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Applying Hadoop Cloud Computing Technique to Optimal Design of Optical Networks

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Outline

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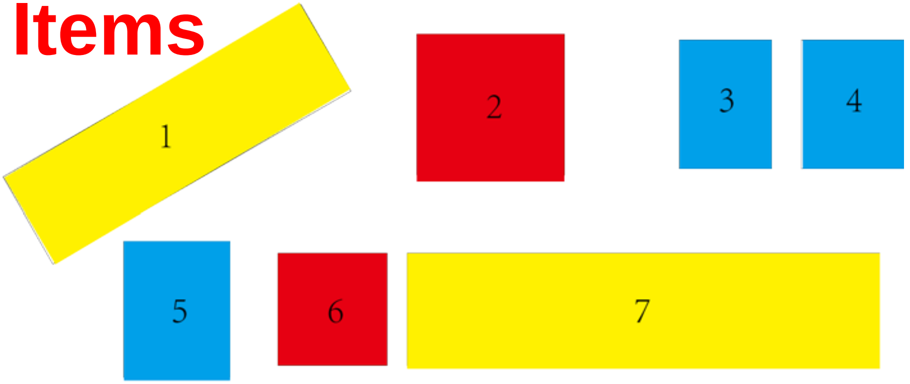
- Background
- Hadoop cloud computing system
- Optimization for optical networks with Hadoop system
- Simulation and performance analyses
- Conclusions

Background

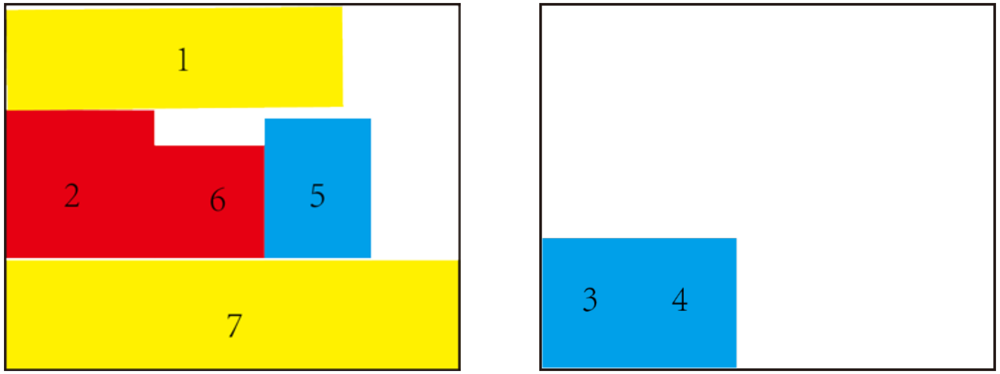
- **Bin-packing problem**
  - → **A classical NP-hard problem that targets to find a minimal number of bins to pack all the (irregular) items**

Items



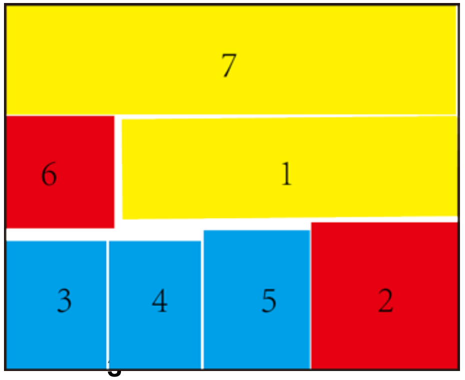
Strategy	Sequence
#1	7,2,6,5,1,3,4
#2	3,4,5,2,6,1,7

