# LiteLab: Efficient Large-scale Network Experiments

Liang Wang, Arjuna Sathiaseelan, Jon Crowcroft, Jussi Kangasharju*
Presented by Otto Waltari*

University of Cambridge, UK
University of Helsinki, Finland*

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# Motivation - Challenges

- Deploying network systems in developing regions is a very difficult task, even for those mature and well-tested systems.
- There are both technical and non-technical barriers such as
  - extreme environment,
  - inefficient transportation,
  - lack of local technicians,
  - limited equipment,
  - poor infrastructure,
  - and many other socio-economical challenges.

# Motivation - Requirements

- ”Trial and error” method will simply fail in the rural context due to its high cost. To reduce both investment risk and maintenance overhead, we need to obtain a comprehensive understanding of the system.
- Due to the large parameter space, researchers usually need to run thousands of experiments with different parameter combinations.
  - Replayability is critical in modern network experiments.
  - Flexibility in the platform: easy to configure and extend.
  - Take advantage of the computation and storage resources in the cluster.
  - Reduce the experiment complexity and speeds up experiment life-cycle.
  - Provide satisfying accuracy.

# Background – Multiple Options

- There are generally two methodologies to evaluate a system: model-based evaluation and experiment-based evaluation.

- Model-based: apply analytical models, mathematically tractable; but the complexity may explode as a system becomes more complicated.

- Experiment-based: take advantage of the ever-growing computation power to explore the problem space; suitable for large and complex systems; simulation, emulation, and real testbed.

