



Aalto University
School of Electrical
Engineering

Cooperative Security for the Internet and 5G

Raimo Kantola
raimo.kantola@aalto.fi
Aalto University, Comnet, Finland

Tampere University of Technology – CyberTrust Sprint- Tue, Jan 10th, 2017

Agenda

- Research Background – state of the art
- Premises for Cooperative security
- Solution
 - *Customer Edge Switching*
 - *Realm Gateway*
 - *Policy Management*
 - *Privacy Preserving Trust Management for the Internet*
- Security gains

www.re2ee.org & ResearchGate

Background

Current security attitude: I worry about my hosts and my network

- **I don't care what other people do**
- **I cooperate with other people if forced to by the Regulator**
- **I don't want to reveal any bad stuff that happened in my network if not forced to do so**

BUT...

State-of-the art in cooperative security

- **CERT – national cyber security...**
- **Vulnerability data bases**
 - CVE – Common Vulnerabilities and Exposures
- **Sharing of threat intelligence**
 - E.g. to combine cloud capabilities with host based security software functions
 - Vendor specific

Scattered developments/few standards/no ubiquitous deployment

Nrof security breaches/a is not going down!

CLAIM: There is no End-to-End solution to the issue of Trust in the Internet

Prisoner's Dilemma:

	Nice user	Hacker
Nice user	(1, 1)	(s, t)
Hacker	(t, s)	(0, 0)

$$t > 1 > 0 > s$$

1. Single round solution: mutual defection
2. Un-ended game in a group: mutual cooperation – e.g. tit-for-tat strategy
3. Internet: prerequisites for cooperation are not in place among hosts BUT situation is like in single round game:
 - weak identification of hosts
 - dynamic IPs, NATted hosts, spoofing
 - reflection attacks (e.g. using DNS)



Agent at network edge + cloud based trust

Signaling Cases

Sender Behind CES (new Edge)	CES acts as NAT	Customer Edge Traversal Protocol used To signal tunnels Thru the core
Legacy IP sender	Traditional Internet	Inbound CES acts as ALG/ Private Realm Gateway or (server side) DNAT
	Legacy receiver	Receiver behind CES/RGW

What is a Customer Edge Switch?

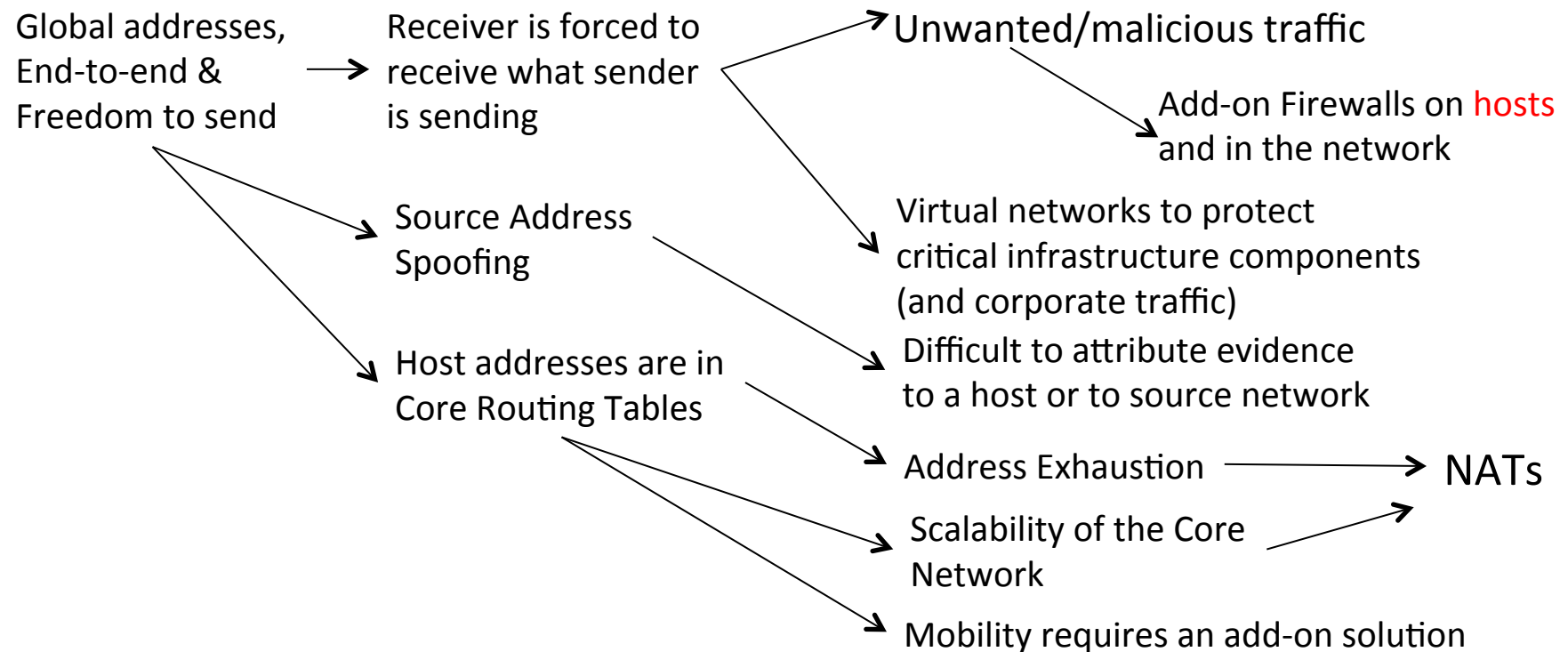
- **Replacement and Generalization of NAT**
- **Cooperative Firewall**
 - Flows admitted by policy
- **An Address/ID split solution for the Internet**
 - Globally unique AND private addresses (IPv4, IPv6, Ethernet)
 - FQDN (or Service FQDN) for identification
- **Edge to edge tunneling endpoint**
- **Split to Control/Data plane**
- **Deployment: one customer network at a time**

