DUST: Resource-Aware Telemetry Offloading with A Distributed Hardware-Agnostic Approach

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Outline

1. Overview and Motivation
2. Proposed Solution System Architecture
3. DUST System Nodes and Workflows
4. Optimized Network Monitoring Placement
5. Performance Evaluations
6. Conclusion And Future Work

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Overview & Motivation

Network Monitoring:

A critical part of network deployment, conventionally deploying in a central approach e.g., SNMP, sFlow, etc.

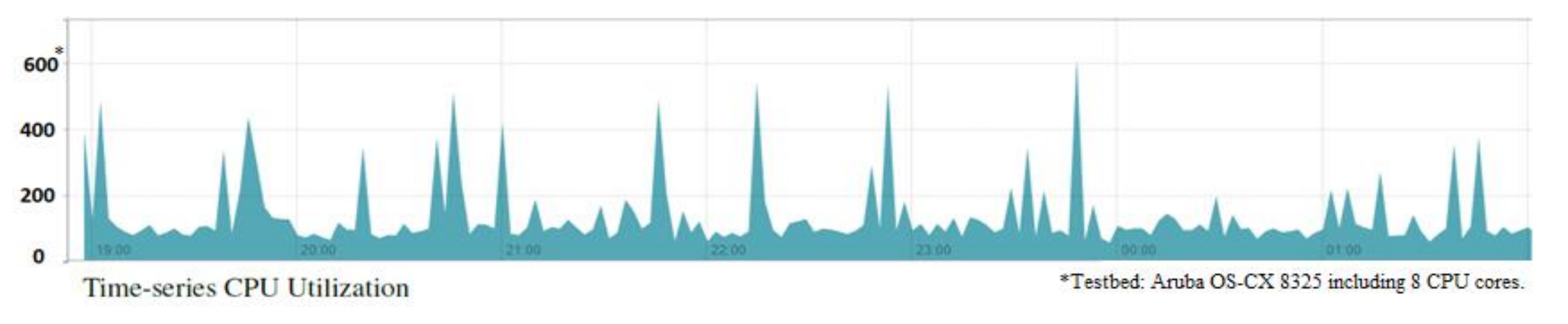
<u>In-device Network Telemetry</u>:

- Leverage *device computing* to empower *distributed*
- Gaining insights into the devices' status and behavior
- Precise collection ➔ Eliminates excessive data traverse
- Usage-based application, fine-grained data collection
- Real-time data collection, processing, and action

- Computational and storage heavy;
- Device-level functionality and scale;
- Resource efficiency and accuracy dilemma;
- Lack of central configuration & management
- Unsupported on low-profile switches;

Problem Motivation

Illustration of the extent of excessive resource usage of in-device telemetry:



- CPU consumption of a modular in-device analytic engine on a database-driven network OS enterprise switch.
- User-defined modular in-device monitoring agents; e.g., network protocol health, Rx/TX packet rates, resource utilization.

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Opportunities and Solution:

There are **ample computing resources** available in high-performance and industry-leading devices as opposed to certain nodes facing resource constraints while running in-device network monitoring,

➔ **Discarding these resources is not cost-effective for users.**

A study of NERSC's Perlmutter (HPC system), revealed that a **quarter of CPU node-hours achieved high utilization**, while **GPU-accelerated nodes were utilized for only 0-5% of the node-hours**.

➔Typical issue in HPC systems with primarily assigned resources

With the **emergence of DPUs and smart Fabrics/ASICs**, diverse computational capabilities in **servers and network switches are available** in data centers and High-Performance Computing (HPC)

- **DUST relies on utilizing the abundant but often underutilized computing resources in top-performing devices across the network.**