Sequence 1



Bin 1 **Bin 2**

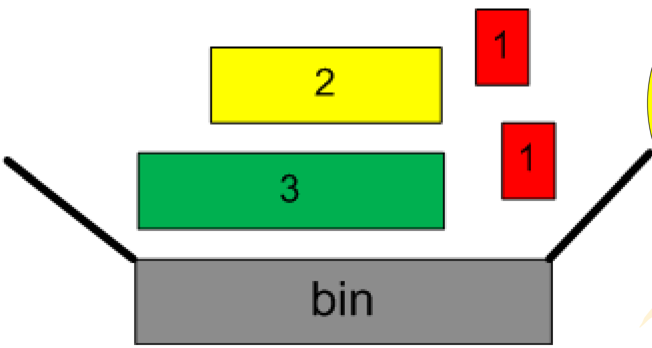
Sequence 2

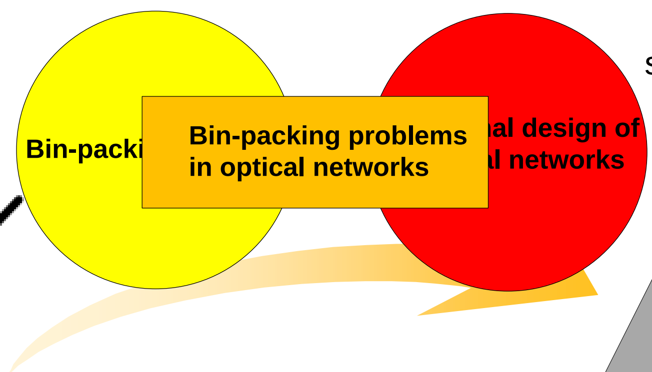


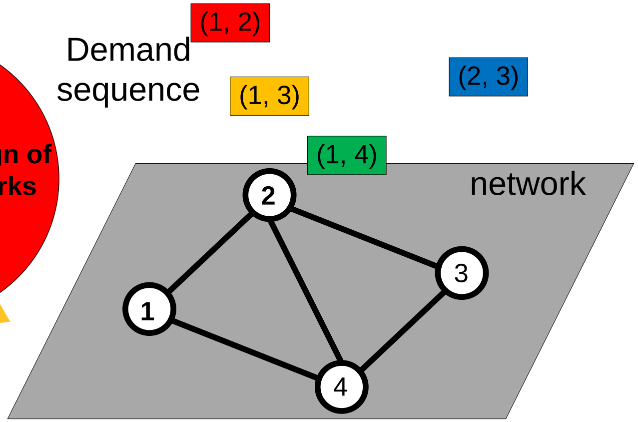
Bin 1

Background (cont's)

- **Bin-packing problems in optical networks**
  - → **Energy minimization problem, shared backup path protection (SBPP) planning problem, adaptive FEC assignment problem, etc.**
  - → **For a traffic demand, in addition to its size (i.e., traffic volume), we also need to consider its shape (i.e., the route of the demand) when packing (i.e., serving) them**
  - → **For these research problems like serving network traffic demands, the simple largest-smallest ordering strategy cannot guarantee good performance**







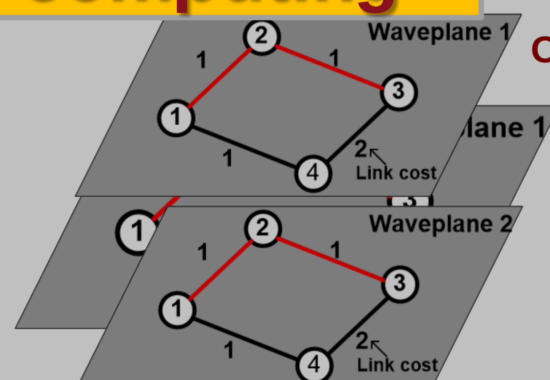
Background (cont's)

- **Impact of demand sequence**
  - → To achieve good performance, the most straightforward strategy is to randomly shuffle the demand sequences
  - → Then implement an efficient heuristic algorithm for each of them and finally choose the one with the best performance
  - → A sh... ategy has been verified to be successful for the r... problem [1]

Parallel computing

Example

Demand Sequense 2
(1, 2) / (1, 3)
(2, 3)
(1, 2) / (1, 3)



Only one wavelength / Two wavelengths

However, it becomes *computationally intensive* and *time-consuming* if a huge number of shuffuled demand sequences are evaluated

[1] G. Shen, Y. Li, and L. Peng, "Almost-optimal design for optical networks with Hadoop cloud computing: ten ordinary desktops solve 500-node, 1000-link, and 4000-request RWA problem within three hours (Invited)," in Proc. *ICTON 2013*.