Emerges from “Future Internet” research topic

- Exhaustion of IPv4 addresses
- Scalability of the core of Internet (large routing tables)
- Unwanted/malicious traffic
- IPv6 has been around for a long time but adoption is not taking place as expected by IETF
- Role of IP has been going down, add-on solutions like MPLS, Firewalls, NATs are playing an increasing role → deterioration of the Architecture
- Power consumption is becoming an issue
- Poor fit of IP to the needs of wireless battery-powered devices:
 - Internet has 3,5B users, AND 3.6B are using mobile broadband (by end of 2016)!

Hundreds of projects in the US, EU, Japan, China, Korea etc.

Causal relations of the problems(1)



Causal relations of problems (2)

Private addresses &
Network Address Translators
(or NATs)

→ Hosts with private addresses normally not reachable

→ Cumbersome NAT traversal mechanisms (STUN, TURN, ICE):

- Overhead on air interface
- Slow session setup
- Battery consumption
- Application specific code
- Security?

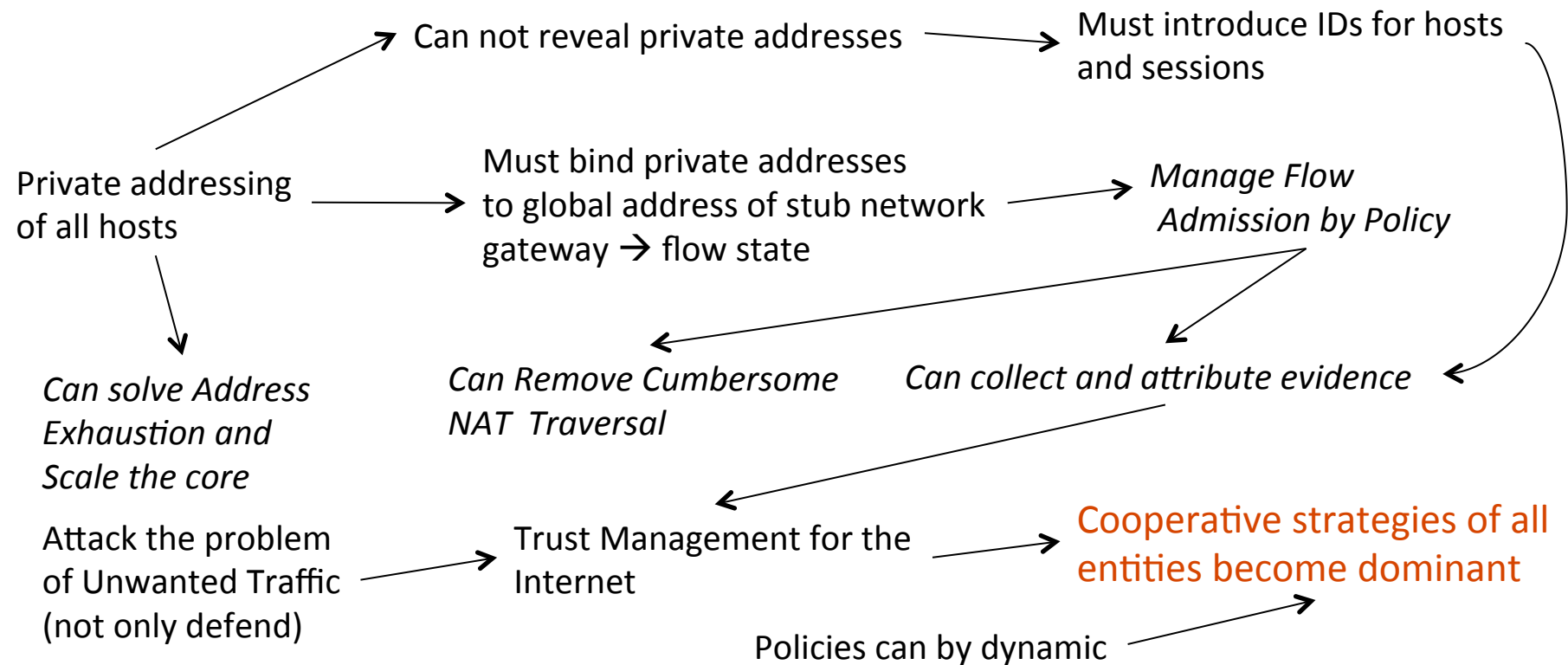
IP over everything

→ Difficult to optimize using several criteria

Related work on Future Internet

- Proposals can be classified by where changes are required:
 - Hosts; network nodes; if network nodes, which?
 - It is critical for adoption that the investor gets his money back
- IPNL, TRIAD, MILSA, Pub/Sub, Shim6, HIP, PBS (permission based sending), Information Centric Networks
- Typical weaknesses
 - Most popular motivation: scalability of the core → where is the new revenue?
 - Have to make changes in many places
 - Investments and benefits are not perfectly aligned or for some proposals: start Melcalfe's law from zero!

