Effects of Processing Delay on Function-Parallel Firewalls

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Abstract

- Firewalls filter packets between networks.
- Unfortunately, they introduce significant delay to a system.
- Given issues with current high speed networks, how will firewalls cope with future networks?
- This presentation will introduce a parallel firewall system that can:
  - Maintain integrity of original system.
  - Mitigate Denial of Service.
  - Provide High Scalability.
  - Maintain Quality of Service.

Modeling Precedence

- A **rule** is an ordered tuple and an associated action.
- A **policy** is an ordered set of rules.
- In a Policy DAG Vertices are rules, edges are **precedence relationships**.
  - Rules intersect if their every tuple of their set intersection is non-empty.
  - Edge exists between r_i and r_j, if $i < j$ and the rules intersect.
- If two rules intersect, then the order is significant.

Accept Sets

- An **accept set** *A* is the set of all possible unique packets which a policy will accept.
- A **deny set** *D* is the set of all possible unique packets which a policy will deny.

- A **comprehensive** policy *R* is one where $\overline{D} = A$.
- R and R′ are **equivalent** if $A = A'$.
- If *R′* is a modified *R* then **integrity** is maintained.

Data Parallel

- A system is Data parallel (load-balancing) if:
  - Distributes packets evenly to all firewall nodes.
  - Duplicates original policy to each firewall node ($R_i = R$)
- Maintains integrity since $A_i = A$.
- Better throughput than traditional designs.
- Does not allow for Quality of Service or state.
- Benefit is related to load, when enough traffic exists to split.
- Does not directly focus on reducing processing delay.

Function Parallel with Gate

- A system is Function parallel (with gate) if:
  - Duplicates packets to all firewall nodes.
  - Distributes local policy R_i to each firewall node, where

$$\bigcup_{i=1}^{m} A_i = A$$

- A **gate** coordinates local policy results.
- Incoming packets are also duplicated to the gate.
- Multiple nodes may find an accept match for the same packet if: $A_i \cap A_j, i \neq j$
- A gate node is needed to preserve precedence.

Function Parallel with no Gate

- If the nodes could be designed to act independently then the gate could be removed.
- A system is Function parallel, and does not require a gate if:
  - Duplicates packets to all firewall nodes.
  - Distributes a local policy R_i to each node, where both

$$\bigcup_{i=1}^{m} A_i = A \qquad \bigcap_{i=1}^{m} A_i = \emptyset$$

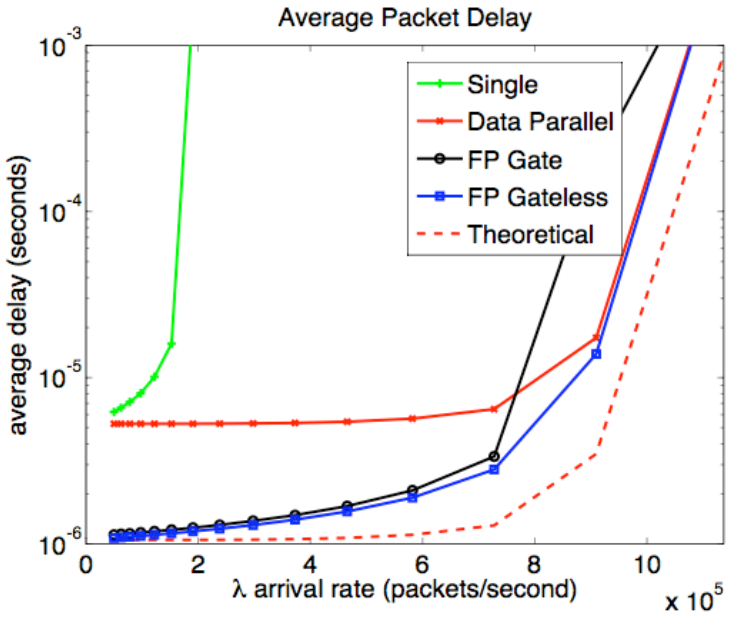
- Since no accept sets intersect, only one node will find an accepting match.