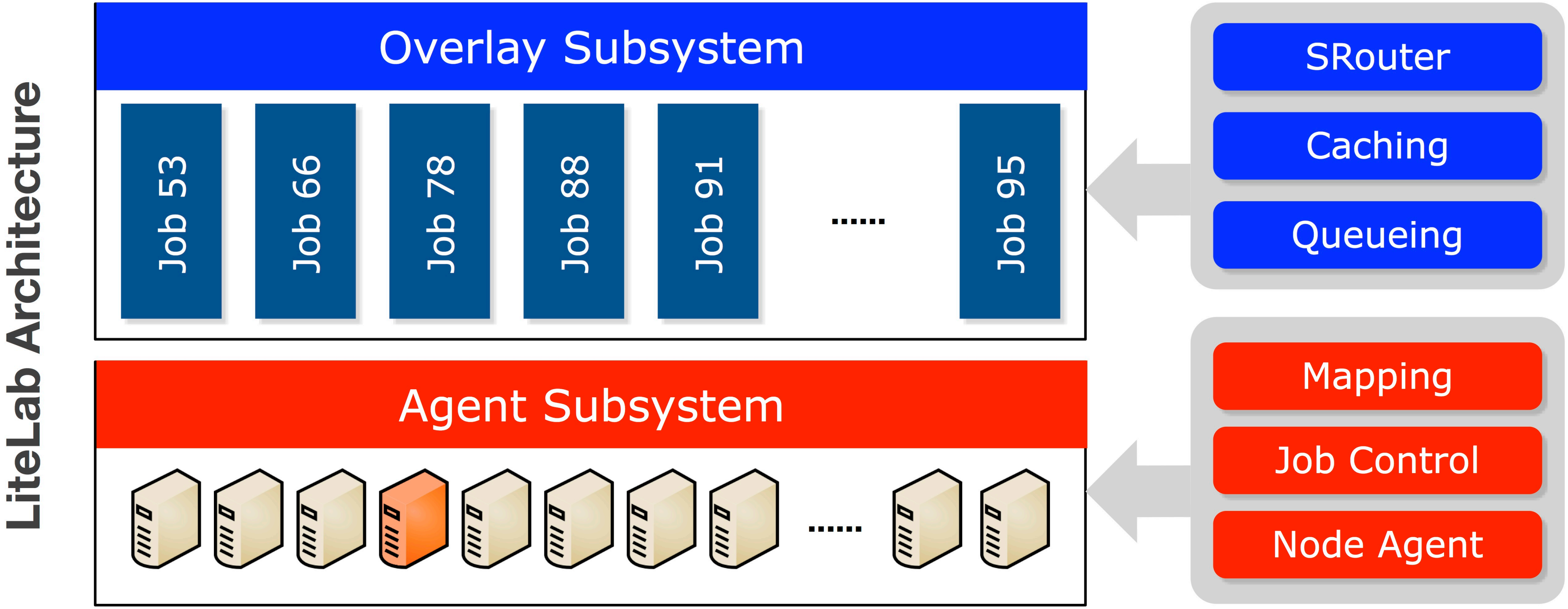
# Three Exemplars

- Simulators: NS2 and NS3
  - one of the most famous among general purpose simulators;
  - has many tunable parameters to allow more realistic settings;
- Emulator: Emulab
  - tries to integrate simulation, emulation and live network into a common framework; the configuration and setup can be quite complicated.
- Internet: PlanetLab
  - a platform for live network experiments. The traffic goes through the real Internet and is subject to real-life dynamics.
- Many others, specialised in different.

# LiteLab Architecture

- LiteLab consists of two subsystems: *Agent Subsystem* and *Overlay Subsystem.*
- All experiments are *jobs* in LiteLab and are defined by a job description archive provided by a user.
- A user submits the job to LiteLab which processes the job description archive, determines needed resources and allocates necessary physical nodes from the available nodes.
- LiteLab informs the selected nodes and deploys an instance of the Overlay Subsystem on them.
- LiteLab starts the experiment, and the logs are saved.

# LiteLab Architecture



# Agent Subsystem

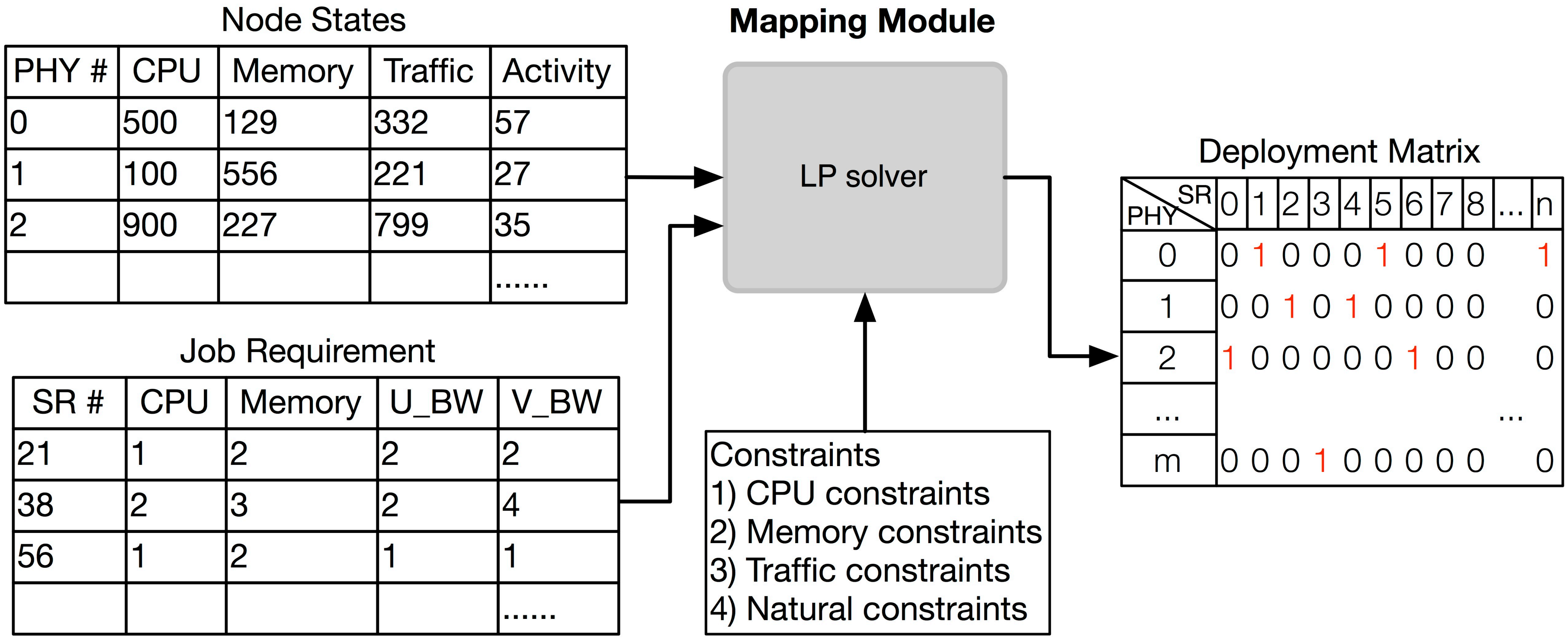
- The Agent Subsystem provides a stable and uniform experiment infrastructure. It hides the communication complexity, resource failures and other underlying details from the Overlay Subsystem.