Solution logic: reshape Internet based on IPv4

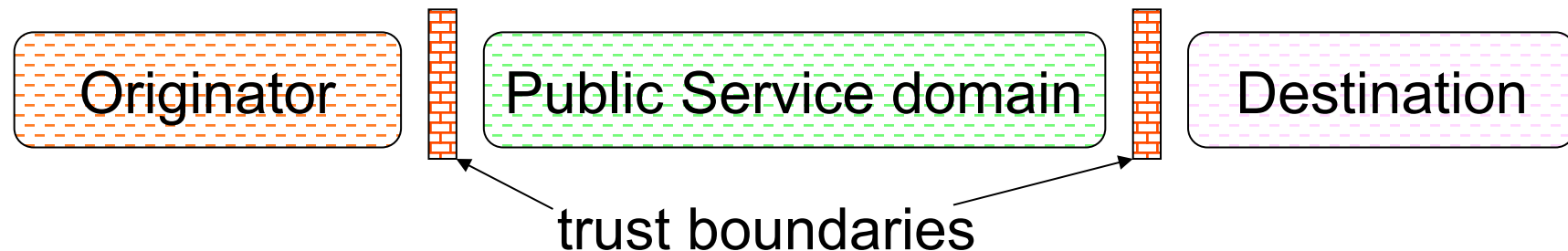


Business: makes sense to pay attention to where the growth is: mobile broadband!

Constraints on the solution

- Because we can not solve the problems of unwanted traffic and NAT traversal in hosts for battery powered wireless devices
 - → MUST change a network node
 - → MUST not require changes in hosts at all
- Changes only in one place at a time: must bring benefit to the adopter irrespective what other players are doing

Communication over Trust Domains

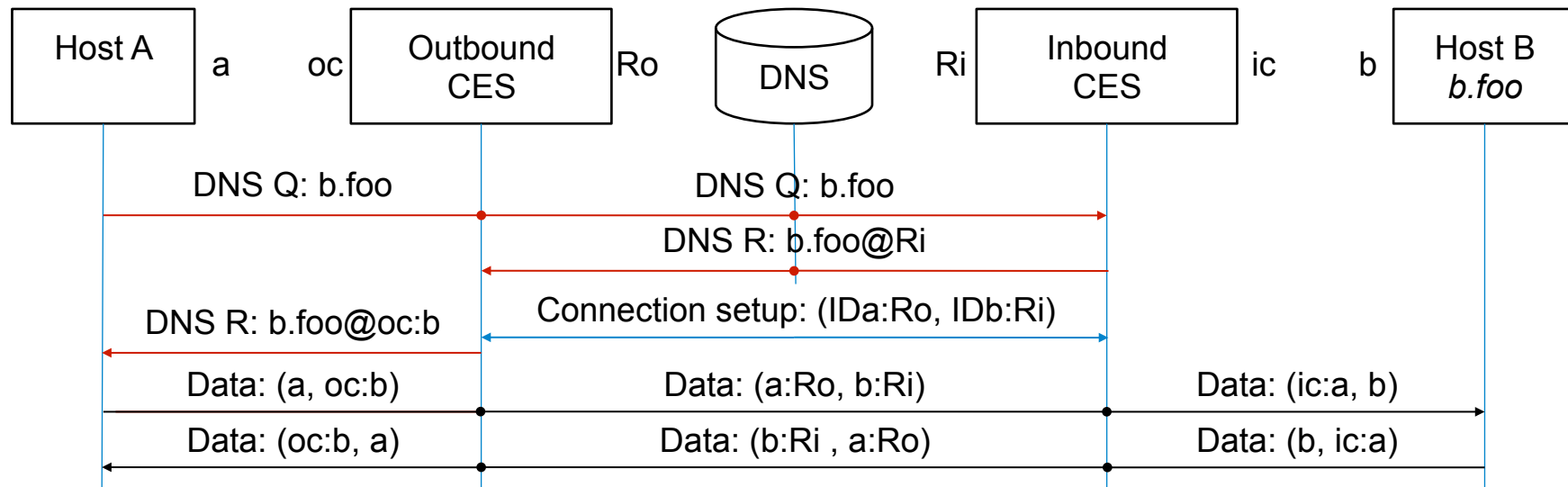


Originator and Destination are customer networks (stub networks in terms of IP routing)
+ each of them may have one or many private address spaces;
+ extreme case: mobile network addressing model: each user device is in its own address space and all communication takes place through the gateway or edge node connecting the user devices to the Internet

Trust Boundary == Customer Edge Switch == cooperative firewall

A CES has one or several RLOCs (routing locators) that make it reachable in the public service domain

Customer Edge Switching PoC



a – IP address of host *a*
b – IP address of host *b*
Ro – Routing locators of outbound CES
oc – Address pool of outbound CES
oc:b – IP address representing host *b* to host *a*
IDa:Ro – Representation of *IDa* in outbound CES
a:Ro – Representation of *hosta* in outbound CES

IDa – ID of host *a*
IDb – ID of host *b*
Ri – Routing locators of inbound CES
ic – Address pool of inbound CES
ic:a – IP address representing host *a* to host *b*
IDb:Ri – Representation of *IDb* in inbound CES
b:Ri – Representation of *hostb* in inbound CES

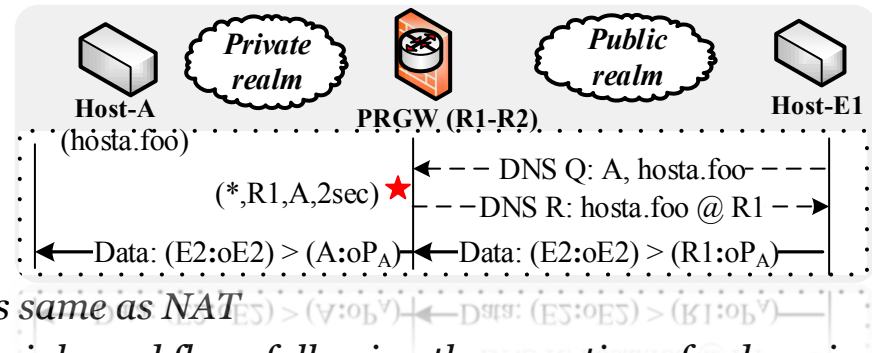
CES can...