Proposed Solution System Architecture

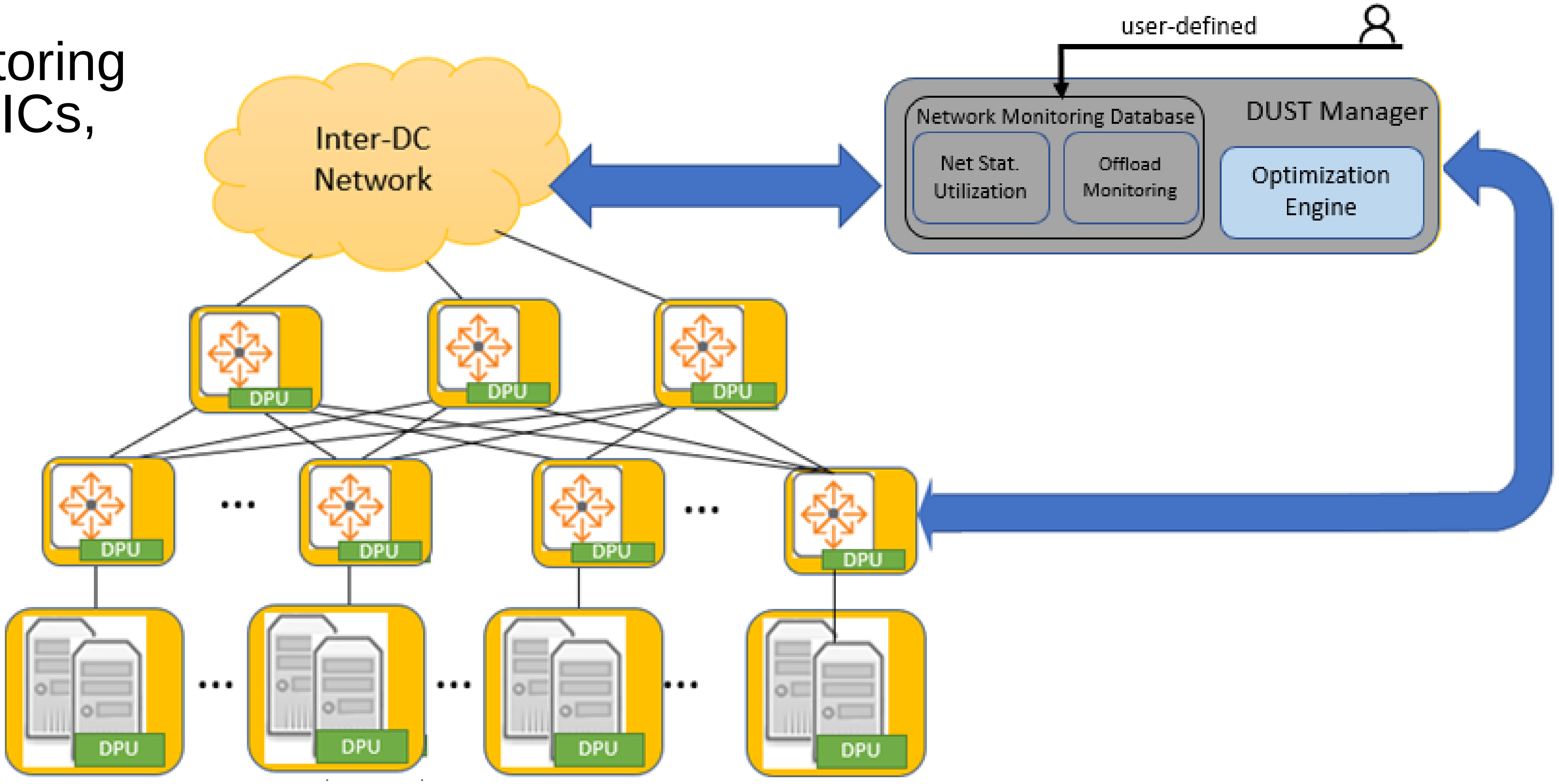
DUST: Dynamic and Distributed Usage-based Service Telemetry

Novel distributed usage-based monitoring service, can be deployed on SmartNICs, DPUs, Switches, or Servers.

Goal: Distribute and monitoring placement by leveraging available compute resources across network' nodes.

DUST two main parts:

- DUST –Client
- DUST –Manager



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Network Monitoring Placement Problem

Goals:
- Distribute the network monitoring tasks
- Optimal remote node selection for offloading

Constraints:
- Minimize monitoring data movement & response time

Solution:
- System-level architecture for workflow redistribution and packet flow communication
- Optimal remote node selection algorithm (ILP and heuristic)
- Controllable routing decisions