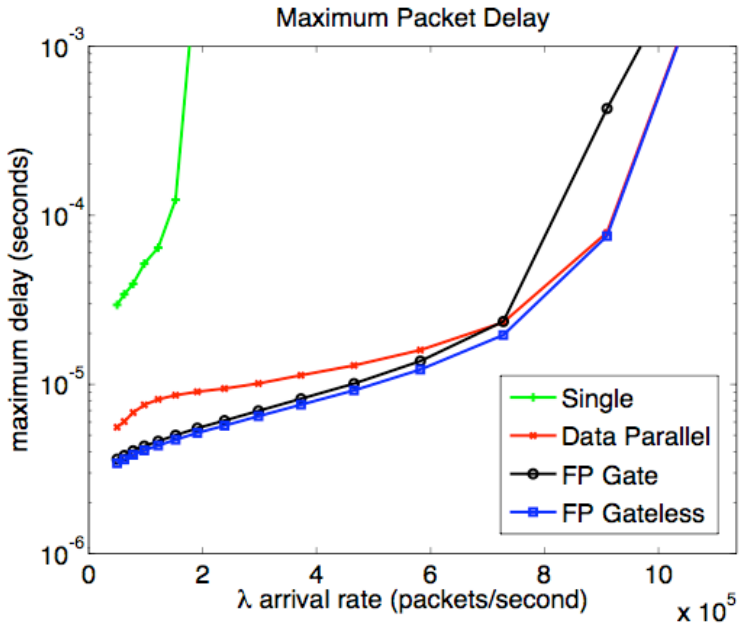
Simulation Comparison

- Assumptions:
  - Each node could process 6 x 10^7 rules per second.
  - Inter-arrival rate scheduled on **Poisson** distribution.
  - Rule match probability according to **Zipf** distribution.
  - No additional delay for Data Parallel packet distribution.
  - Constant gate delay for Function Parallel with Gate
- Cases were ran to determine the performance of:
  - Increasing arrival rates.
  - Increasing policy size.
  - Increasing number of nodes.

Delay vs Arrival Rate

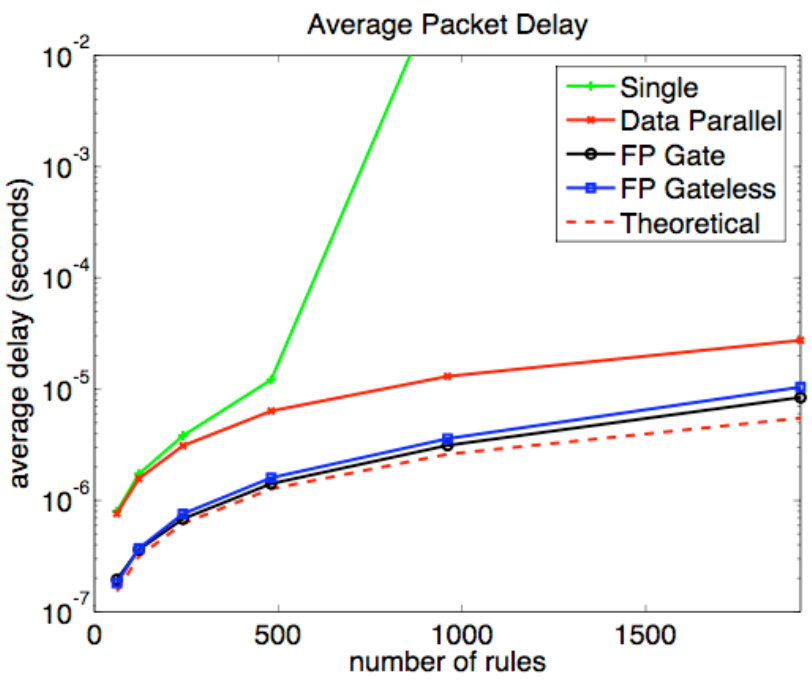
- Parallel systems consisted of 5 nodes.
- Policy size was 1024 rules.
- Arrival rate was varied from 300 Mbps up to 6 Gbps.