- Be deployed one network at a time by combining it with Realm Gateway
- Switch between IPv4/IPv6/Ethernet – is agnostic to forwarding protocol
- Execute outbound AND inbound policy
 - Cache info to minimize communication overhead
 - We separate CES policies from Host policies
 - ASK for any types/values of IDs, certificates
 - iCES can ask oCES to slow down

Introduction to Private Realm GW

IFIP Networking 2016

- PRGW is a client and server-side NAT solution.
- Deployment:
 - It can replace NATs at network edges, or can be part of a rich cooperative firewall.
 - Doesn't require changes in end-hosts or applications.



- Operations (compared to NAT):
 - **For outbound connections**, the behavior is same as NAT
 - **For inbound connections**, CPPA admits an inbound flow, following the reception of a domain query for Fully Qualified Domain Name (FQDN) of the private host.
- Advantages:
 - Scalable NAT traversal solution, optimal for mobile devices.

PRGW solution

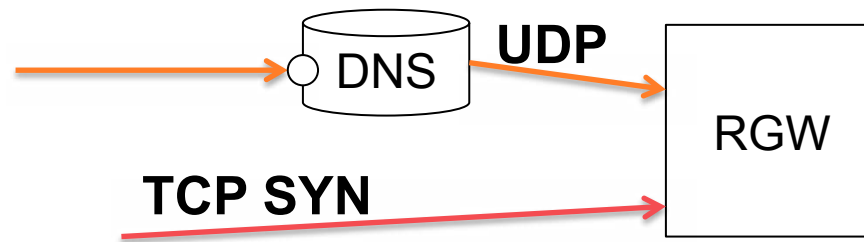
- Circular pool of public IP addresses (CPPA) enables unilateral initiation of connection towards the private hosts.
- Upon receiving a DNS query for FQDN of the private host, PRGW creates a temporary ***half connection state***, *which* allows forwarding of the subsequent inbound flow to the private host.
 - *It contains a public IP address from the pool to represent the host in the Internet.*
 - The half connection state applies ***endpoint independent filtering relative to the client***
- Upon receiving the first inbound packet from the client, PRGW creates a ***full connection state*** for the flow and returns the allocated public address to CPPA for future allocations.
 - *Full connection state applies **address and port dependent filtering** relative to client.*

Principles of Security mechanisms

It is possible to take clean-slate approach to design new architectures free of any weaknesses, at the cost of a huge deployment difficulty. In our work, we take these deployment constraints into account.

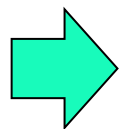
- 1) To favor deployment, security algorithms and heuristics shall not require changes to end-hosts, protocols, or application.
- 2) Flow acceptance must be limited to verifiable sources, to tackle address spoofing and prevent resource exhaustion
- 3) UDP flow initiations are admitted only after a connection has been signaled through a secure channel e.g. SIP(s) → Now adding “loose UDP”
- 4) Under the network stress, resource access should be granted based on the source reputation.

Preventing DNS Abuse/Exploitation



Normally, DNS runs over UDP + initial requester info/path of the request
Is not present in the query

- Spoofing → reflection attack
- There are DNS servers (e.g. Google) that respond to any host



Run DNS over TCP → eliminate spoofing + New Source info extension

SLA with ISP: use ingress filtering = serve only known hosts

→ Whitelisted/Grey/Black DNS servers

Rate limit/DNS server + Rate limit/destination FQDN

Experience from the first PoF Customer Edge Switching

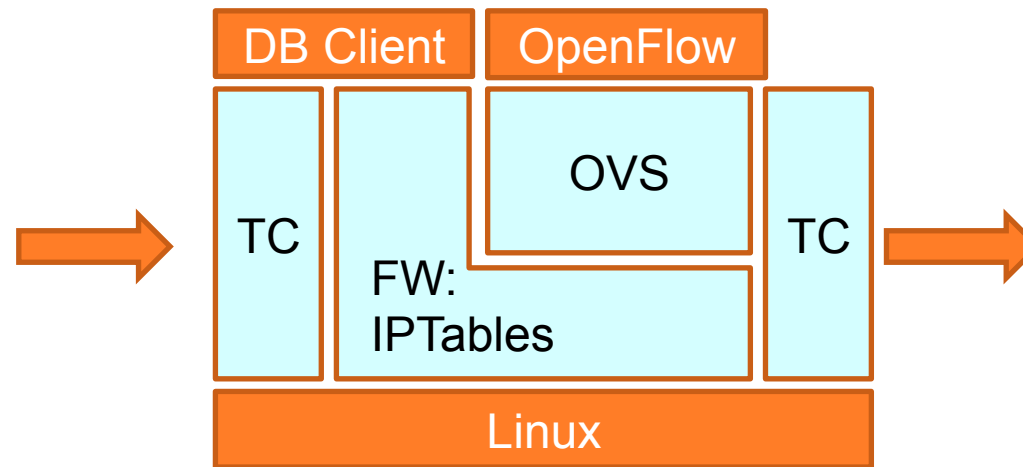
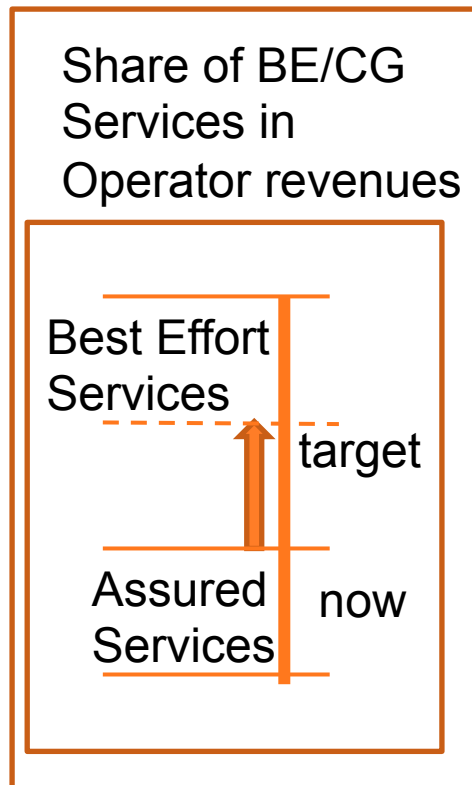
In principle it works – Robot framework testing ongoing
But

