CS528

Reliability, IoT and Edge

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Reference:

Xie et.al, *Minimizing Redundancy to Satisfy Reliability Requirement for a Parallel Application on Heterogeneous Service-oriented Systems,* IEEE Trans. On Service Computing. 2017.

Introduction

- Large Data Center have many generations of Server
- Bound to be heterogeneous and different failure rate
- Reliability is widely identified as
  - an increasingly relevant issue in heterogeneous service-oriented systems
  - Because processor failure affects the QoS to users
- Replication-based fault-tolerance is
  - a common approach to satisfy application’s reliability requirement

Reliability

- Reliability is defined as
  – the probability of a schedule successfully completing its execution,
  – and it has been widely identified as an increasingly relevant issue
- Fault-tolerance by primary-backup replication
  – A primary task will have 0, 1, or k backup tasks
  – is an important reliability enhancement mechanism.
- problem of minimizing redundancy
  – to satisfy reliability requirement for DAG-based parallel application
  – on heterogeneous service-oriented systems

Reliability: Measure

- primary-backup replication scheme
  - The primary and all the backups are called replicas
- Although replication-based fault-tolerance is
  - an important reliability enhancement mechanism
  - but can not be 100% reliable in practice
- Therefore, if an APP application can
  - satisfy its specified reliability requirement
  - Named as reliability goal or reliability assurance then it is considered to be reliable
- Example: APP's reliability requirement is 0.9
  - Only if APPS 's reliability exceeds 0.9, will be reliable.

Issue with Reliability using Redundancy

- Reliability is important QoS requirements
- Replication-based fault-tolerance
- For resource providers,
  - minimizing resource redundancy caused by replication is one of the most important concerns
- Adding more replicas
  - Could increase both reliability and
  - Redundancy for a parallel application
- Both criteria are conflicting
  - low redundancy and high reliability,
  - short schedule length and high reliability

Application Models

- Let $U = \{u_1, u_2, \ldots, u_{|U|}\}$ represent a set of heterogeneous processors
  - where $|U|$ is the size of set U
- Parallel application running on processors is
  - Represented by a DAG $G=(N, W, M, C)$ with known values.
- N represents a set of nodes in G, and
  - Each node $n_i \in N$ is a task with different execution time values on different processors.
- Task executions is non-preemptive

