Hi^3: AN ANALYTICAL STUDY OF THE SCALABILITY

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InfraHIP Project
(Infrastructure for Host Identity Protocol)
by Helsinki Institute for Information Technology

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Outline

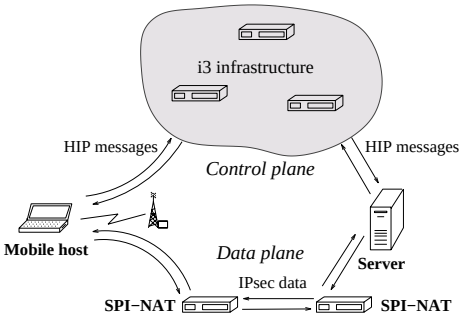
0. **What is Hi^3**
   Host Identity Protocol (HIP), Internet Indirection Infrastructure (i^3), and Hi^3 architecture.

1. **Hi^3 analysis**
   Aim, subject and assumptions.

2. **Basic Hi^3 scenarios**
   HIP messages and their traveling through the infrastructure.
   Hi^3 parameters and latency of HIP messages.

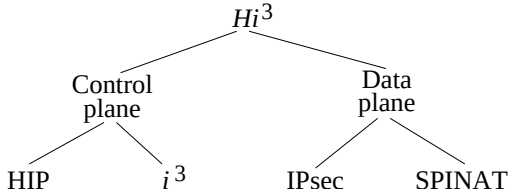
3. **Scalability analysis**
   Hi^3 deployment, workload, Hi^3 size, resilience to attacks.

Hi^3 architecture

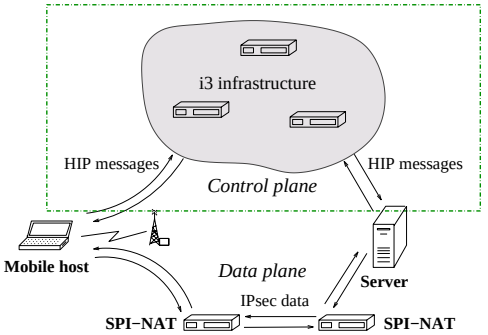


- Host identity layer between transport and network layers
- IP address is a topological label
- i^3 trigger (id, R)
- Separating control and data
- Protecting data traffic

HIP messages (control plane):
- base exchange
- mobility exchange
- ...



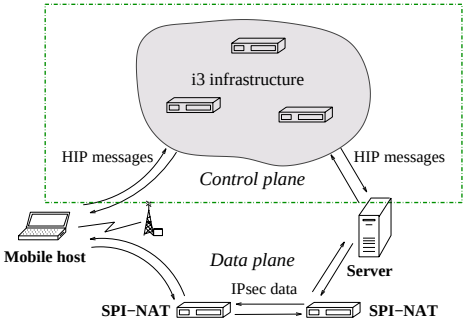
Hi^3 Analysis: 1. Aim and Subject



Scalability properties ?

- HIP messages:
  - base exchange
  - mobility exchange
- i^3 messages:
  - trigger insertion
  - trigger refreshment
  - HIP processing delegation
- Attacks to Hi^3:
  - burst of HIP messages
  - burst of i^3 messages

Hi^3 Analysis: 2. Assumptions

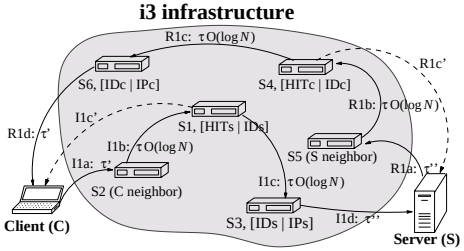


- A few parameters
  - manageable
  - outside i^3
  - required characteristics
- Uniformity of parties involved:
  - i^3 servers
  - mobile hosts
  - Internet servers
- Inexhaustible communication:
  - worst case
  - averaging

Basic trends for scalability ?