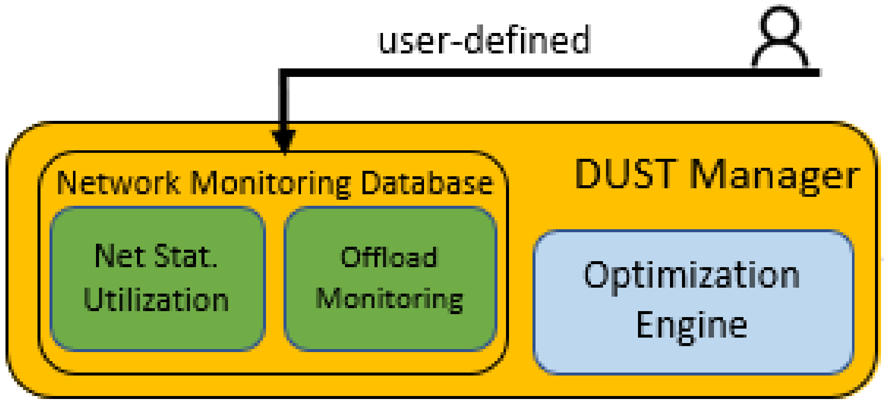
Network Monitoring Placement Overview

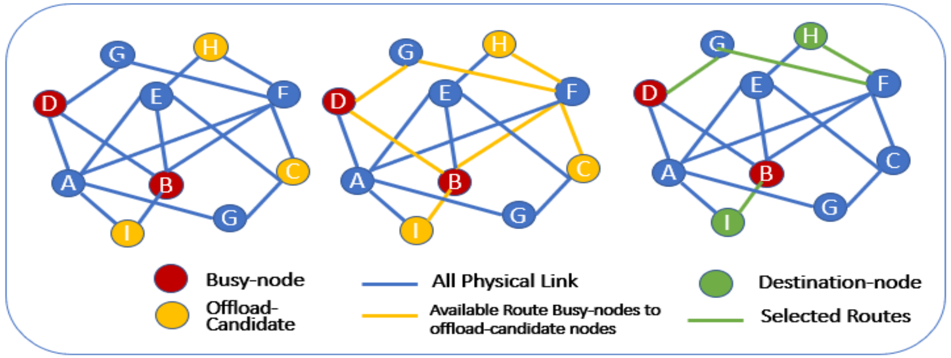
Based on **resource util** and **network stats**, DUST-Client is defined as:

- ’**Busy-nodes**’,
- ’**Offload-Candidate** nodes’,
- **’Offload destination**’ node,
- ’**none-offloading**’ nodes.

Goal: Proposed **controllable route algorithm**.

1. Leverage data sourced from DUST Database to facilitate DUST-Manager in identifying nodes.
2. Optimization engine evaluates all routes between each busy to destination node ➔ selects the minimum cost destination nodes



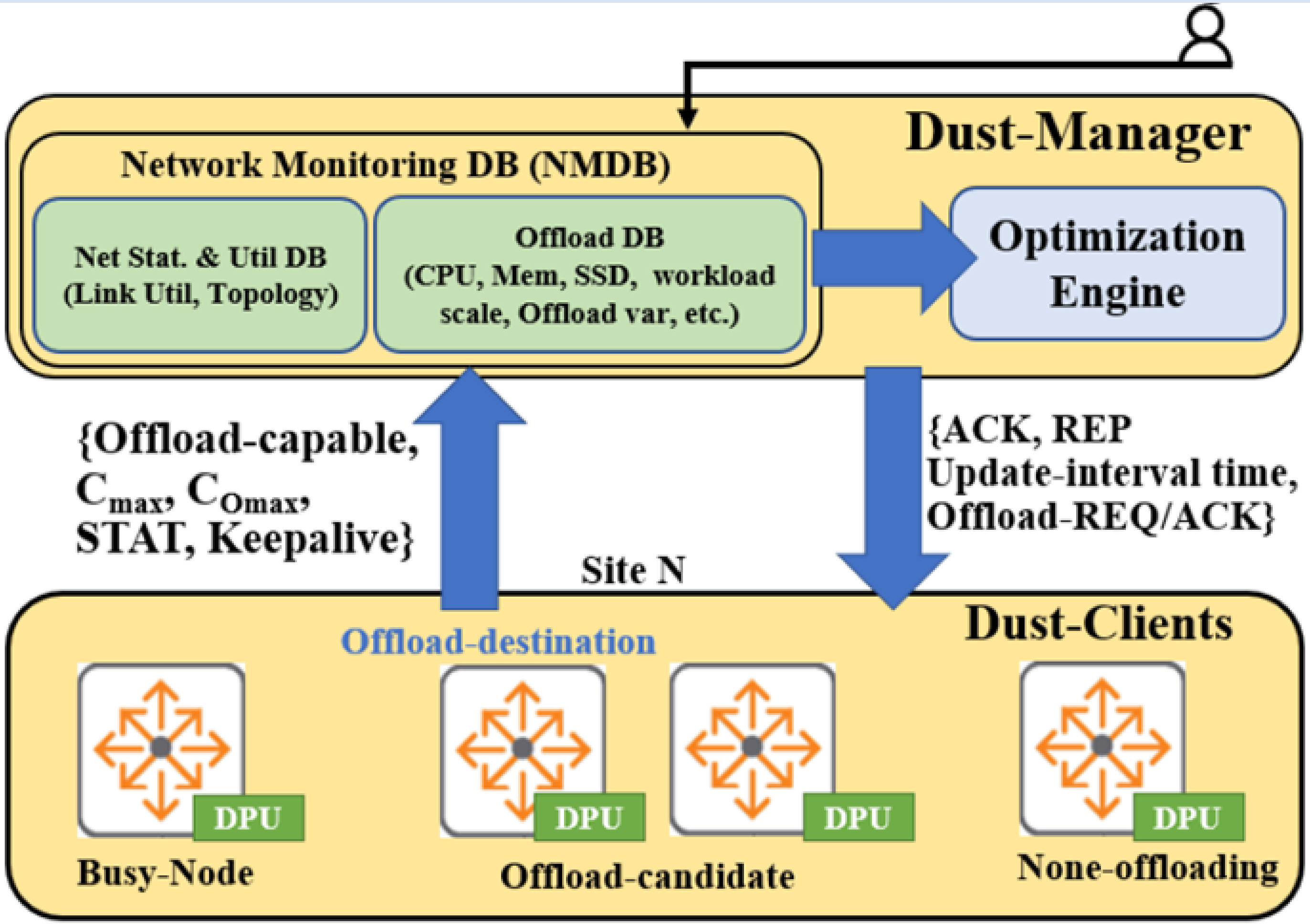


DUST System Nodes and Workflows

Post-offloading Process in DUST:

Following a successful offloading, designed to uphold system performance while simultaneously monitoring the health status of the offloaded workloads

- **QoS Guarantees**
- **Offload-destination Node Status**



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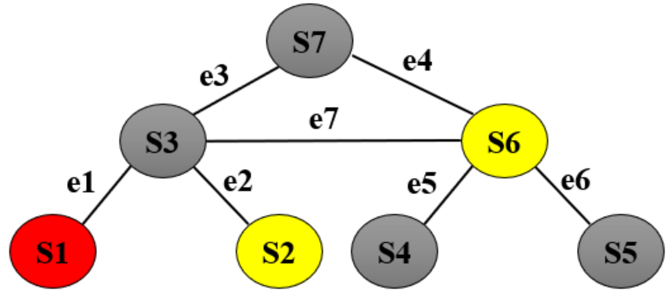
Optimization Algorithm: ILP Formulation



Variables: Max utilized capacity of a node being Busy-node ; Capacity to be considered as offload-candidate node below

$$Cmax\ (\%) \quad , C_b \geq C_{max}$$
$$Comax\ (\%) \quad , C_o \leq CO_{max}$$

Variables: Minimum Response time between node i to j, Monitoring data Di, Link utilization Luij

$$Tr_{i,j} = \frac{D_i(\text{Mb})}{Lu_{i,j}(\text{Mbps})}$$
$$Tr_{i,j}(r_k) = \sum_{\forall e \in r_k} \left(\frac{D_i}{Lu_e}(sec)\right) \quad \forall i \in V_b, \forall j \in V_o, \quad \forall r_k \in p$$

Objective: objective function β of minimizing response time for every selected decision variable

$$\text{Minimize} \quad \beta = \sum_{i \in V_b} \sum_{j \in V_o} x_{ij} * T_{rmin,i,j}$$

Capacity to offload from every busy node ∀i ∈ Vb
Available Capacity of every offload Candidate node ∀j ∈ Vo

$$Cs_i = C_i - C_{max} \quad \forall i \in V_b$$
$$Cd_j = CO_{max} - C_j \quad \forall j \in V_o$$

Constraint for ∀i ∈ Vb to fully offload the overloaded all extra capacity after Cmax (%)

$$\sum_{j \in V_o} x_{ij} = Cs_i \quad \forall i \in V_b$$

Constraint for ∀j ∈ Vo to not overload the selected destination node after monitoring placement

$$\sum_{i \in V_b} x_{ij} \leq Cd_j \quad \forall j \in V_o$$

Heuristic Algorithms

- **Heuristic Model:** Offload-destination node being selected merely from any available next-hop node of Busy-node, if exists.

- **Goal**: Solving the minimum cost offload problem in large-scale networks in a time-efficient manner by reducing the computational complexity.

- **Heuristic Failure Rate:** defined as amount of monitoring data failed to be offloaded with heuristic node selection to the total of resources required to be offloaded at any given network state.

$$HFR(\%) = \frac{\sum_{i \in V_{hb}} Cse_i}{\sum_{i \in V_{hb}} Cs_i} * 100$$

Algorithm 1: Heuristic Algorithm of min-cost problem

```
for every node k ∈ V of graph G = (V, E) and node capacity C_k do
    Determine set of Busy nodes, V_hb = {V_hb0, V_hb1, ..} if C_k ≥ C_max
    for every Busy node i ∈ V_hb do
        Determine set of Offload-candidate nodes,
          V_ho = {V_ho0, V_ho1, ..}, including every node j if C_j
          ≤ CO_max and within shortest path of max-hop=1 to a
          given Busy node V_hbi
        Calculate Cs_i = C_i - C_max
        for every Offload-candidate node j in set V_ho , calculate
          Cd_j = CO_max − C_j do
            Define continuous optimization decision variable X_ij
              for every given Busy node i and within its
              Offload-candidate nodes set V_ho do
                Minimize β (Equation 3) for defined heuristic set
                  of nodes and X_ij
```