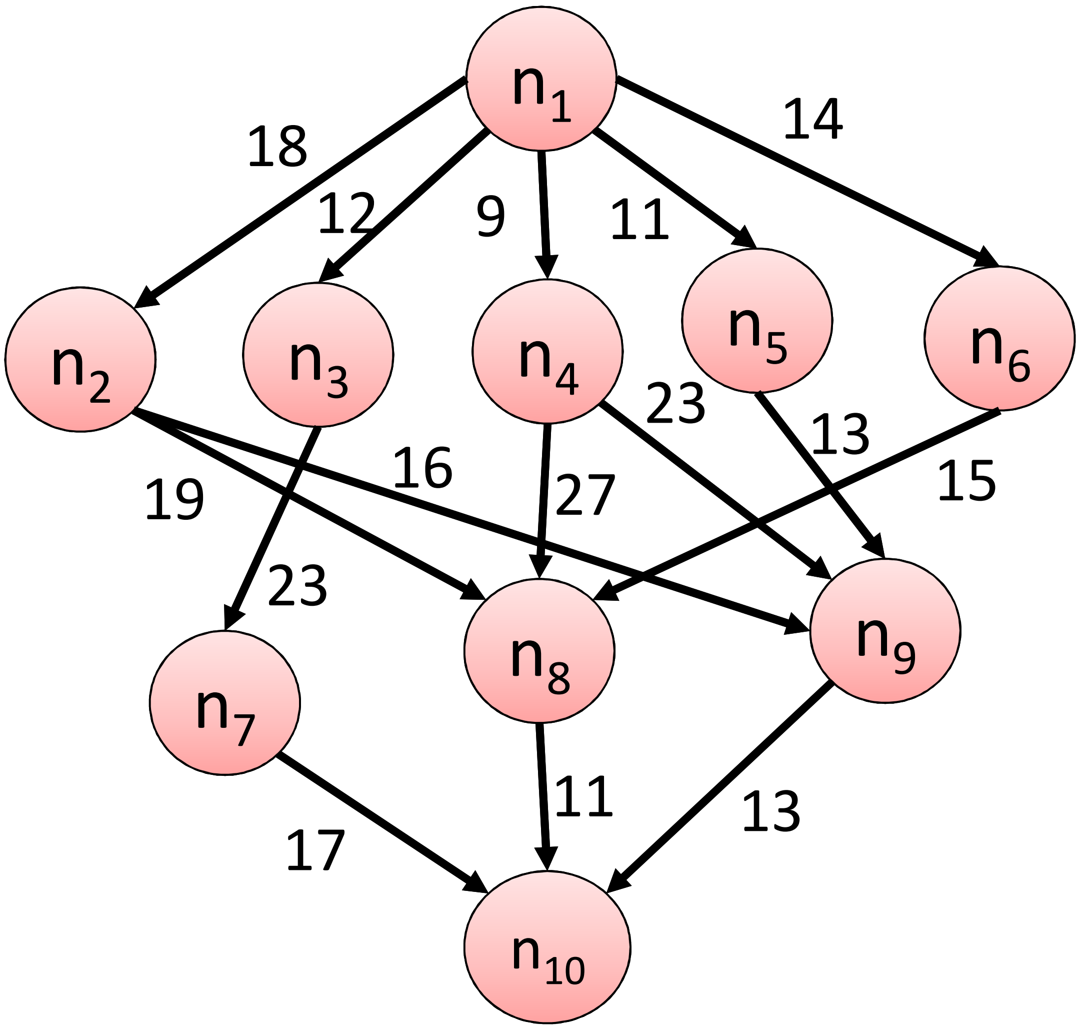
Application Models

- Set of immediate predecessor tasks of n_i :$pred(n_i)$
- set of immediate successor tasks of n_i : $succ(n_i)$
- Tasks without predecessor tasks : n_{entry}
- Tasks with no successor tasks : n_{exit}
- If an application has
  - Multiple entry a dummy entry node
  - Multiple exit tasks, then a dummy exit task
  - Dummy task with zero-weight dependencies is added to the graph.
- *Weight* W is an $|N|X|U|$ matrix in which
  - $w_{i,k}$ denotes the execution time of n_i running on u_k

Application Models

- Set of communication edges is M
  - each edge $m_{i,j} \in M$: communication from n_i to n_j
- Communication time $c_{i,j} \in C$: of $m_{i,j}$
  - if n_i and n_j are assigned to different processors
  - because two tasks with immediate precedence constraints need to exchange messages.
- When tasks n_i to n_j : allocated to same processor,
  - $c_{i,j}$ becomes zero because
  - Intra-processor communication cost is negligible

Application Models: Example



Task	u_1	u_2	u_3
n_1	14	16	9
n_2	13	19	18
n_3	11	13	19
n_4	13	8	17
n_5	12	13	10
n_6	13	16	9
n_7	7	15	11
n_8	5	11	14
n_9	18	12	20
n_{10}	21	7	16

Reliability Model

- Two major types of failures
  - transient failure (also called random hardware failure)
  - permanent failure
- Once a permanent failure occurs
  - Processor cannot be restored unless by replacement.
- Transient failure appears for a short time
  - and disappear without damage to processors
- Mainly takes the transient failures into account in our consideration

Reliability Model

- Suppose you are going from IITG to Airport
  - **CAR M** : 1990 model Maruti 800 car, car is around 30 year old and chances of failure is high
  - **CAR** B : BMW 5 series 2020 car, new cars, chances of failure is low
- Occurrence of failure is dependent on
  - Failure rate of CAR and Distance travelled
- I will prefer not to go above 1km in Car M
- Reliability: Exponential of Failure Rate and Distance $\boldsymbol{R(F, D) = e^{-F.D}}$

Reliability Model

- Occurrence of transient failure for a task follows
  - Poisson distribution
- Reliability of an event in unit time *t* is

$$R(t) = e^{-\lambda . t}$$

  - where $\boldsymbol{\lambda}$ *constant failure rate per time unit* of processor
- Let $\boldsymbol{\lambda}_k$ is failure rate of the processor $\boldsymbol{u_k}$
- Reliability of $\boldsymbol{n_i}$ executed on $\boldsymbol{u_k}$ in its execution time

$$R(n_i, u_k) = e^{-\lambda_k w_{ik}}$$

- Failure probability for $\boldsymbol{n_i}$ without using the active replication is $1 - R\,(n_i, u_k) = 1 - e^{-\boldsymbol{\lambda}_k w_{ik}}$