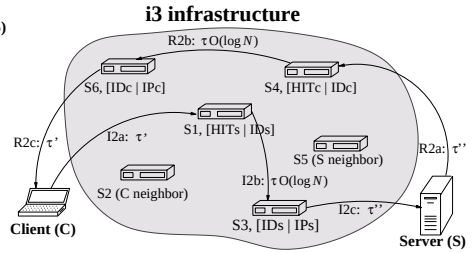
Average estimates for a “globally worst case”

Hi^3 scenarios: 1. Pure association setup (1/3)



I1 and R1 packets

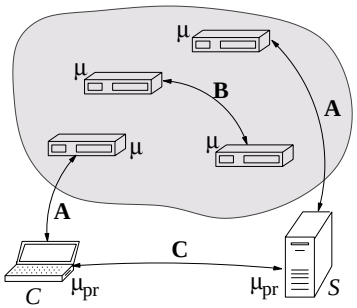
HIP base exchange in Hi^3



I2 and R2 packets

Hi^3 scenarios: Parameters

i3 infrastructure of size N



Number of i^3 servers: N

Transit time: in average, ms

A. host $\leftrightarrow$ i^3: $\tau' = \tau_C^{\mathrm{Hi3}}$, $\tau'' = \tau_S^{\mathrm{Hi3}}$

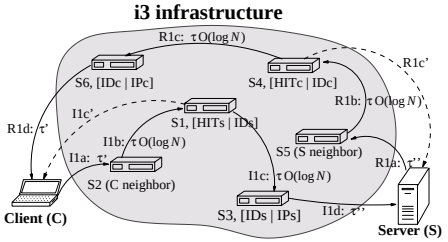
B. i^3 server $\leftrightarrow$ i^3 server
1. direct IP: τ
2. i^3 lookup: $\tau O(\log N)$

C. host $\leftrightarrow$ host: $\tau_{SC} = \tau_{CS}$

Processing time: in average, ms
1. one packet forward: μ
2. HIP cryptography: μ_{pr}

i^3 **lookup:** $(\tau+\mu)O(\log N) \sim \dfrac{\tau+\mu}{2}\log N$

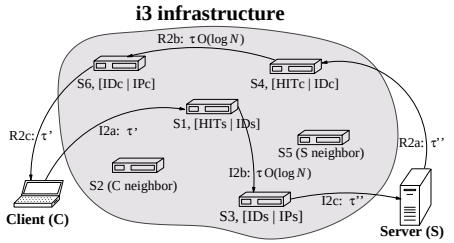
Hi^3 scenarios: 1. Pure association setup (2/3)



I1 and R1 packets

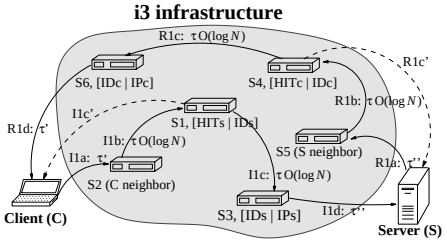
Latency L^{Hi3} ***?***

- Time inside i^3 and outside
- Four packets in HIP base exchange
- $L_{\mathrm{s}}^{\mathrm{Hi3}} = 4(\tau^{\mathrm{Hi3}} + \tau^{\mathrm{out}})$



I2 and R2 packets

Hi^3 scenarios: 1. Pure association setup (3/3)

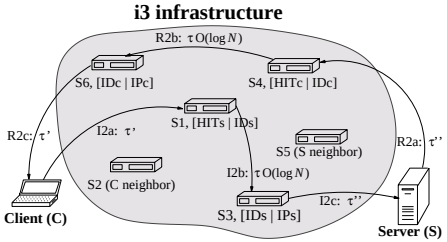


I1 and R1 packets

$$L_{\rm s}^{\rm Hi3} = 4\tau_C^{\rm Hi3} + 3(\tau+\mu)\log N + \\ + 4\tau_S^{\rm Hi3} + 2\mu_{\rm pr} \quad (1)$$

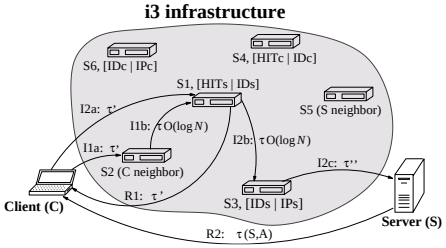
and

$$4\tau^{\rm Hi3} = 3(\tau+\mu)\log N \\ 4\tau^{\rm out} = 4\tau_C^{\rm Hi3} + 2\mu_{\rm pr} + 4\tau_S^{\rm Hi3} \quad (1a)$$