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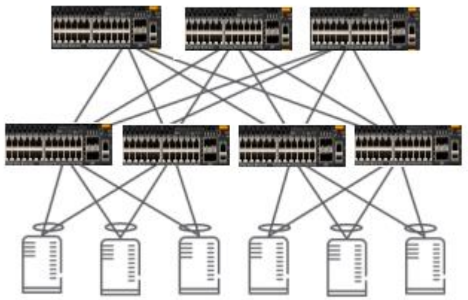
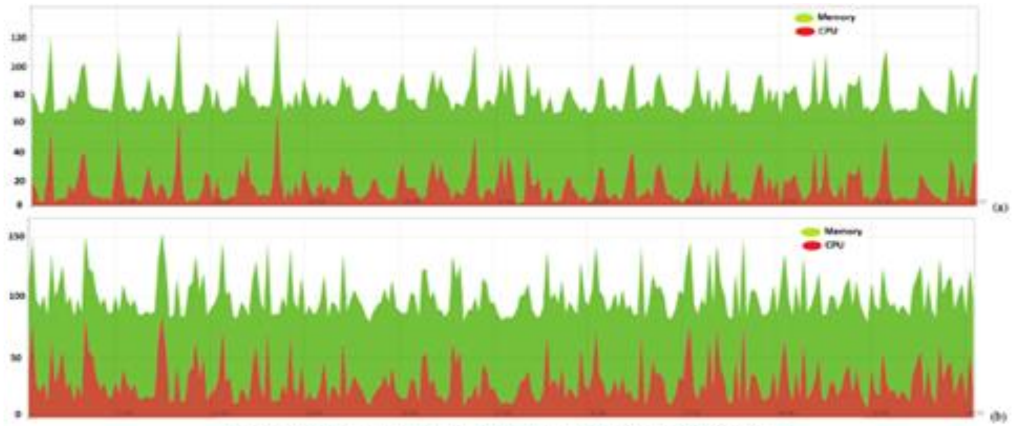
Performance Evaluations



Testbed:

- Real prototype with a VxLAN data center spine/leaf topology and high-performance ToR commercial enterprise switches, installed 10 monitoring agents.



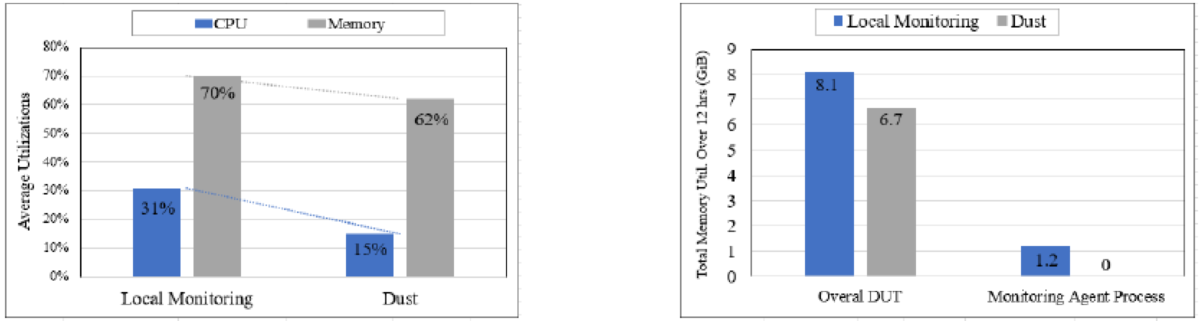
Average resource's Utilization (a) Dust (b) Local Monitoring

Experimental Parameters:

- Performance comparison and resource utilization between DUST (where user-defined monitoring agents were offloaded) and local monitoring.

Results:

- By average, 52% and 12% of CPU and memory saving by offloading, respectively.
- indicates that monitoring workloads are perfect offloading candidates for network switches



(a) Avg. resource utilization.

(b) Total resource utilization.

Memory and CPU resource utilization comparison in DUST and local monitoring.

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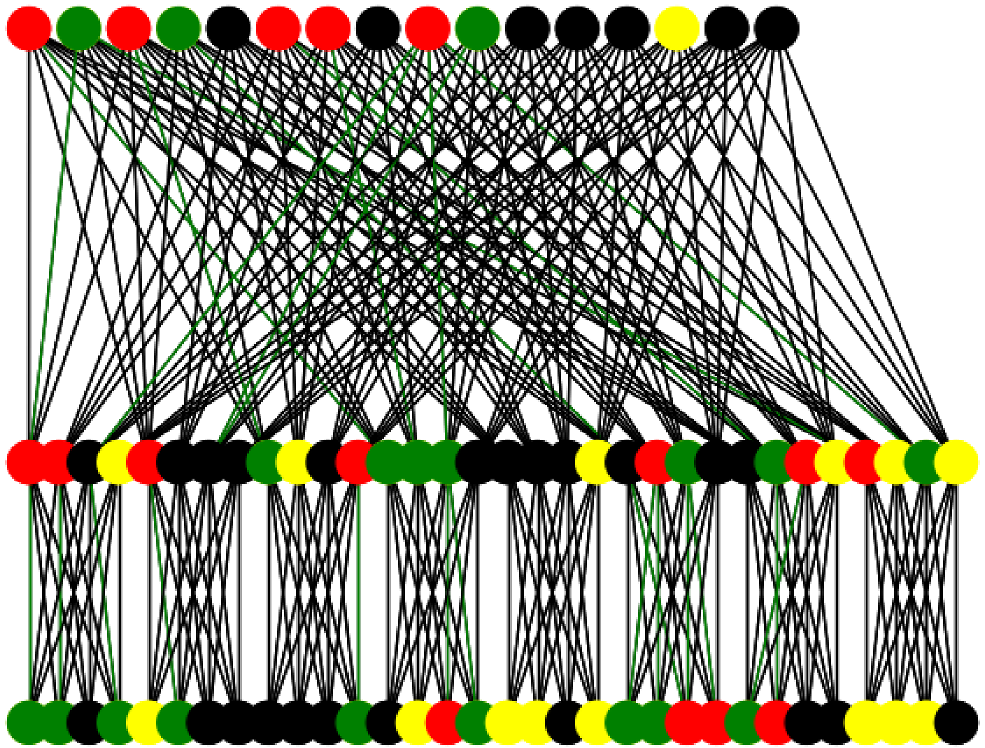
Fat-tree Topology Monitoring Placement