- There are three main components in Agent Subsystem:
  - **NodeAgent** represents a physical node;
  - **JobControl** manages all the submitted jobs in LiteLab;
  - **Mapping** maps virtual resources to physical resources;

# Resource Allocation – Static Mapping

- Resource allocation focuses on the mapping between virtual nodes and physical nodes, and it is the key to platform scalability.
- The mapping maximises the resource utilisation, guarantee there is no violation of physical capacity.
- Four metrics are taken into account as the constraints: CPU load, network traffic, memory usage and use of pseudo-terminal devices.
- The mapping is formulated as an optimisation problem.

# Static Mapping – Inputs and Outputs




Node States

| PHY # | CPU | Memory | Traffic | Activity |
|---|---|---|---|---|
| 0 | 500 | 129 | 332 | 57 |
| 1 | 100 | 556 | 221 | 27 |
| 2 | 900 | 227 | 799 | 35 |
| | | | | ...... |

Job Requirement

| SR # | CPU | Memory | U_BW | V_BW |
|---|---|---|---|---|
| 21 | 1 | 2 | 2 | 2 |
| 38 | 2 | 3 | 2 | 4 |
| 56 | 1 | 2 | 1 | 1 |
| | | | | ...... |

Constraints
1) CPU constraints
2) Memory constraints
3) Traffic constraints
4) Natural constraints

Deployment Matrix

| PHY \ SR | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | ... | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | 0 |
| ... | | | | | | | | | | ... | |
| m | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | 0 |