- One can not implement a real FW with OpenFlow Switch, because
 - *OpenFlow has limited set of operations for processing packets*
 - *No general purpose – packet level processing except send it to Control Plane*
 - *FW → must send **all** packets to CP*

Have now moved to OVS + Linux dataplane node

- Linux can do packet level processing in kernel: IPTables

Practical Data Plane of Edge Gateway



TC – Traffic Control

Role of OVS: mangle packets/reformat forwarding formats

Role of IPTables: packet filtering, rate limiting of new flows,
rate limiting of service flows, spoofing elimination

CP resides in the DC and will have rules DB, Flow level Firewalling
logic with edge to edge signaling and Connection control

TC and IPTables use a common flow abstraction

Preventing DNS Abuse/Exploitation (2)

- **DNS Relay front end:** implemented to protect PRGW from direct exposure to the Internet. This is to prevent the CPPA exhaustion from malicious domain resolutions, e.g. inbound DNS floods and spoofed requests. Under this model, PRGW is protected by virtue of delegating the DNS security to its ISP.
- The approach draws upon the use of DNS reverse proxies in ISP networks and cloud-based security solutions that aim to secure networks against DNS abuses.
- The delegation of security to a dedicated DNS-Relay element offers multiple benefits:
 - 1) *It lessens the load of executing the complex DNS security algorithms from PRGW.*
 - 2) *The dedicated relay element can independently leverage the existing state-of-the-art and future research in DNS threat detection, to serve the PRGW with legitimate traffic only.*

Preventing DNS Abuse/Exploitation.. (3)

Name Server classification

- *PRGW classifies the public DNS servers into: whitelist, greylist and blacklist. Servers on each list are treated differently in PRGW and are dynamically promoted/demoted, based on the influx of attack traffic.*
- *Whitelist servers are specifically configured in PRGW. By default, rest are greylisted*
- *Whitelisting can be based on business contracts and service level agreements (SLAs) between service providers, and may require networks to meet a set of pre-conditions.*
 - *For example, Use DNS/TCP to forward domain requests, DNSSEC, ingress filtering*

- **Circular pool address allocation model**

- *Rate limits the number of simultaneous DNS queries from a DNS server.*
- *Rate limits the number of simultaneous DNS queries to a private host/service.*
- *Total CPPA allocations to greylist servers < a portion of the circular pool.*
 - *Ensures that under the load situation, whitelist servers have preferred access to PRGW.*

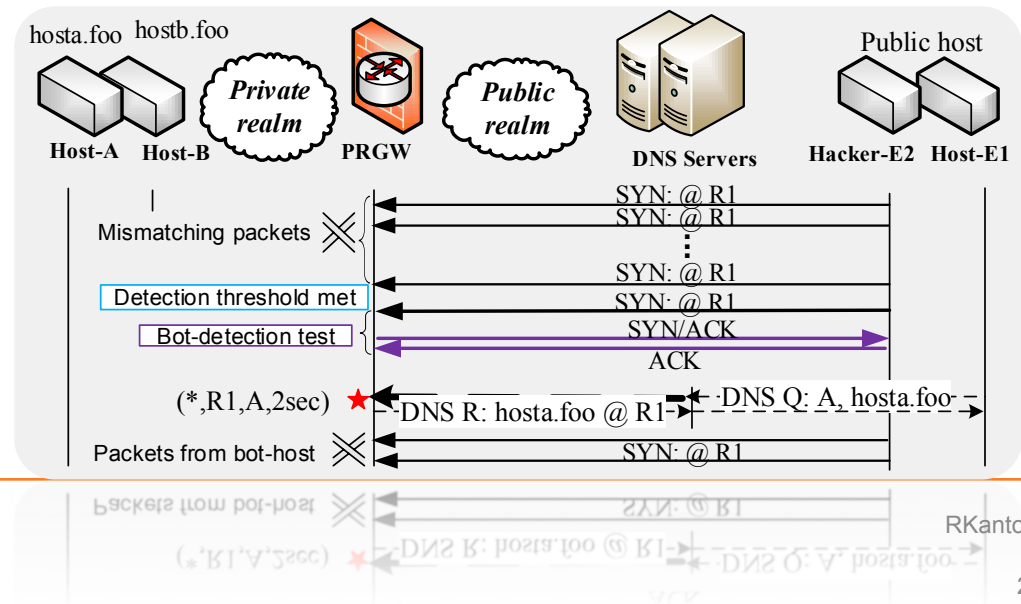
- TCP-Splice

- Outcome:

Figure 1 illustrates the network scenario and the sequence of events. The network topology shows Host-A and Host-B in the Private realm, connected via a PRGW to the Public realm, which contains DNS Servers and Host-E1. The sequence diagram shows the interaction between Host-A, Host-B, PRGW, DNS Servers, and Host-E1. Host-A sends a request to Host-B, which then sends a request to the PRGW. The PRGW sends a DNS query (DNS R) to the DNS Servers, which respond with a DNS response (DNS Q). The PRGW then establishes a TCP connection with Host-E1, showing a TCP Hand-shake and subsequent TCP data flow. A legend indicates that a green star represents state allocation to the legacy host and a purple circle represents adjusting the (SEQ, ACK) number across the PRGW for end-to-end TCP flow.

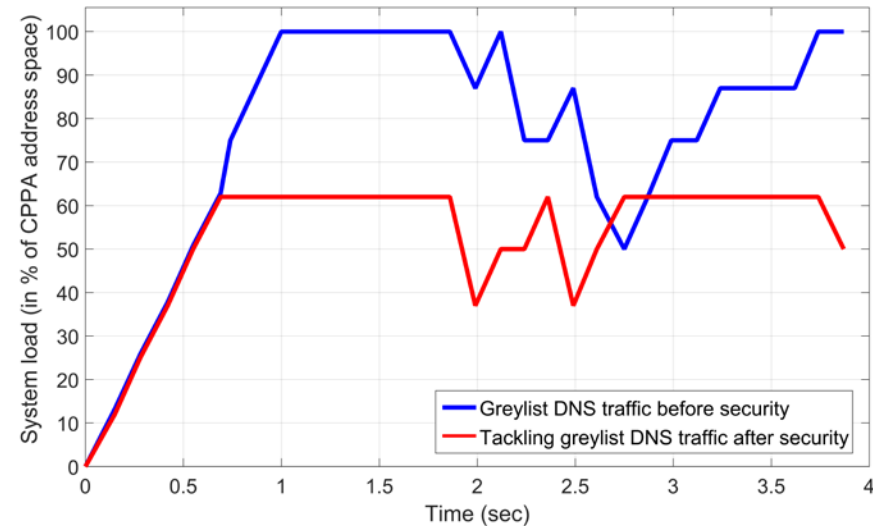
Filtering Malicious flows.. (2)

- Bot-Detection method
 - *Complements the limitations of TCP-Splice*
 - *Attempts to protect PRGW against SYN floods from botnets*
- Outcome
 - *Filters flows from aggressive non-spoofed sources.*



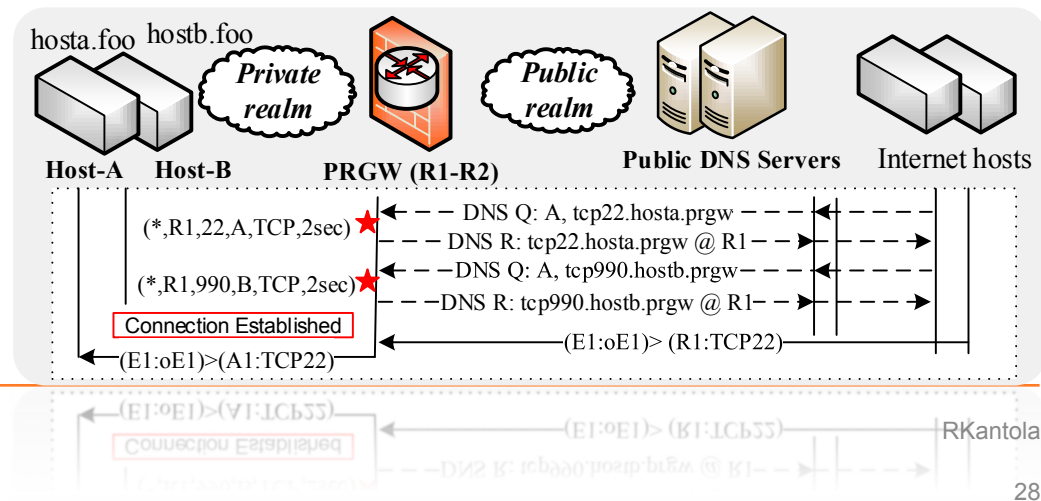
Security Evaluation: White/Grey DNS servers

- Protection against DNS floods
 - *Without heuristics*, DNS flood would reserve all the CPPA resources and force PRGW into DoS.
 - Address allocation model notes that the DNS source is greylist, and limits the resource allocations to a portion of the circular pool.
 - This ensures preferred access to whitelists servers, particularly under attack/load conditions.



Service FQDN

- New algorithm for allocating the public IP addresses of the circular pool.
- The underlying idea is to address the services and endpoints simultaneously.
 - For example, an SSH service at Host A – *a.foo* can be represented as *ssh.a.foo* or it can be defined as combination of port number and transport protocol: **tcp22.a.foo**.
- Since it includes both the endpoint and the service, PRGW creates **endpoint independent but port dependent filtering** in the half state relative to the client.