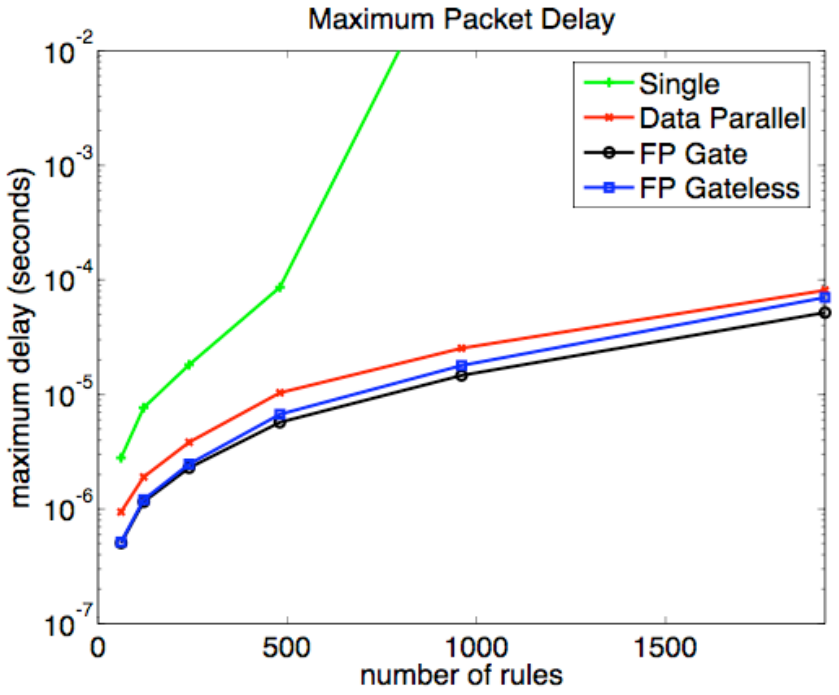




Delay vs Policy Size

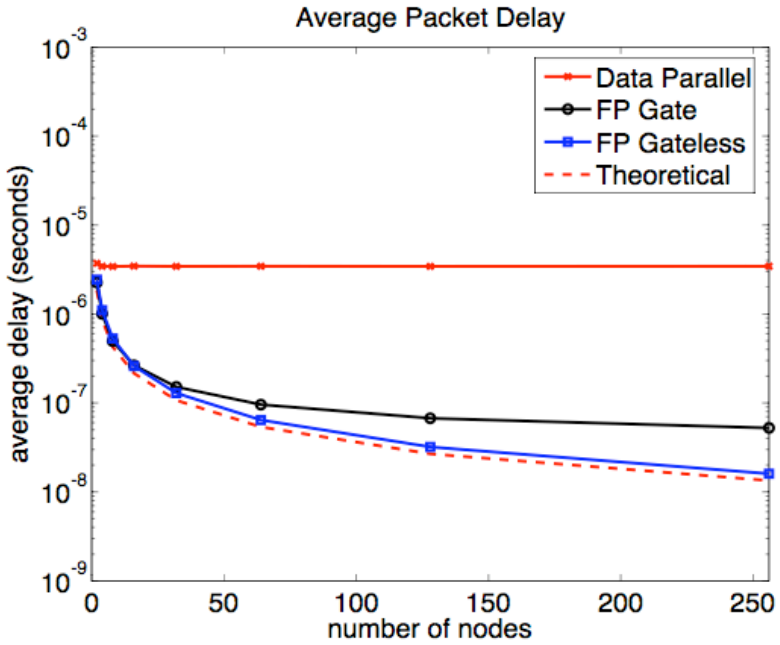
- Parallel systems consisted of 5 nodes.
- Arrival rate was established at 650 Mbps.
- Policy size was incremented from 2 to 2048.