Reliability with Replicas

- Each task has replicas with the active replication
- Let num_i ($num_i \leq |U|$) : number of replicas of n_i.
  - Replica set of n_i is $\{n^1_i, n^2_i, \ldots, n^{num_i}_i\}$
  - where n^1_i is the primary and others are backups.
- As long as one replica of n_i successfully completed
  - then recognize, there is no occurrence of failure for n_i
- Reliability of n_i is updated to

$$R(n_i) = 1 - \prod_{x=1}^{num_i} 1 - R(n_i^x, u_{pr(n_i{}^x)})$$

where $u_{pr(n_i{}^x)}$ represents assigned processor of n^x_i

- Reliability of the parallel application with precedence-constrained tasks $R(G) = \prod_{n_i \in N} R(n_i)$

Problem Statement

- Assign replicas and corresponding processors for each task,
  - While minimizing the number of replicas and
  - Ensuring that obtained reliability of application $R(G)$
  - Satisfies application's reliability requirement $R_{req}(G)$
- Find the replicas and processor assignments of all tasks to minimize

$$NR(G) = \sum_{n_i \in N} num_i$$

– subject to $R(G) = \prod_{n_i \in N} R(n_i) > R_{req}(G)$

$$\forall i : 1 \le i \le |N|$$

Solution Approaches: Task Prioritizing

- Fault-tolerant scheduling generally consists of
  - 1) task prioritizing,
  - 2) processor selection, and
  - 3) task execution.
- Therefore, first compute task priority before processor selection
- Upward rank ***rank***$_u$ of a task as task priority standard
- Tasks are ordered : descending order of ***rank***$_u$

$$rank_u(n_i) = \overline{w_i} + \max_{n_j \in succ(n_i)} \{\, c_{ij} + rank_u(n_j) \,\}$$

  - Where $\overline{w_i}$ is average execution time of n_i

Solution Approaches: MaxRE

- As application reliability is
  - Product of all the task reliability values
- So such problem is usually solved
  - by transferring application's reliability requirement to the sub-reliability requirements of tasks
- Sub-reliability requirement for each task

$$R_{req}(n_i) = \sqrt[|N|]{R_{req}(G)}$$

- If sub-reliability requirement of each task can be satisfied by active replication $R(n_i) \geq R_{req}(n_i)$
- Main idea is to iteratively select
  - Replica n^x_i and processor $u_{pr(n_i{}^x)}$ with the maximum $R(n_i^x, u_{pr(n_i{}^x)})$ until $R(n_i) \geq R_{req}(n_i)$

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MaxRE: Example

- Suppose $\boldsymbol{R_{req(G)} = 0.9}$ and $\boldsymbol{4}$ tasks in DAG
- Sub-reliability requirement for each task

$$\boldsymbol{R_{req}(n_i) = \sqrt[4]{0.9} = 0.97401}$$

- Each task need to satisfy the reliability above $\mathbf{0.97401}$

Solution Approaches: RR

- Demerits of MaxRE
  - Sub-reliability requirements of all tasks are equal and high,
  - such that it needs more replicas with extra redundancy
  - to satisfy the sub-reliability requirement of each task
- Unequal task sub-reliability may yield good solution
  - **Start with equal reliability**
- Lower down the sub-reliability requirement
  - of tasks while still satisfying the application's reliability requirement

Solution Approaches: RR

- First, the sub-reliability requirement
  - for entry task is $\boldsymbol{R_{req}(n_i) = \sqrt[|N|]{R_{req}(G)}}$
- But for the next sequence of task can
  - calculated based on required and already archived

$$\boldsymbol{R_{req}\left(n_{seq(j)}\right) = \sqrt[|N|-j+1]{\frac{R_{req}(G)}{\prod_{x=1}^{j} R\left(n_{seq(x)}\right)}}}$$