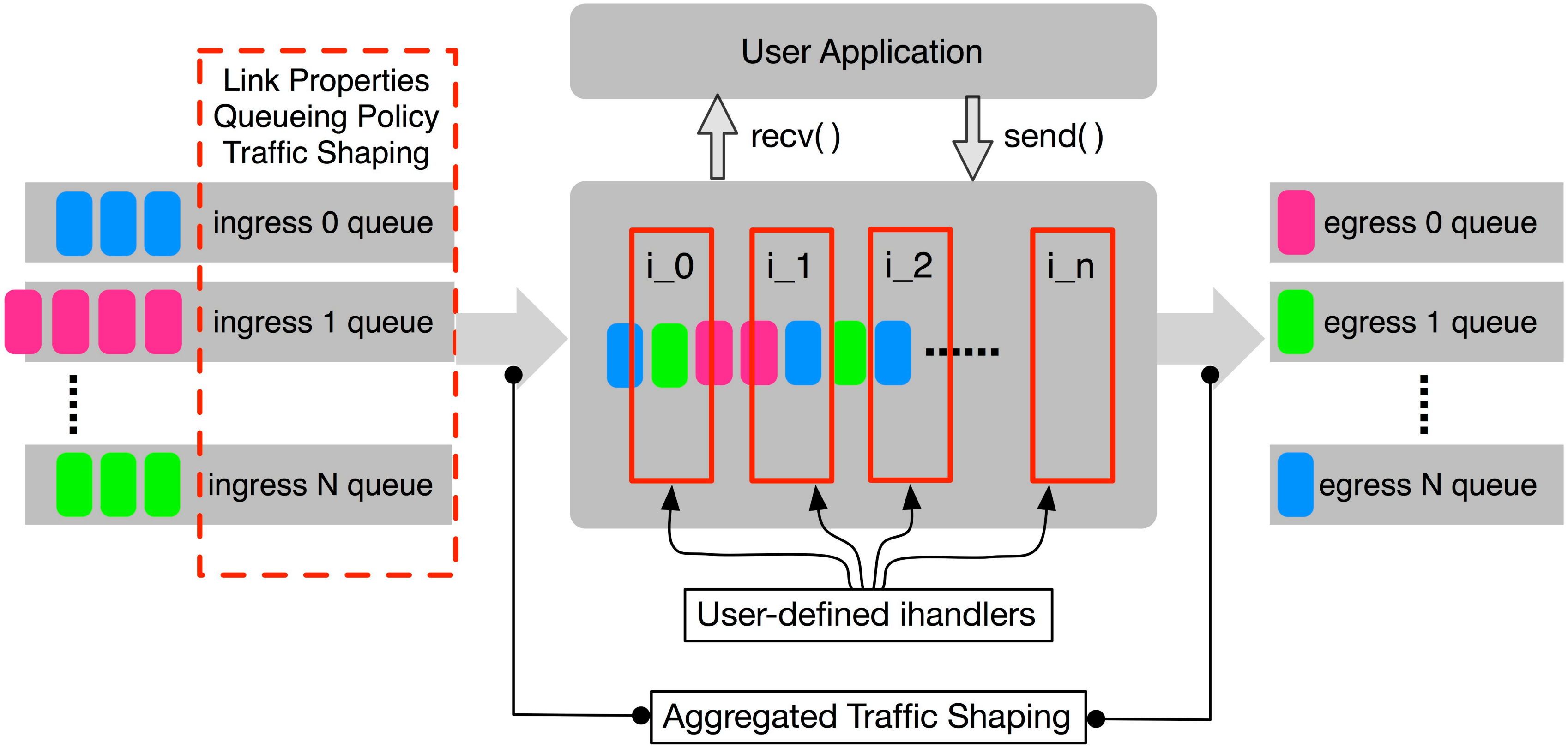
# Resource Allocation – Dynamic Migration

- The static mapping cannot efficiently handle the dynamics during an experiment. An overloaded node may impact the experiment results.
- Dynamic migration is implemented as a sub-module in NodeAgent. It keeps monitoring the on its host.
- If NodeAgent detects a node is overloaded, some tasks will be moved onto other machines without restarting the experiments.
- Migration is not able to completely mask the effects from other users, but can alleviate the worst problems.

# Overlay Subsystem

- Overlay Subsystem constructs an experiment overlay by using the resources from Agent Subsystem.
- One overlay instance corresponds to a job, therefore LiteLab can have multiple overlay instances running in parallel at the same time.
- The most critical component in Overlay Subsystem is SRouter, which is a software abstraction of a realistic router.

# Innards of SRouter



# Flexible Configurations

- Users can configure many parameters of SRouters, e.g., link properties (delay, loss rate, bandwidth), queue size, queueing policy(Droptail, RED), and so on.
  - Queues: iqueue, equeue, cqueue;
  - Processing Chain: similar concept as the chains of rules in *iptables*;
  - VID: a logical ID (VID) to identify a Srouter, neutral to any naming scheme;
  - Routing: is based on VID, can plug in different routing algorithms;
  - User Application: ihandler provides a passive way to interact with SRouters.