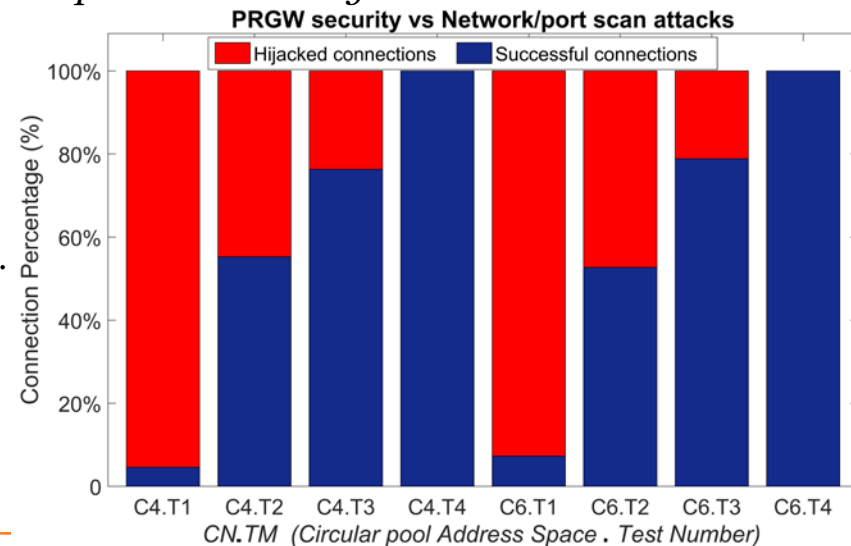


Advantages of Service FQDN

- *More specific half connection state,*
 - allows reusing a public IP address for several different services, improving the scalability of CPPA.
 - contributes to security, by increasing the attack surface for hacker i.e. Hacker must target the allocated port besides the public-IP → more difficult to force the blocking state.
 - Attacker will have more opportunities to meet the detection threshold, and get blacklisted.
- *Service-FQDN = key to security policy*

Security Evaluation – Quantifying sFQDN

- **Contribution of Service-FQDN (SFQDN)**
- Stress the prototype with below traffic patterns, at network delay of 200 msec and a constant load of 4 connections per second.
 - Connection load is distributed among private hosts. -> Exponentially distributed.
 - In parallel, a network scan attack at 40 SYNs/sec from public nodes targets PRGW.
- Inbound traffic patterns:
 - Test1: 100% FQDNs based inbound traffic.
 - Test2: 50% of the inbound traffic is FQDN.
 - Test3: 75% of inbound traffic is SFQDN; the rest FQDN.
 - Test4: 100% of the inbound traffic is SFQDN.



RKantola

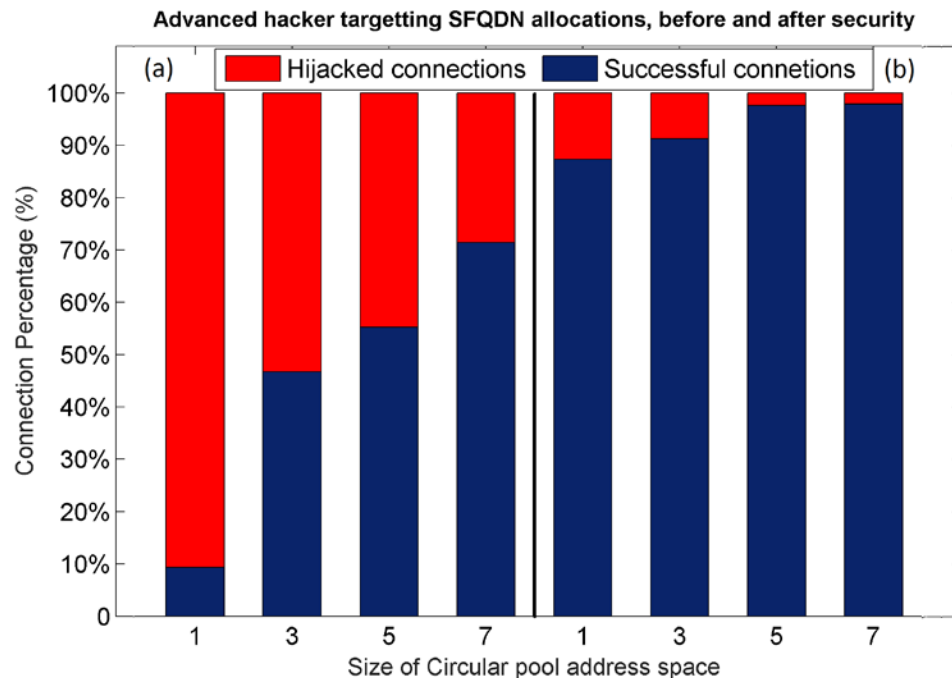
Security Evaluation: spoofing

- **Filtering of malicious flows**
- Due to TCP-splice mechanism, packets from spoofed addresses failed to claim any half connection states.
 - *TCP-splice obviates spoofing, at the cost of delaying claim to the connection state.*
 - *In terms of performance, this limits the reusability of the public IP address and the port combination by the same duration for the next inbound connection.*
- For non-spoofed (i.e. bot-controlled hosts)
 - *Bot-Detection would track the sender of repeatedly mismatching packets, and then performs a bot-detection test. When detected as non-spoofed, it is blacklisted.*
 - *Under this method, an attack with more active bots is filtered.*
 - *It is possible that a hacker stays below the Detection threshold and thus avoids Bot-Detection.*

