single identifier HRPs

		App. Layer Success		Same Identifier	
Port	# HRPs	# HRPs	>90 % Success	# HRPs	HRP [%]
443	64 435	54 203	26715	2718	10.2
8443	13 048	3287	809	384	47.5
25	33 294	3493	2210	2041	92.4
110	11 394	2553	2379	1944	81.7
853	8352	565	379	53	14.0

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- Few HRPs provide actual service on all addresses
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    - We found different reasons for CDNs deploying HRPs:
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New Application Layer Scanning Approach

- Filter HRPs from port scans before running the application layer scan
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New Application Layer Scanning Approach

- Filter HRPs from port scans before running the application layer scan
- Scan HRPs selectively (DNS and sample-based)
- We applied this approach to our previous data:
  - 99 % of unique certificates are discovered
  - –75 % application layer probes

Conclusion

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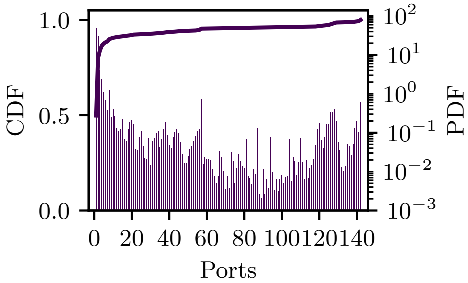
  - Evaluated DNS and TLS data
  - Proposed a new more ethical scanning approach
- *Tool and data openly available*
  - Tool to detect HRPs in port scans
  - Weekly new HRP data for ports 80 and 443

https://hrp-stats.github.io/

Backup Slides

HRPs on multiple TCP ports



- 50% of HRPs appear only on a single port
- Spikes are due to our different data sources and logarithmic PDF axis
- Some prefixes are highly responsive on all analyzed ports

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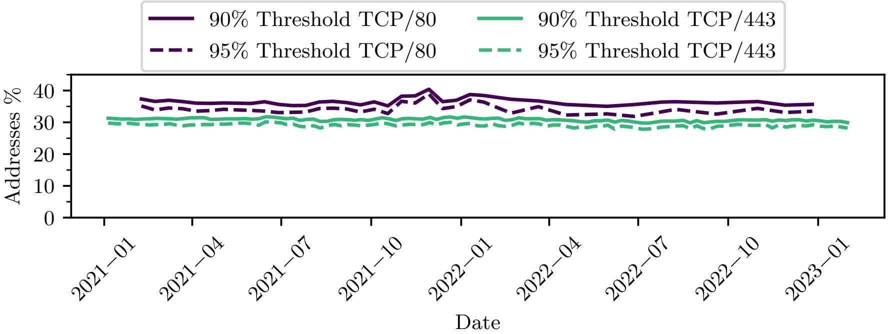
HRP Stability



- Stable results over the period of two years
- We validated the stability of results between vantage points (see results in the paper)

Backup Slides

Domains in HRPs

- HTTP/S HRPs expose a larger number of DNS references
- Overall only a small fraction of responsive addresses is referenced by in DNS

	HRP	IP addresses	
DNS Ports (Using A records of NS names):			
TCP/53	12.0%	40.9k	1.4%
UDP/53	25.5%	29.0k	3.1%
Mail Ports (Using A records of MX names):			
TCP/25	18.5%	172.4k	2.0%
TCP/110	26.4%	126.0k	4.4%
TCP/143	26.3%	121.6k	4.3%
HTTP/S Ports (Using A records):			
TCP/80	34.4%	4.7M	11.0%
TCP/443	30.8%	2.0M	6.3%
TCP/8443	56.8%	517.3k	16.7%

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- Overall only a small fraction of responsive addresses is referenced by in DNS
- A large number of FQDNs and SLDs depend on services in HRPs

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TCP/53	12.0%	40.9k	1.4%	161.6 k	115.6 M
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Bibliography

[1] O. Gasser, Q. Scheitle, P. Foremski, Q. Lone, M. Korczynski, S. D. Strowes, L. Hendriks, and G. Carle.
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