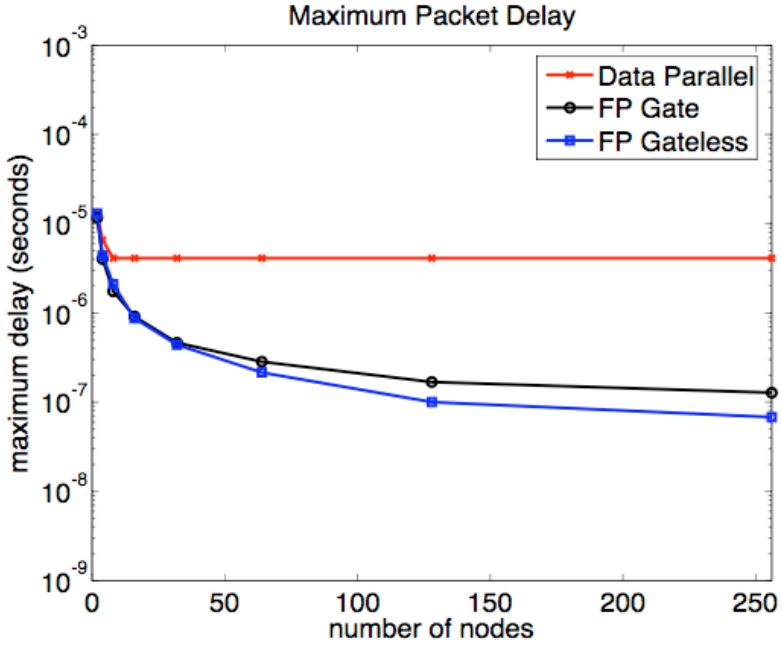




Delay vs Number of Nodes

- Arrival rate was established at 650 Mbps.
- Policy size was 1024 rules.
- Parallel systems varied number of nodes from 2 to 256.





Summary of Simulations

- Illustrates advantage of parallelism.
- Reducing **processing time** is more advantageous than reducing **arriving traffic load**.
- Removing the gate delay helps function parallel approach theoretical rates.

Conclusions

- It is important that a firewall acts transparently to users.
- Unfortunately, firewalls quickly become bottlenecks.
- Particularly in **High Speed Networks**.
- Improving implementations and hardware is not as scalable as needed.
- Enter **Parallel firewalls**.
- **Data parallel** does not address processing delay.
- **Function parallel with gate** is flexible, but has the added gate delay.
- **Function parallel** with no gate solves scalable processing delay issues.

Future Direction of Work

- Extend rule distribution and optimization methods for Function parallel with no Gate.
- Incorporate Distributed IDS/IPS.

- New Start-up company
  - Great Wall Systems. Winston-Salem, NC, USA.
  - Basis is two patents created through research from DOE grant.
  - Dedicated to High Speed Networking Devices for IDS/IPS systems.

Candidate for Parallelism

- Several solutions for improving firewall performance:
  - Optimize algorithms.
  - Optimize rules.
  - Parallelize system.
- Improvements to the single firewall design are temporary.

- Can divide load two ways:
  - Data Parallel - divide data processed.
  - Function Parallel - divide work of processing.

How the Gate Works

- Firewall nodes do not execute an action.
  - Send decision as a **vote** to the gate.
  - Vote consists of at least the rule number and action.
    - **No match** is a valid response.
    - Matches in state would have uniformally lower values.
- The gate caches the packet until a decision can be made.
- First match method is accomplished by executing the action of the vote with the lowest rule number.

Other Considerations

- Redundancy can be provided as long as accept sets are not violated.
- Gate can use knowledge of DAG to remove necessity of some votes.
- Processing the traffic asynchronously would increase work efficiency.
- Removal of need for the gate would eliminate associated processing delay.

Theoretical Comparison

- Standard formula for delay of a cascading system is:

$$E(T) = \sum_{i=1}^{q} \frac{1}{\mu_i - \lambda_i}$$

- Data parallel is:

$$E_d(T) = \frac{1}{\frac{x}{n} - \frac{\lambda}{m}}$$

- Function parallel is:

$$E_f(T) = \frac{1}{\frac{m \cdot x}{n} - \lambda}$$

- Relationship of delay is:

$$\frac{E_f(T)}{E_d(T)} = \frac{1}{m}$$