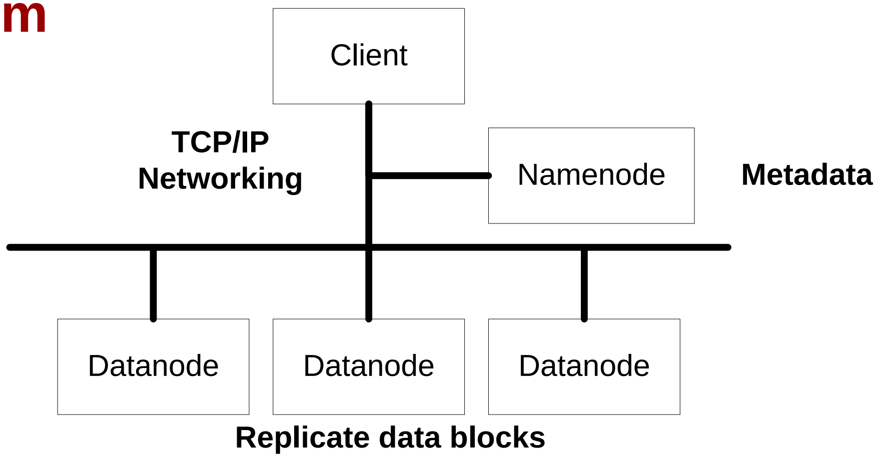
Hadoop cloud computing system

- **Features and advantages**
  - → Open source software framework
  - → Employ many low-end ordinary machines
  - → Provide high parallel computation capacity
  - → Cost effective

- **Key functional modules**
  - → Hadoop Distributed File System (HDFS)
  - → Map/Reduce process

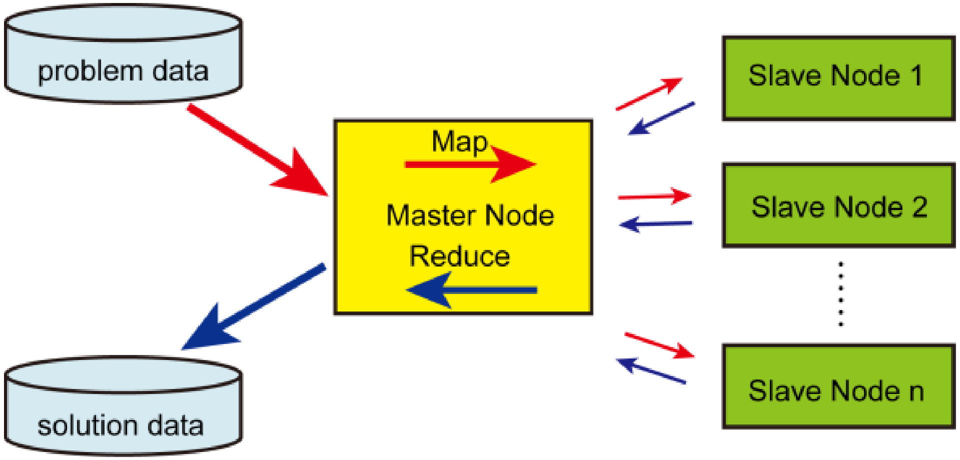
Hadoop cloud computing system

- **Hadoop Distributed File System (HDFS)**
  - → A highly fault-tolerant distributed file system designed for commodity hardware
  - → A HDFS instance typically includes a Namenode and many Datanodes
  - → Namenode is a coordinator and Datanodes provide storage for HDFS
  - → TCP/IP communication protocol employed for data transmission in the file system



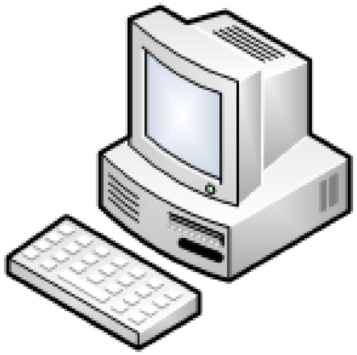
Hadoop cloud computing system

- **Map step**
  - → **Receive problem data**
  - → **Divide the problem into smaller sub-problems**
  - → **Distribute them to Slave nodes which will solve the sub-problems and feedback their obtained results to the Master node**
- **Reduce step**
  - → **Master node is employed to collect the answers to all the sub-problems and combine them in some way to form a final solution**