Testbed: A simulator implemented by using the Gurobi optimization toolkit - model **fat-tree** topology.

Goal: Addressing the scalability of our optimization algorithms in large-scale networks.

- **Busy node (red)**
- **Offload candidate (yellow)**
- **Destination node (green)**
- **Controllable data route (green edges)**

Flexible Offloading is supported**.**



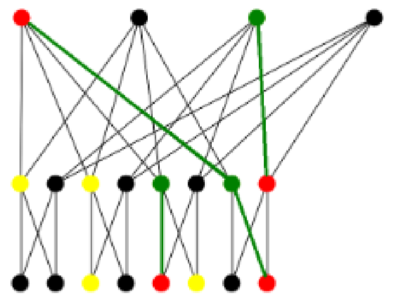
DUST Scalability Analysis

k-port	Nodes	Edges
4	20	32
8	80	256
16	320	2048
64	5120	131072

- *Small-Scale Network Evaluation*
  - Defined as a network, data center pod, or network zone comprising 20 or fewer network nodes (equivalently represented as a three-level 4-k port fat-tree topology with 20 nodes and 32 edges.)

- *Large-Scale Network Evaluation*
  - Defined as a network or data center architecture with more than 20 network nodes (equivalently represented as a three-level 8-k, 16-k, and 64-k ports fat-tree topology with 80, 320, and 5120 nodes along with 256, 2048, and 131072 edges, respectively.)

Small-Scale Network Evaluation

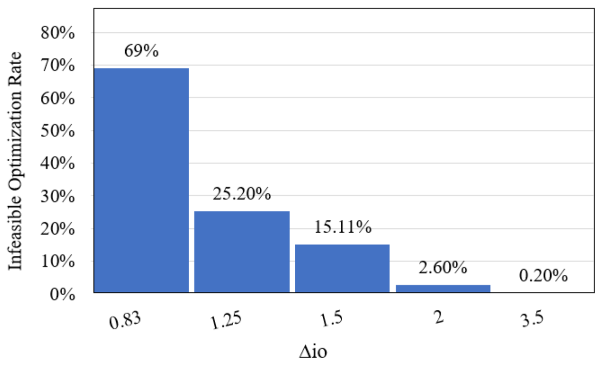


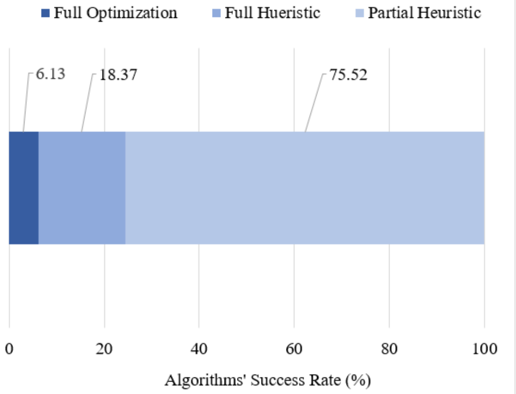
Testbed: Fat-tree 4-K three-level data center over 1000 iterations.

- Benchmark for selecting optimal user-defined values of Cmax,COmax to improve the optimization efficiency

  ➔ reduce the impossible optimization rate (%).

$$\Delta_{io} = \frac{\Delta_o}{\Delta_b} = \frac{CO_{max} - x_{min}}{100 - C_{max}} \quad , \quad \Delta_{io} \geq K_{io}$$