Attack proficiency vs PRGW Security

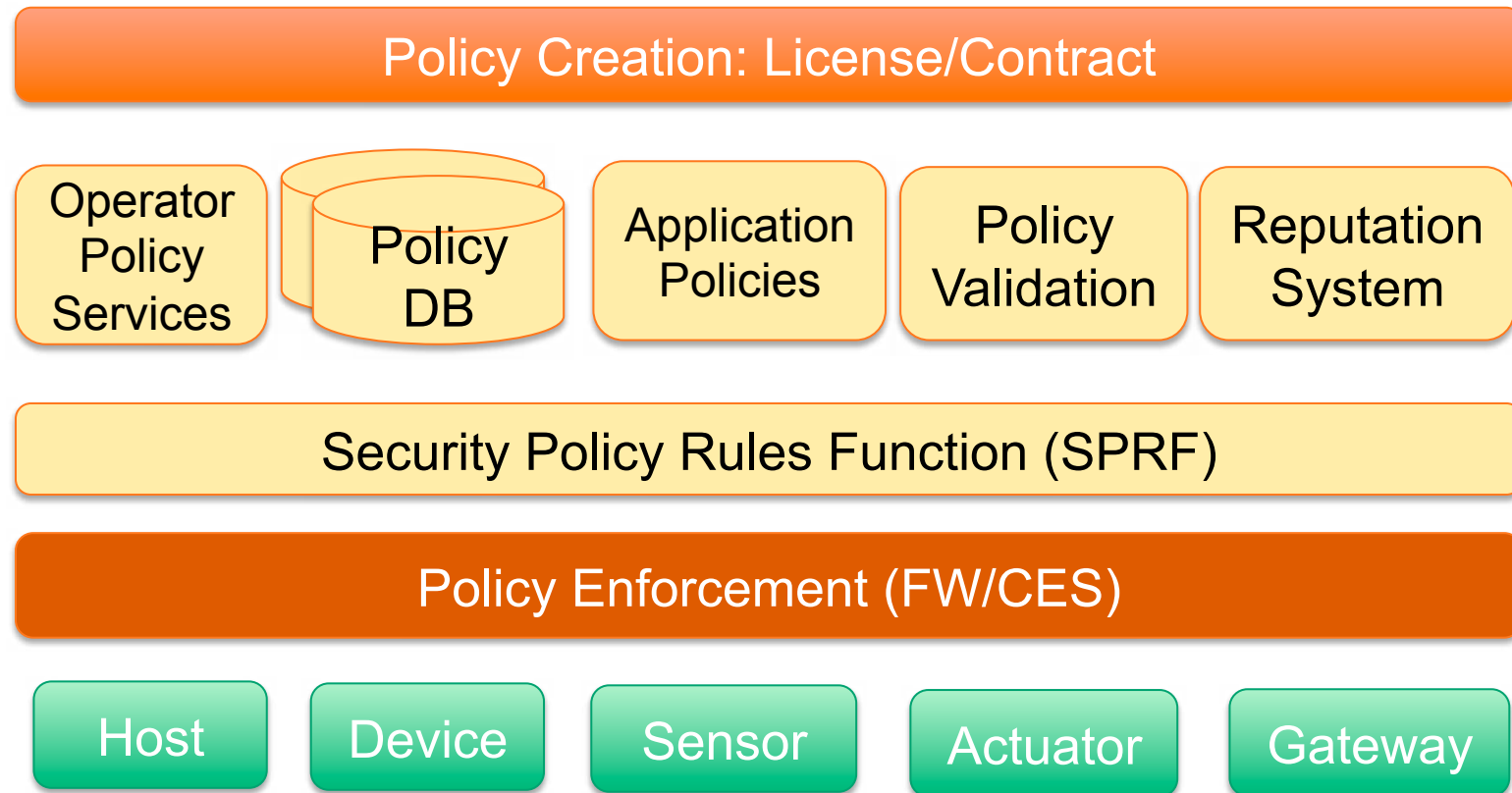
- Hacker proficiency
 - *a) Probing/scanning/amateur hacker*
 - A probing hacker scans the entire CPPA address space and port range to discover the available services, IP addresses or NAT mappings.
 - Such an attacker due to its limited victim's knowledge will fail to attack PRGW
 - *b) Advanced hacker*
 - may already know services/ports in the target network, via knowledge sharing among hackers or by consuming bots from bot-rental business or via first setting up legitimate flows thru RGW
 - As a result, the hacker can target the SYN floods to the specific service ports.

Attack proficiency vs PRGW Security



**In case the same organization
Owns the network with servers
And the clients→
Device management can change
The ports used for services
→ Wider attack surface**

Policy Architecture for CES networks



Privacy preserving unwanted traffic control based on trust management

Motivations:

- Many entities either refuse or are reluctant to share attack evidence
- Monitoring of traffic by ISP is not allowed because of privacy of communications without evidence of malicious activity - that is a threat to the network



Our proposal → a privacy preserving unwanted traffic control based on trust management and homomorphic encryption.

Principles of Privacy Preserving Trust Management for the Internet

- Entities: Host; corporate network; ISP; Trust Operator
- Host/corporate network shares evidence in encrypted form – its Identity is anonymized by ISP
- ISP aggregates evidence using Homomorphic crypto
- Trust Operator processes → Trust and credibility value for each entity → Send Greylist to ISP=authorize ISP monitoring → ISP Decrypts suspect IDs → Monitored list by ISP → ISP monitors, gets conclusive evidence → containment + deliver black lists to all CES

Security gains from CES and Trust Mgt

- Block, root out DDoS and Address Spoofing
- Take amateur hackers out of business (?)
- Deploy security patches in network nodes → no need to involve users → ubiquitous and fast deployment
 - E.g patch security for consumer devices
 - (Professionals using zero-day vulnerabilities will carry on)
- Due to cloud based control plane – scale security to any speeds
- Personalize security for each user
- Encourage users/companies to share evidence → *one for all and all for one principle*
- Improve National response to Cyber warfare

References

1. www.re2ee.org
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Thank You
(Questions? )

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