I2 and R2 packets

Hi^3 scenarios: 2. Optimized association setup



I1, R1, I2, and R2 packets

$$L_{\rm so}^{\rm Hi3} = 4(\tau^{\rm Hi3} + \tau^{\rm out}) \\ L_{\rm so}^{\rm Hi3} = 3\tau_C^{\rm Hi3} + (\tau+\mu)\log N + \\ + \tau_S^{\rm Hi3} + \tau_{SC} + 2\mu_{\rm pr} \quad (2)$$

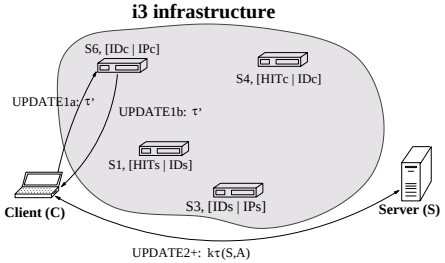
and

$$4\tau^{\rm Hi3} = (\tau+\mu)\log N \\ 4\tau^{\rm out} = 3\tau_C^{\rm Hi3} + 2\mu_{\rm pr} + \tau_S^{\rm Hi3} + \tau_{SC} \quad (2a)$$

The optimization benefit is more than $\frac{3}{2}(\tau+\mu)\log N + {\rm RTT}(S, {\rm Hi3})$

For $N \sim 500$ it is more than 1 second!

Hi^3 scenarios: 3. Location update



UPDATE1 and UPDATE2+ packets

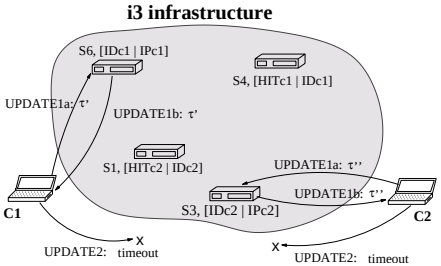
$$L_{\rm lu}^{\rm Hi3} = 2\tau_C^{\rm Hi3} + \mu + k\tau_{SC} \approx \\ \approx {\rm RTT}(C, {\rm Hi3}) + \frac{k}{2}{\rm RTT}(C,S) \quad (3)$$

and

$$2\tau^{\rm Hi3} = \mu \approx 0 \\ (2+k)\tau^{\rm out} = {\rm RTT}(C, {\rm Hi3}) + \\ + \frac{k}{2}{\rm RTT}(C,S) \quad (3a)$$

Infrastructure load is small

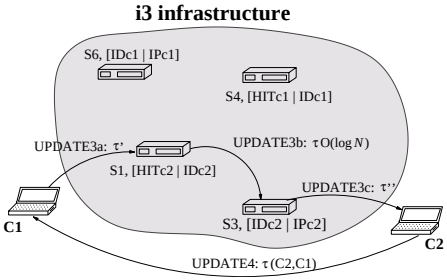
Hi^3 scenarios: 4. Simultaneous host movement



UPDATE1 and UPDATE2 packets

$$2\tau^{\rm Hi3} = \frac{\tau+\mu}{2}\log N \\ 2\tau^{\rm out} = \tau_{C1}^{\rm Hi3} + \tau_{C2}^{\rm Hi3} + \tau_{C2,C1} \quad (4a)$$

$$L_{\rm su}^{\rm Hi3} = 2(\tau^{\rm Hi3} + \tau^{\rm out}) \\ L_{\rm su}^{\rm Hi3} = \tau_{C1}^{\rm Hi3} + \frac{\tau+\mu}{2}\log N + \\ + \tau_{C2}^{\rm Hi3} + \tau_{C2,C1} \quad (4)$$