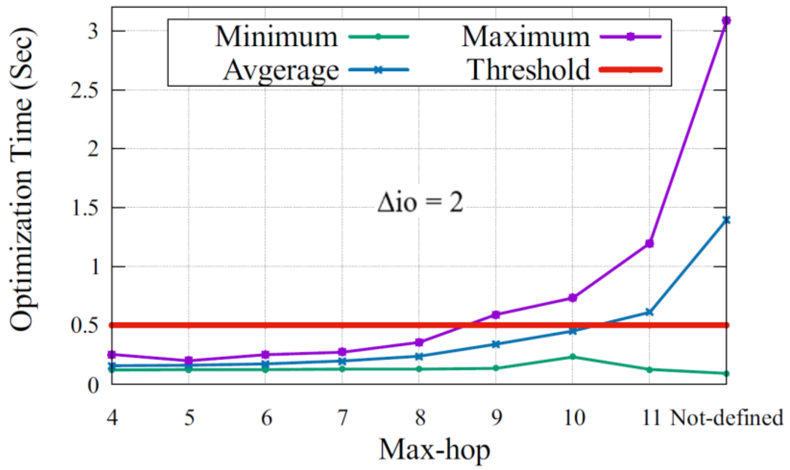




Results:

- Maximum optimization time remains below 3.5 sec

➔ Suitable for time-constrained applications.



Large-Scale Network Evaluation

Testbed: Fat-tree 8-K, 16-K three-level data center

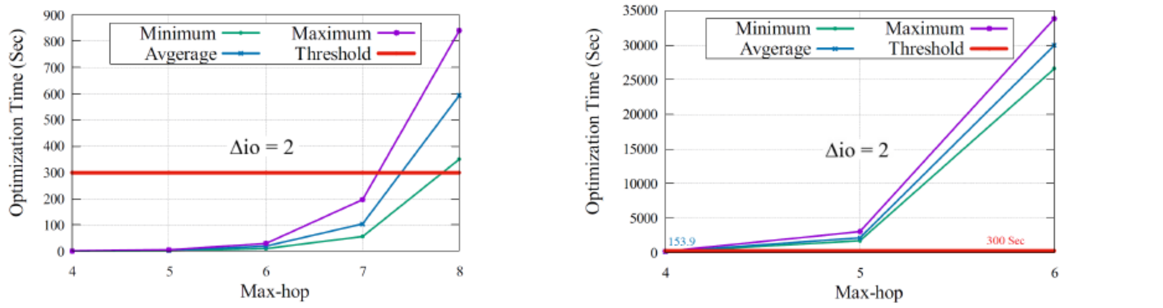
Results:

- max-hop with a threshold response time.
- Number of hops is significantly decisive and cost-effective.

As the network scale grows:

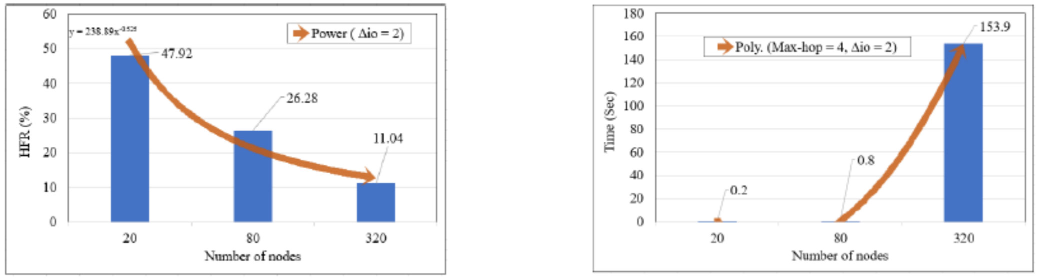
➔Average optimization time increases, HFR decreases

➔Heuristic algorithm gains an advantage over optimization.



(a) 8-k ports fat-tree network (b) 16-k ports fat-tree network

DUST ILP optimization computation time in large-scale network equivalent of (a) 8-k and (b) 16-k ports fat-tree.



(a) HFR (%) rate. (b) Average optimization time (sec).

scalability evaluation (a) HFR rate of heuristic algorithm (b) average computation time of optimization algorithm.