Hadoop cloud computing system

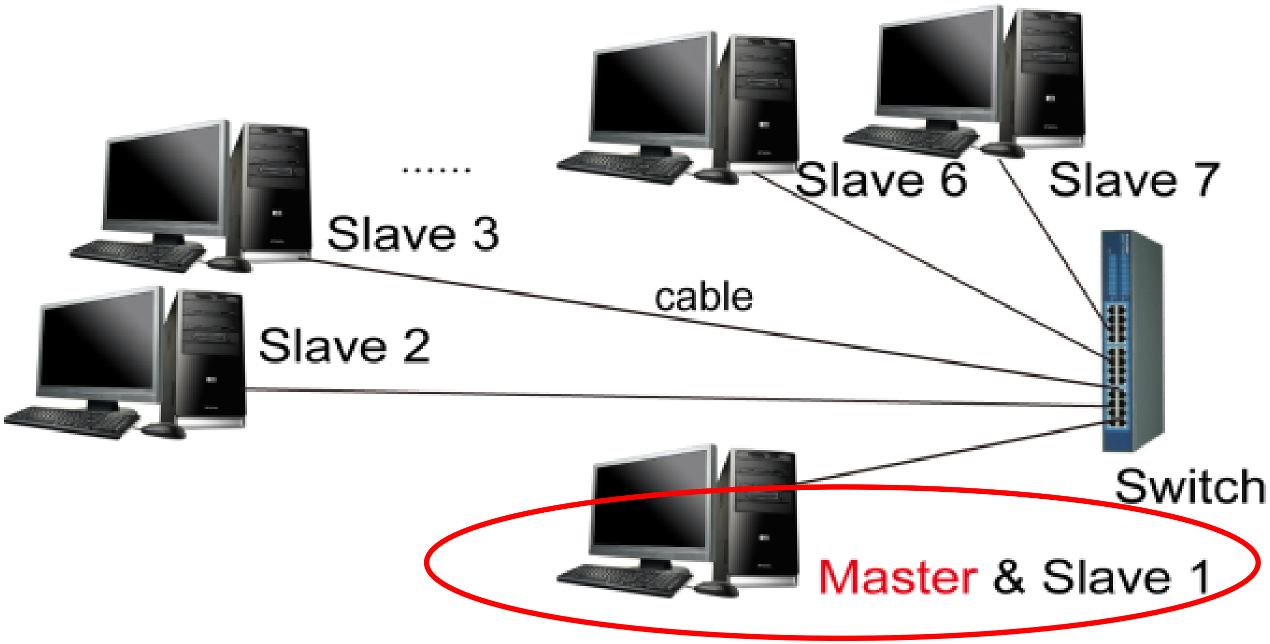
- **Hardware**
  - → **Lenovo YangTian T4900d (Dual cores 2.9-GHz CPU)**
- **Software**
  - → **Linux (Ubuntu 12.04 LTS)**
  - → **Hadoop-1.0.3**
  - → **JDK: Sun-java6-jdk**
  - → **SSH**



SSH

Hadoop cloud computing system

- **Seven ordinary desktops Hadoop system**
  - → **One master and seven slaves interconnected by a *switch***
  - → **All the computers have *2.9-GHz* dual cores with *2G* memory**
  - → ***Two reduces* on each slave node**



Optimization for optical networks with Hadoop system

- **Energy minimization problem [2]**
  - → **A "Follow the Sun, Follow the Wind" strategy for the IP over WDM network**
  - → **An efficient heuristic algorithm to minimize the total non-renewable energy consumption of the network**
  - → **Shuffling strategy**
    - → Shuffle the node pairs in a list to change their order, and recalculate non-renewable energy consumption
    - → Compare the results and select the least non-renewable energy as our final result

An example with shuffling strategy:

(a) Traffic matrix with serving order 1

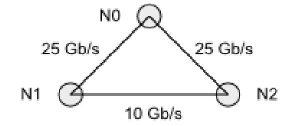
(b) Established virtual topology for serving order 1

(c) Traffic matrix with serving order 2

(d) Established virtual topology for serving order 2

Node pair	Traffic (Gb/s)
(N1, N2)	10
(N0, N1)	25
(N0, N2)	25

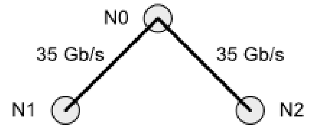
(a)



(b)

Node pair	Traffic (Gb/s)
(N0, N1)	25
(N0, N2)	25
(N1, N2)	10

(c)



(d)

[2] G. Shen, Y. Lui, and S. K. Bose, "“Follow the Sun, Follow the Wind” lightpath virtual topology reconfiguration in IP over WDM network," *IEEE/OSA Journal of Lightwave Technology*, vol. 32, no. 11, pp. 2094-2105, Jun. 2014.