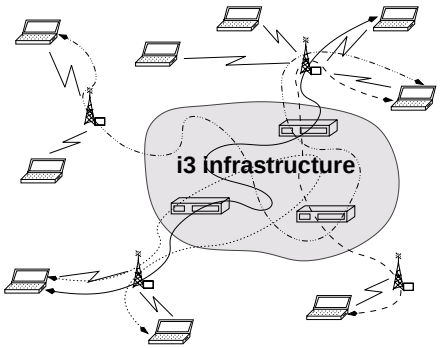


UPDATE3 and UPDATE4 packets

Hi^3 scenarios: Summary

Scenario	#pkts	Inside Hi^3	Outside Hi^3	Occurrence
Pure setup	4	$3(\tau+\mu)\log N$	$4\tau_C^{\mathrm{Hi3}}+2\mu_{\mathrm{pr}}+4\tau_S^{\mathrm{Hi3}}$	medium
Opt. setup	4	$(\tau+\mu)\log N$	$3\tau_C^{\mathrm{Hi3}}+2\mu_{\mathrm{pr}}+\tau_S^{\mathrm{Hi3}}+\tau_{SC}$	medium
Loc. update	$2+k$			frequent
phase 1	2	μ	$\mathrm{RTT}(C,\mathrm{Hi3})$	
phase 2	k	0	$\frac{k}{2}\mathrm{RTT}(C,S)$	
Sim. update	6			rare
phase 1	$2+2$	2μ	$\mathrm{RTT}(C1,\mathrm{Hi3})+\mathrm{RTT}(C2,\mathrm{Hi3})$	
timeout	—	—	—	
phase 2	2	$\frac{\tau+\mu}{2}\log N$	$\tau_{C1}^{\mathrm{Hi3}}+\tau_{C2}^{\mathrm{Hi3}}+\tau_{C2,C1}$	

Scalability: 1. Mobile peers 1/4



- M is #(mobile hosts)
- N is #(i^3 servers)
- λ is intensity of a mobile host to send a HIP message (λ_{s}, λ_{so}, λ_{u})
- P_{su} is probability that a location update becomes a simultaneous update.
- Workload W is #requests (average) to an i^3 server:

$$W = \frac{\lambda M}{N} \cdot \#(i^3 \text{ servers for a HIP message})$$

Scalability: 1. Mobile peers 2/4

Scenario	Hi^3 workload, W	Inside i^3, T^{Hi3}
Pure setup	$\frac{3\lambda_{\mathrm{s}} M\log N}{N}$	$3(\tau+\mu)\log N$
Opt. setup	$\frac{\lambda_{\mathrm{so}} M\log N}{N}$	$(\tau+\mu)\log N$
Update	$\frac{\lambda_{\mathrm{u}} M}{N}\left(1+\frac{1}{2}P_{\mathrm{su}}\log N\right)$	$\mu + P_{\mathrm{su}}\frac{\tau+\mu}{2}\log N$ $\approx P_{\mathrm{su}}\frac{\tau+\mu}{2}\log N$ or $\approx (\tau+\mu)\left(1+\frac{P_{\mathrm{su}}}{2}\log N\right)$

$$N \approx \frac{\lambda M\cdot T^{\mathrm{Hi3}}}{(\tau+\mu)W} = \frac{\lambda M\cdot T^{\mathrm{Hi3}}(N)}{(\tau+\mu)W(N)} \qquad (5)$$

Scalability: 1. Mobile peers 3/4

- HIP messages are mixed:

$$W_{\mathrm{tot}} = W_{\mathrm{s}} + W_{\mathrm{so}} + W_{\mathrm{u}}\ , \qquad T_{\mathrm{avg}}^{\mathrm{Hi3}} = \frac{\lambda_{\mathrm{s}} T_{\mathrm{s}}^{\mathrm{Hi3}} + \lambda_{\mathrm{so}} T_{\mathrm{so}}^{\mathrm{Hi3}} + \lambda_{\mathrm{u}} T_{\mathrm{u}}^{\mathrm{Hi3}}}{\lambda_{\mathrm{s}} + \lambda_{\mathrm{so}} + \lambda_{\mathrm{u}}}$$