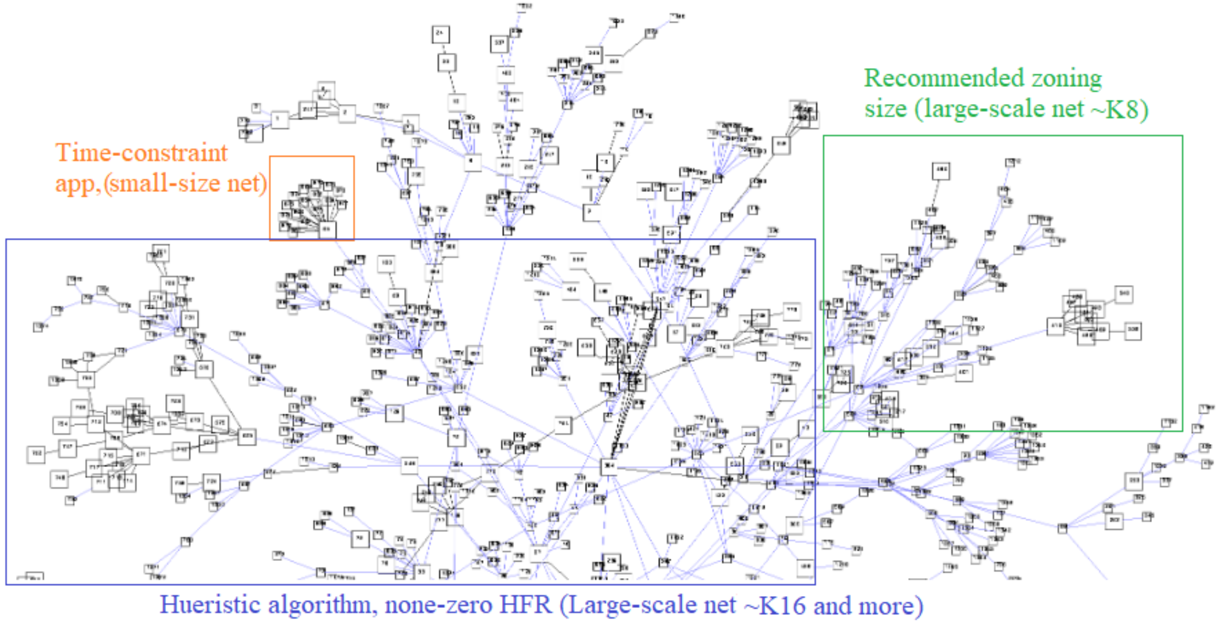
Scalability of Heuristic Algorithm

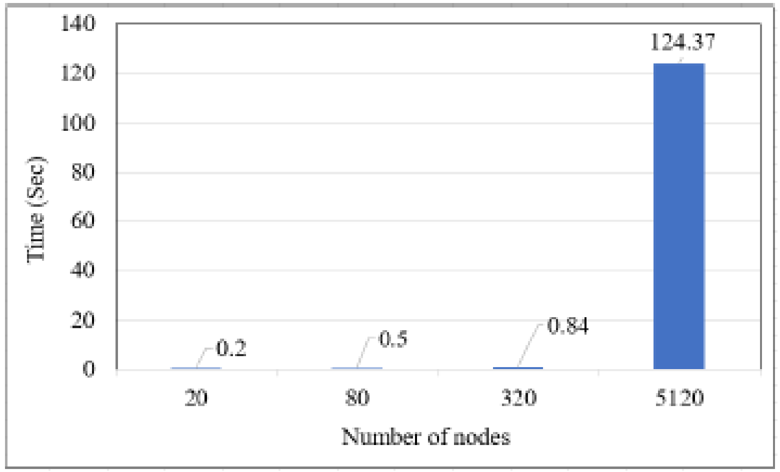
Dividing large-scale networks into zones with a max of 80 nodes

Results:

➔ **Optimization** cost of 0.8 sec, max-hop of 7 nodes

➔ ***Heuristic algorithm*** For larger networks, 124 sec with 5120 nodes.





Scalability evaluation of heuristic algorithm

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Conclusion

- **Distributed Resource and Traffic Awareness** network in-device monitoring
  - **Hardware agnostic** by harnessing available compute resources of network,
  - Supporting network monitoring for **low-profile switches** over remote offloading.
  - **Offloading decision** is central while **monitoring** is distributed
  - Comprehensive **system-level** solution with **node designation** and **workflows** for optimized distributed offloading
  - **Dynamic** & **flexible offloading** with a **controllable route** solution

- Optimized distribution based on network-defined **constraints**, targeting **minimum response time** to mitigate the compute vs connectivity trade-off
- Mathematically formulated the optimal relocation of computations as an ILP, along with a **heuristic algorithm,** addressing the **scalability** concerns associated with the **computational complexity of optimization**

Future Work

- DUST-Manager to integrated with large-scale and cloud-based network providers e.g., **HPE GreenLake, AFC**, AMD Pensando **Policy Service Manager (**PSM) **; render a one-stop solution**
- Facilitating **dynamic policy updates** by interacting with policy managers
- DUST-Client to integrate with **DSS switch** equipped with a Smart ASIC e.g. **AOS-CX 10000**
- Applicable to **broader applicability** than service telemetry, finding relevance and utility in diverse **use cases and network services**.
- **AI** Improvement for **optimization model** and **offloading workload; traffic engineering**

Thank You!

Questions?

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Complexity Analysis:

ILP Optimization vs. Heuristic Algorithm:	
p: feasible routes between each desired pair of nodes {i,j},	
maximum |p| : order of k^2 between each node pair (k-port fat-tree)	
F(|p|): time complexity of moving data between nodes.	
Assuming : all k(k + 1) nodes being either Busy nodes or Offload-candidate nodes	
ILP Optimization Complexity	**Heuristic algorithm Complexity**
F(|p|) : $k^4(k+1)^2 \approx k6$	F(|p|) : $k^2(k+1) \approx k3$