Optimization for optical networks with Hadoop system

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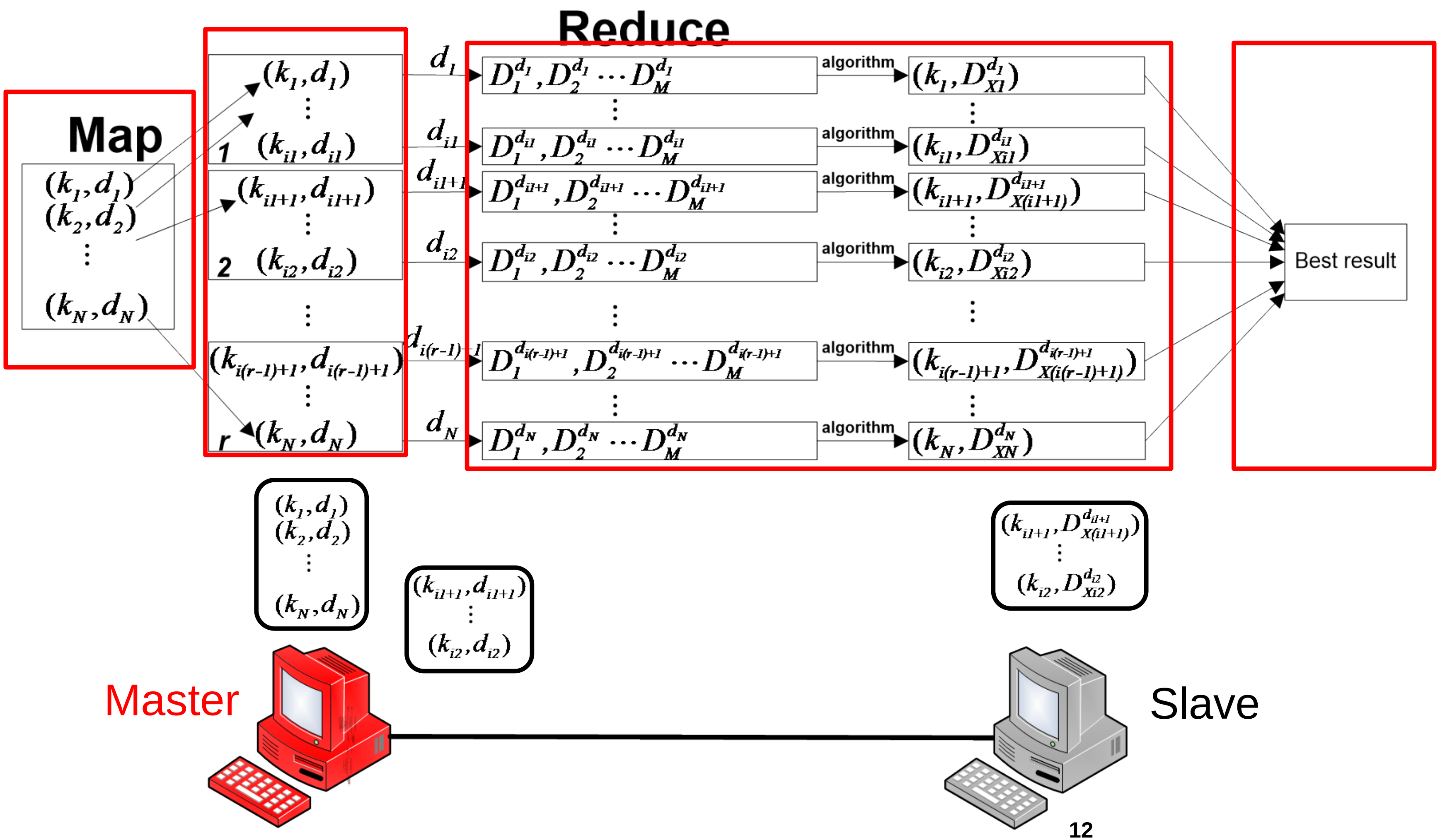
- **The diagram of Map/Reduce process**



Optimization for optical networks with Hadoop system

- ## Map/Reduce process
  - **Map:**
    - Generates a total of N key-value pairs (k_i, d_i), for each of which k_i and d_i are both set to be i, i.e.,k_i=d_i=i
    - The key-value pairs are forwarded to *r* Reduce functions for parallel computing
  - **Reduce:**
    - Each of the Reduce functions has N/r key-value pairs
      - For each key-value pair (k_i, d_i), we randomly shuffle the demand list M times with value d_i as a random seed.
      - Each of the shuffled demand sequences is then served by the heuristic "algorithm" to generate M results for each key-value pair (k_i, d_i)
    - We compare these results to choose the one with the best performance for each Reduce function
  - **Compare the best results of each Reduce function to obtain a final global optimum, i.e., "*best result*"**