- More precise:

$$W_{\mathrm{tot}} = \frac{\lambda_{\mathrm{tot}} M\log N}{N} + \frac{\lambda_{\mathrm{u}} M}{N}\ , \quad T_{\mathrm{avg}}^{\mathrm{Hi3}} = \frac{\lambda_{\mathrm{tot}}}{\lambda_{\mathrm{s}} + \lambda_{\mathrm{so}} + \lambda_{\mathrm{u}}}(\tau+\mu)\log N\ ,$$

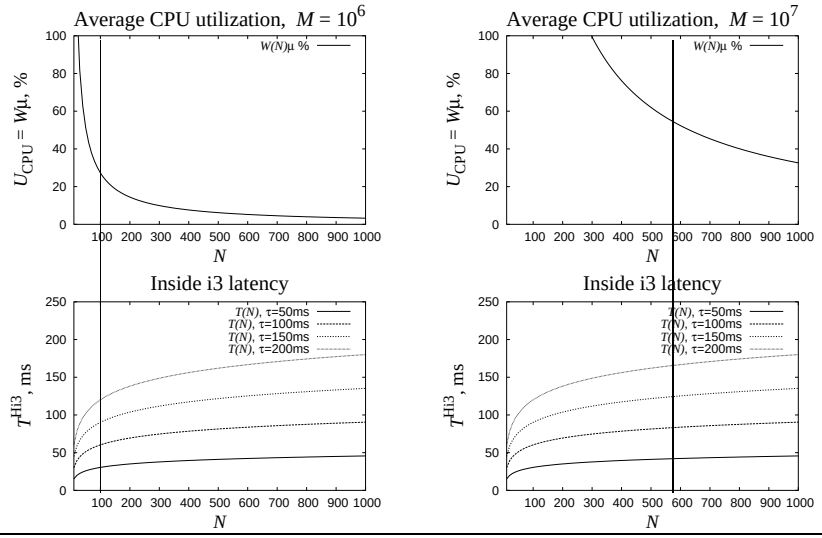
  where $\lambda_{\mathrm{tot}} = 3\lambda_{\mathrm{s}} + \lambda_{\mathrm{so}} + \frac{P_{\mathrm{su}}}{2}\lambda_{\mathrm{u}}$

- Scalability estimation:

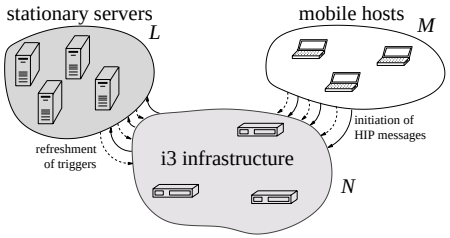
$$N = \frac{\lambda M\cdot T_{\mathrm{avg}}^{\mathrm{Hi3}}}{(\tau+\mu)W_{\mathrm{tot}}} \qquad (6)$$

Scalability: 1. Mobile peers 4/4

$\lambda_s = \lambda_{so} = 30\text{min}^{-1}$, $\lambda_u = 1\text{min}^{-1}$, $P_{su} = 10^{-2}$, $\mu = 1\text{ms}$



Scalability: 2. Stationary and mobile hosts



- M is #(mobile hosts)
- N is #(i^3 servers)
- L is #(stationary Internet servers)
- λ is intensity of a mobile host to send a HIP message (λ_s, λ_{so}, λ_u, P_{su})
- λ_r is intensity of a server to refresh its public trigger in i^3.

$$W_{tot} = \frac{\lambda_{tot} M \log N}{N} + \frac{\lambda_u M + 2\lambda_r L}{N}$$

Scalability: Summary

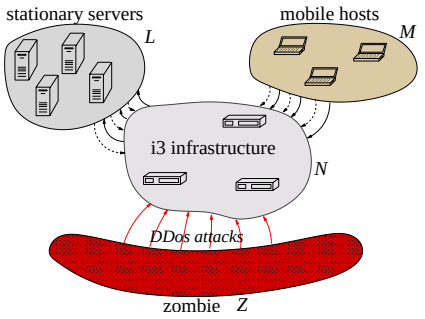
Increasing N leads to:

- Workload decreases as $W = C_1(\lambda, \#) \cdot \frac{\log N}{N} + C_2(\lambda, \#) \cdot \frac{1}{N}$
- Inside latency increases as $T^{\text{Hi3}} = C_3(\lambda, \tau + \mu) \cdot \log N$

Infrastructure size N is proportional:

- $N \approx C_4(\lambda, \#, \frac{1}{\tau + \mu}) \cdot \frac{T^{\text{Hi3}}}{W}$

Application scenarios: 3. Zombie attacks 1/3



Workload:
average #requests to an i^3 server

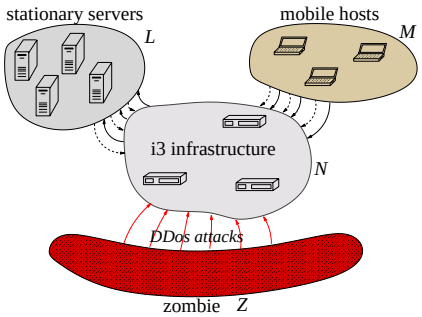
Attack types:

- Trigger insertion: $W_{zi} = \frac{\lambda_{zi} Z \log N}{N}$
- Initiation of association setup
  1. send I1
  2. receive R1
  3. immediately reply with I2 and wrong puzzle solution

Pure base exchange: $W_{zs} = \frac{5\lambda_{zs} Z \log N}{2N}$

Optimized base exchange: $W_{zso} = \frac{\lambda_{zs} Z \log N}{N}$

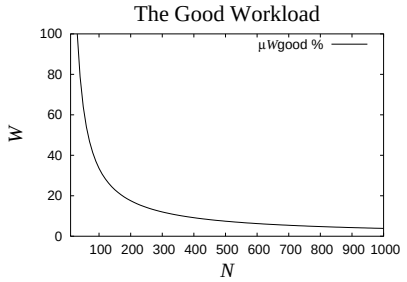
Application scenarios: 3. Zombie attacks 2/3

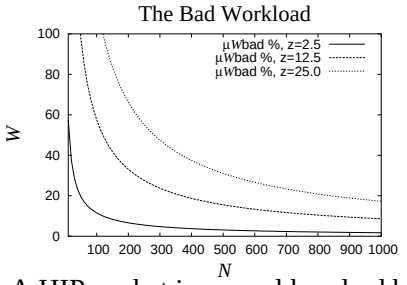


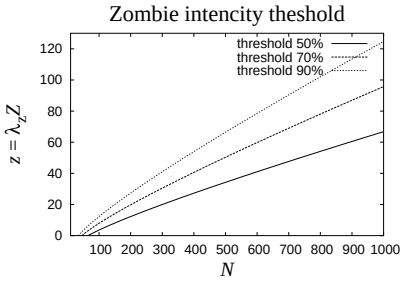
- $W_{\text{good}} = W_{\text{s}*} + W_{\text{u}} + W_{\text{r}}$
  $W_{\text{bad}} = W_{\text{z}*} = \dfrac{\lambda_{\text{z}} Z \log N}{N}$
- $W_{\text{tot}} = W_{\text{good}} + W_{\text{bad}}$
- Criteria: $W_{\text{tot}}\mu \leq W_{\text{threshold}}\mu$
  e.g. $W_{\text{threshold}}\mu = 50\%, 70\%, 90\%$
- Threshold: $z = \lambda_{\text{z}} Z = ?$

$$z = (W_{\text{threshold}} - W_{\text{good}})\frac{N}{\log N}$$

Application scenarios: 3. Zombie attacks 3/3







A HIP packet is several hundred bytes, or ≈ 0.5 Kbytes $= 4$ Kbits.

$\max \lambda_{\text{z}} \approx 0.25$ for 1Mbs throughput

Z	$z = \lambda_{\text{z}} \cdot Z$	N
10	2.5	< 50
50	12.5	< 100
100	25.0	< 200

Conclusion

1. Simple assumptions leads to ***basic trends only***
2. Hi^3 has ***acceptable inside latency*** and ***satisfactory scalability property***
3. Infrastructure of ***a few nodes*** ($\sim 10^2$) is suffi cient for ***a large set*** of HIP hosts ($\sim 10^6..10^7$)