# Evaluation - Accuracy

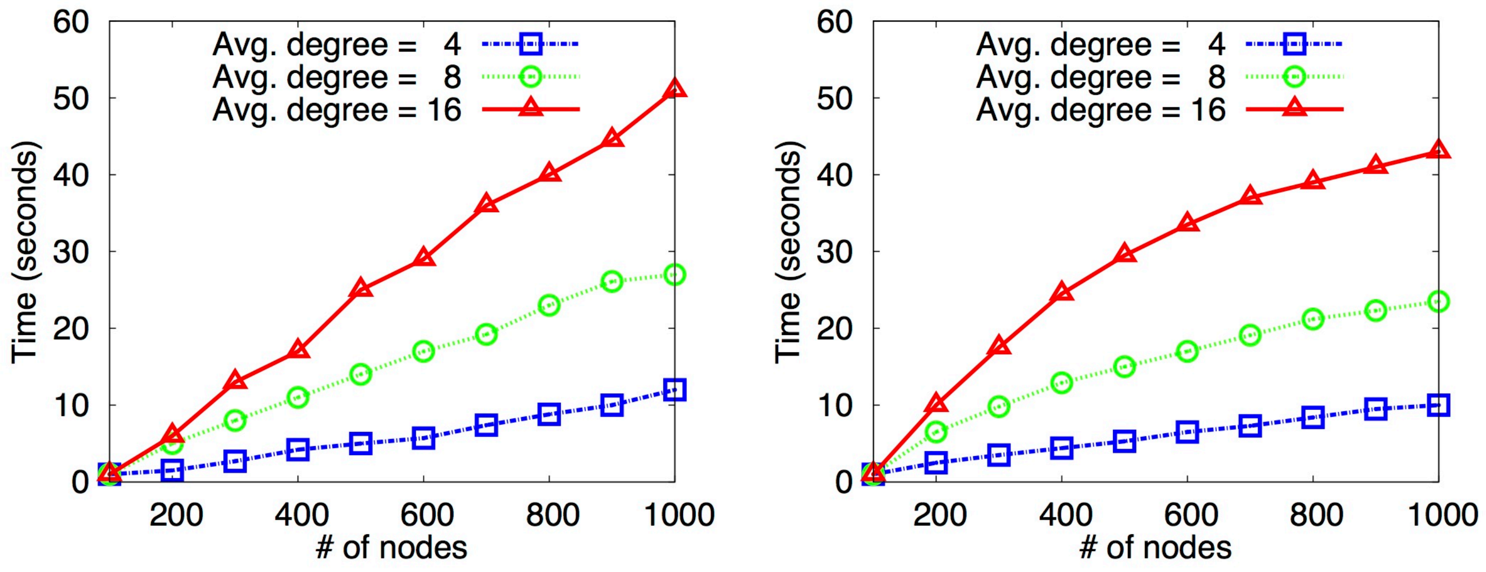
TABLE I: Accuracy of SRouter's bandwidth control as a function of link bandwidth and packet size.

| Bandwidth (Kbps) | Packet Size | Observed Value | |
|---|---|---|---|
| | | bw (Kbps) | % err |
| 56 | 64 | 55.77 | 0.41 |
| | 1518 | 57.62 | 2.89 |
| 384 | 64 | 382.56 | 0.37 |
| | 1518 | 387.96 | 1.03 |
| 1544 | 64 | 1539.23 | 0.31 |
| | 1518 | 1546.32 | 0.15 |
| 10000 | 1518 | 9988 | 0.12 |
| 45000 | 1518 | 44947 | 0.12 |

TABLE II: Accuracy of SRouter's delay at maximum packet rate as a function of 1-way link delay and packet size.