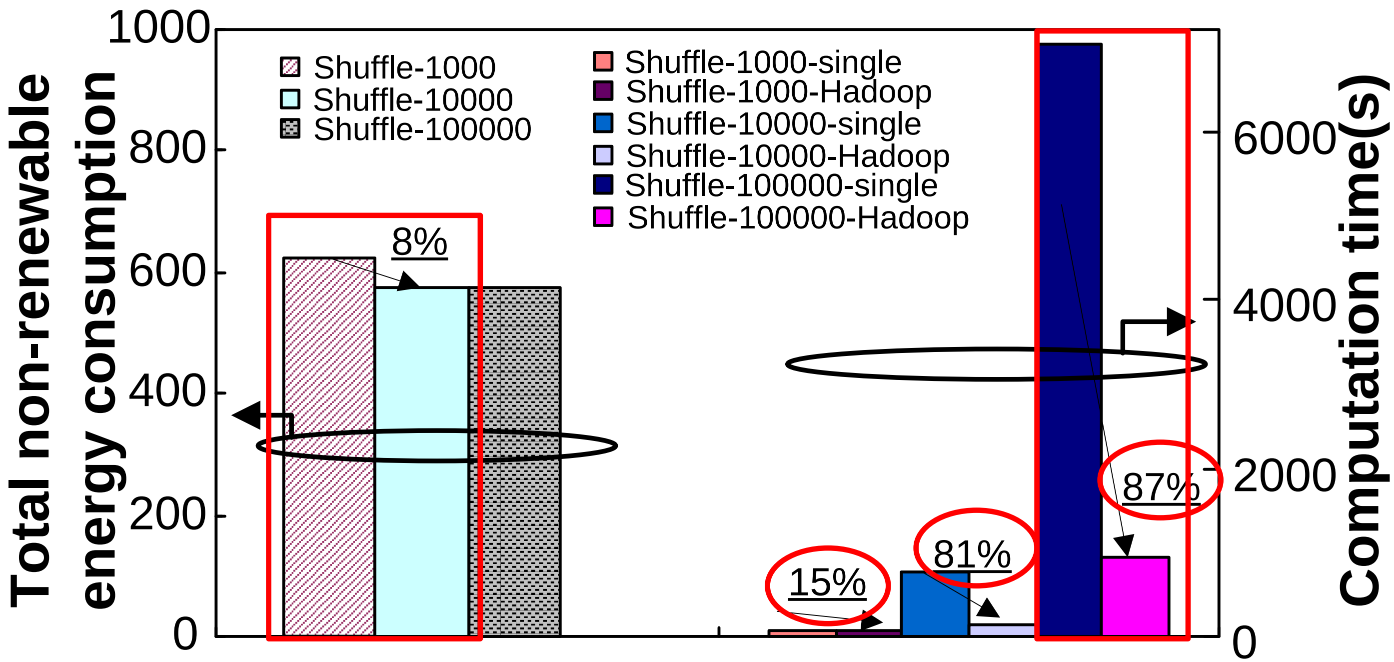
The whole process evaluates a total of $\boldsymbol{N \cdot M}$ shuffled demand sequences to obtain the final best solution

Simulation conditions

- **Map/Reduce process**
  - → **M:** ***10***
  - → **N:** ***[100, 10,000]***
  - → **Shuffled demand sequences:** ***[1,000, 100,000]***
- **Energy minimization problem**
  - → **Test network case: 43-link US backbone network (USNET)**
  - → **Traffic demand between each node pair is randomly generated within the range of *[10, 30]* Gb/s**
  - → **The total non-renewable energy consumption is shown for USNET on May 2th, 2014**

Performance analyses

- **Total non-renewable energy consumption and computation time (USNET)**



- **When the number of shuffled demand sequences increases from 1,000 to 10,000, the total non-renewable energy consumption decreases 8%.**
- **Hadoop system can significantly shorten computation time for the same number of shuffled demand sequences**
- **Hadoop system is more efficient for a larger optimization problem**

Optimization for optical networks with Hadoop system

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- **SBPP network planning problem [3]**
  - → **Distance adaptive routing and spectrum assignment (RSA) for SBPP-based elastic optical networks**
  - → **An efficient heuristic algorithm based on spectrum window planes (SWPs) to minimize the maximal number of required frequency slots (FSs) in the entire network**
  - → **Shuffling strategy**
    - → Shuffle the node pair list many times
    - → Run the heuristic algorithm for each shuffled node pair list to obtain the required number of FSs, FS_i
    - → Finally compare the obtained FS_i to choose the one with the smallest number, i.e., $FS_{min} = min\ \{FS_i\}$.