| OW Delay (ms) | Packet Size | Observed Value | | |
|---|---|---|---|---|
| | | RTT | stdev | % err |
| 0 | 64 | 0.190 | 0.004 | N/A |
| | 1518 | 0.221 | 0.007 | N/A |
| 5 | 64 | 10.200 | 0.035 | 2.00 |
| | 1518 | 10.230 | 0.009 | 2.30 |
| 10 | 64 | 20.212 | 0.057 | 1.06 |
| | 1518 | 20.185 | 0.015 | 0.92 |
| 50 | 64 | 100.209 | 0.060 | 0.21 |
| | 1518 | 100.218 | 0.031 | 0.22 |
| 300 | 64 | 600.189 | 0.083 | 0.03 |
| | 1518 | 600.273 | 0.034 | 0.04 |

# Evaluation - Scalability




(a) Random (Erdős-Rényi) (b) Scale-free (Barabási-Albert)

Fig. 4: Time to construct synthetic networks of different type.

Figure 4 shows that the time to construct network increases linearly as the number of nodes increases in random networks. However, the growth of time is slower in scale-free networks because the nodes with high degree dominate the construction time.

# Heuristic in Resource Allocation

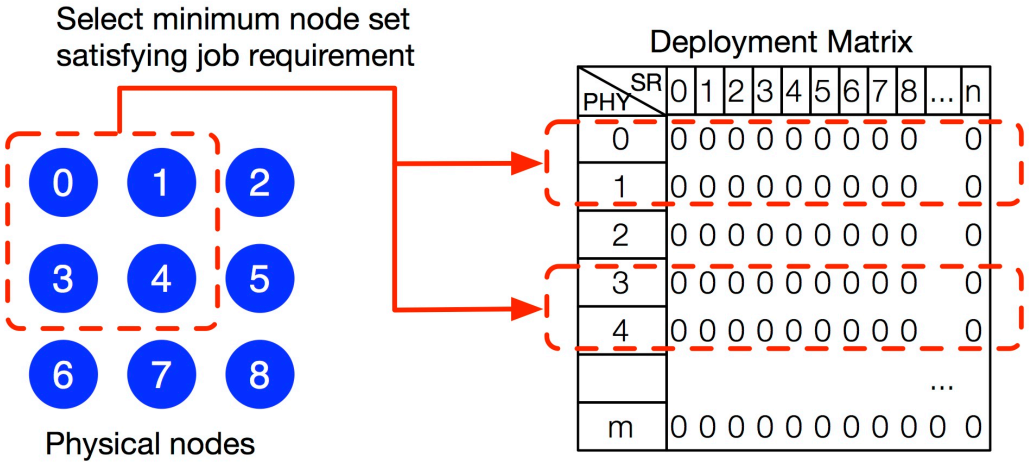



Fig. 5: Reduce deployment matrix size by selecting minimum physical node set that satisfies the job requirement.

**Input:** job requirements **R**, physical nodes **L**
**Output:** minimum physical node set **S**
Calculate overall job requirement **R**
Order nodes from lightest to heaviest load into **L**
**foreach** *node N in L* **do**
  Add **N** to **S**
  Calculate capacity of **S**: **C**
  **if** $R < C$ **then**
    Solve LP
    **if** *optimal solution exists* **then** break
    ;
    **else** $\mathbf{R} \leftarrow 2 \times \mathbf{R}$ ;
  **end**
**end**

**Algorithm 1:** Heuristic to improve mapping efficiency

# Discussion

- LiteLab aims at a flexible, easy-to-deploy experiment platform and in this goal, it makes tradeoffs between accuracy and performance.
- LiteLab cannot completely eliminate external effects from other processes running on the test platform.
- SRouter's processing power is another limitation as it can only process about 10000 packets per second. Adding more user-defined modules will further slow down SRouter.

# Conclusion

- LiteLab which aims to reduce the deployment risk by providing a light-weight platform for both network scientists and practitioners to efficiently evaluate their novel system designs.
- LiteLab combines the benefits from both emulation and simulation: ease of use, high accuracy, no complicated hardware settings, easy to extend and interface with user applications, etc.
- LiteLab is open sourced and is available for download for others.

Thank you!

Questions?