[3] C. Wang, G. Shen, and S. K. Bose, "Distance adaptive dynamic routing and spectrum allocation in elastic optical networks with shared backup path protection," *IEEE/OSA Journal of Lightwave Technology*, vol. 33, no. 14, pp. 2955-2964, Apr. 2015.

Simulation conditions

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- **SBPP network planning problem**
  - → **Test network case: COST239 network**
  - → **Frequency slots in each link: *400 FSs***
  - → **Bandwidth granularity of each FS: *12.5 GHz***
  - → **Modulation format set: BPSK, QPSK, 8-QAM**
  - → **The bandwidth request between each node pair is uniformly randomly distributed within a range of *[10, 400] Gb/s***

Performance analyses

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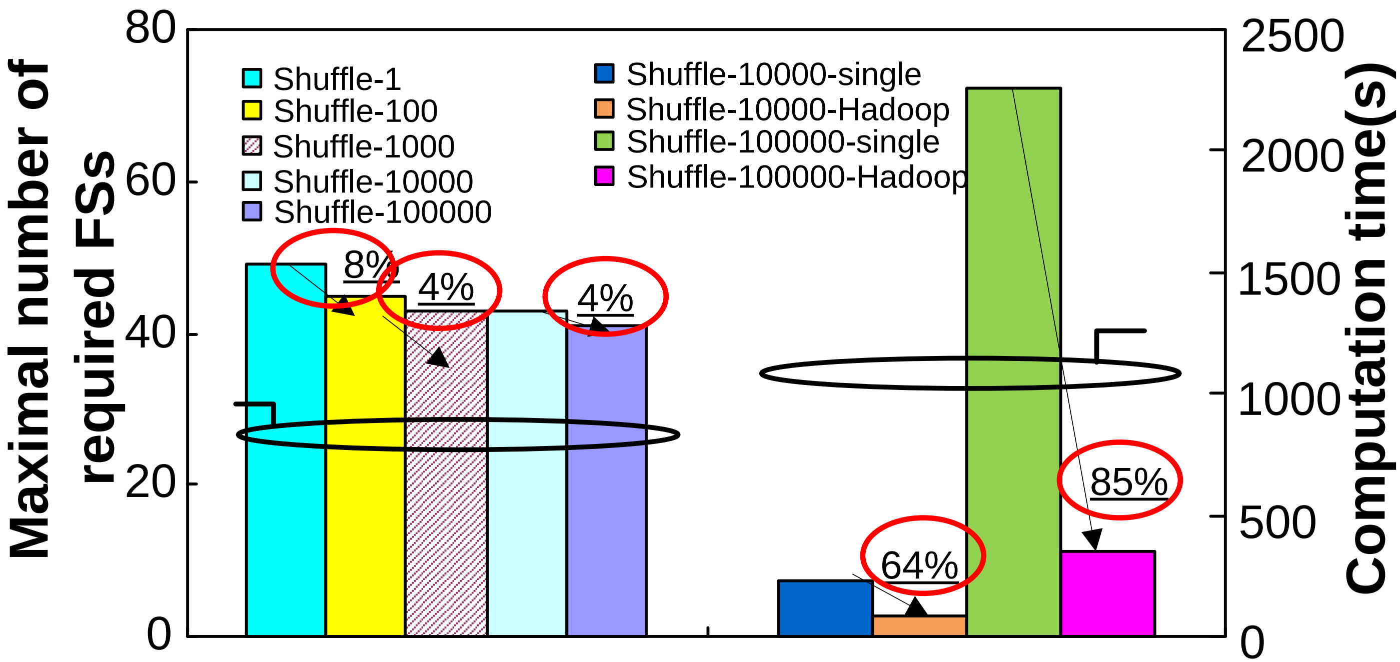
- **Maximal number of required FSs and computation time (COST239)**



- **The shuffling strategy is helpful to significantly reduce the number of required FSs**
- **The Hadoop system does help to reduce computation time compared to a single machine**

Optimization for optical networks with Hadoop system

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- **Adaptive FEC assignment problem [4]**
  - → **A new adaptive FEC assignment strategy for the elastic optical network**
  - → **A heuristic algorithm based on slot window planes (SWPs) to maximize the total number of FSs used for actual user data transmission**
  - → **Shuffle strategy**
    - → Shuffle the lightpath demand list for many times
    - → For each shuffled demand list, the adaptive FEC-based SWP algorithm is applied to find a solution
    - → The best solution is selected as the final solution when all the shuffled demand lists have been evaluated and compared.

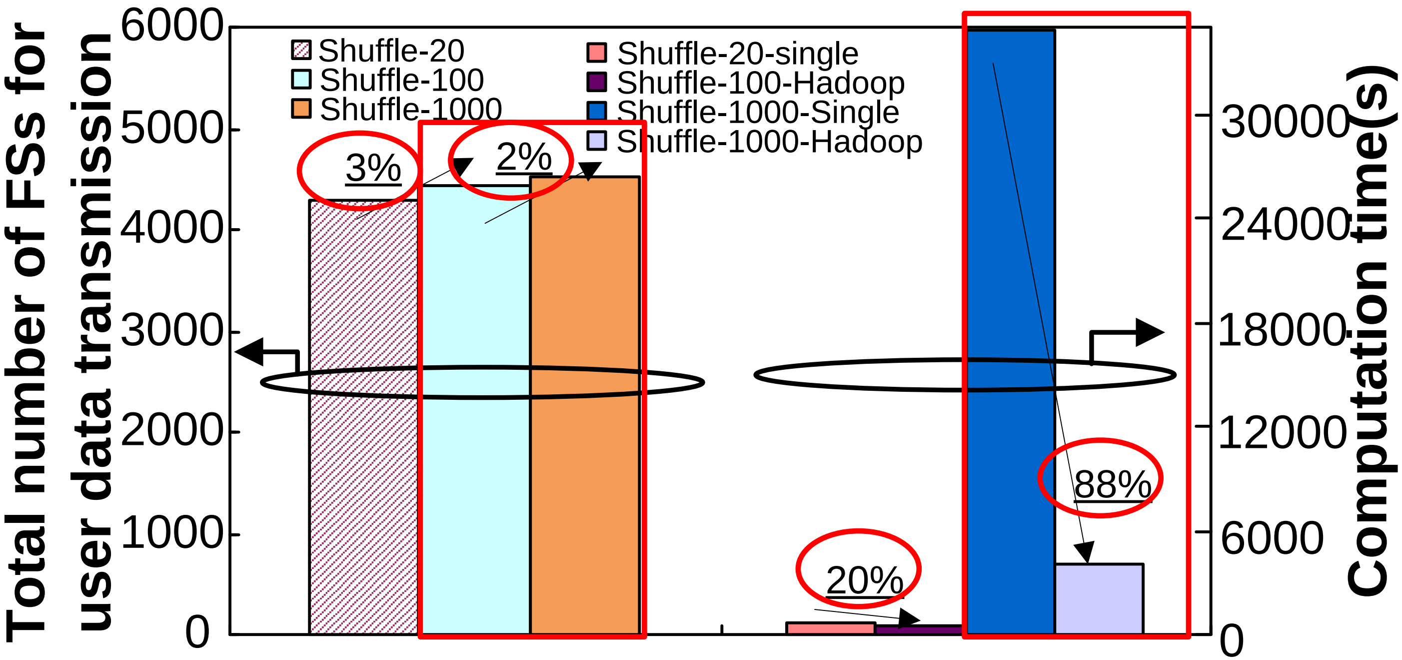
[4] Y. Li, H. Dai, G. Shen, and S. K. Bose, "Adaptive FEC selection for lightpaths in elastic optical networks," in Proc. *OFC 2014*.

Simulation conditions

- **Adaptive FEC assignment problem**
  - → **Test network case: 43-link US backbone network (USNET)**
  - → **Frequency slots in each link: *400 FSs***
  - → **The number of FSs required by users is uniformly randomly distributed within a range of *[25, 35]***

Performance analyses

- **Total number of FSs for user data transmission and computation time (USNET)**



- **The Hadoop system can perform better than a single machine by *3%* and it can also shorten computation time *20%* even though it evaluates 10 times more shuffled demand sequences**
- **A further increase of the number of shuffled demand sequences to 1,000 can lead to 2% furtjer performance improvement, under which the computational efficiency of the Hadoop system is more significant to take only about *1 hour*, while a single desktop took about *9 hours***

Conclusions

- The bin-packing optimization problems in the optical network can be efficiently solved by evaluating multiple shuffled demand sequences
- To overcome the difficulty of high computational complexity, we built a Hadoop computing system to parallel evaluate multiple shuffled demand sequences
- The approach was efficient to find solutions close to optimality and significantly reduce computation times compared to a single machine

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Thank you！