RR: Example

- Suppose $\boldsymbol{R_{req(G)} = 0.9}$ and $\boldsymbol{4}$ tasks in DAG
- Sub-reliability requirement for First task

$$\boldsymbol{R_{req}(n_i) = \sqrt[4]{0.9} = 0.97401}$$

- Suppose we allocate 5 replica to satisfy and we achieved a bit high reliability $0.985 > \boldsymbol{0.97401}$
- We can use this higher value to reduce the reliability for other remaining tasks

$$\boldsymbol{R_{req}(n_i) = \sqrt[3]{0.9/_{0.985}} = 0.97 < 0.97401}$$

Enough Replication for redundancy minimization

- Demerit of RR
  - Reduction ranges of tasks near entry task are much lower than those near to the exit task
  - actual sub-reliability requirements show unfairness among tasks
  - still requires unnecessary redundancy to satisfy application's reliability requirement.
- If one task has $R(n_i) < R_{req}(G)$, then
  - no matter how many replicas for any other tasks
  - $R_{req}(G)$ cannot be satisfied

Lowe Bound on Redundancy

- Lower bound (LB) on $R_{req}(n_i)$ for any task

  $R_{lbeq}(n_i)=R_{req}(G)$ and $R_{req}(n_i)\geq R_{lbreq}(n_i)$

- LB on number of replicas for task n_i to satisfy

$$1-\prod_{x=1}^{lb(n_i)}\left(1-R(n_i^x, u_{pr(n_i{}^x)})\right)\geq R_{lbreq}(n_i)$$

Calculation of LB replication

- Steps to select the replica and corresponding processor with minimum number of replicas
- Steps 1: Calculate $R(n_i, u_k)$ of each task
  - on all available processors
  - if a replica of n_i has been assigned to u_k processor then u_k is unavailable for n_i
- Step 2: to minimize the number of replicas
  - Select the replica n^x_i of task n_i and
  - corresponding processor $u_{pr(n_i{}^x)}$ with the maximum $R(n_i^x, u_{pr(n_i{}^x)})$
- Step 3: repeat Step 1 & 2 to satisfy $R_{lbreq}(n_i)$

Adding Enough Replication

- Using LBR all the tasks merely satisfy

$$R_{lbeq}(n_i)=R_{req}(G)$$

- We should add more new replicas for tasks to satisfy application's reliability requirement.
- Choosing remaining replicas is complex work
  - because different replicas of different tasks
  - may cause different reliability values on different processors

Adding Enough Replica

- Given
  - the current number of replicas for n_i is $h = num_i$
  - and the application reliability is $R(G)$
- if a new replica n_i^{h+1} is assigned
  - to the processor $u_k = u_{pr}(n_i^{h+1})$ for n_i, then the number of replicas is changed to $h+1$
- The task reliability is changed to

$$R_{new}(n_i) = 1 - \prod_{x=1}^{h+1}(1 - R(n_i^x, u_{pr(n_i^x)}))$$

- The application reliability due $R_{new}(n_i)$ is changed to

$$R^i(G) = R_{new}(n_i) * \prod_{n_j \in N, i \neq j} R(n_j)$$

Adding Enough Replica

- **Step 1: Each available task**
  - Available: if replicas of a task have not been assigned to all the processors
  - Assumed to be replicated once on an available processor with maximum $R(n_i, u_k)$ and calculate $R_{new}(n_i)$
- **Step 2: Calculate APP reliability *Ri*(*G*) of each task**
- **Step 3: Select replica n^x_i and processor *with***
  - maximum *Ri*(*G*) from all the generated replicas

$$R_i(G) = \max \{ R_1(G), R_2(G), .., R_{|N|}(G) \}$$

- **Step 4: Repeat Steps (1), (2), and (3)**
  - until R(G) > Rreq(G) is satisfied

Heuristics Replication for Redundancy Minimization (HRRM)

- Similar to RR Approach
  - unassigned tasks can also be pre-supposed as assigned tasks with known reliability values
  - Pre-supposed value: can be upper bound value

$$R_{ubreq}(n_i) = \sqrt[|N|]{R_{req}(G)}$$

- Heuristic: Assume the task to be assigned is $n_{seq}(j)$
  - Ensure : $R_{req}(G)$ is satisfied at each task assignment

$$R_{req}\left(n_{seq(j)}\right) = \frac{R_{req}(G)}{\prod_{x=1}^{j-1} R\left(n_{seq(x)}\right) \times \prod_{y=j+1}^{|N|} R_{ubreq}\left(n_{seq(y)}\right)}$$

Edge Computing and IoT

Edge Computing

- Edge computing
  - Brings computation and data storage closer to the sources of data
  - This is expected to improve response times and save bandwidth
- Edge computing is a topology- and location-sensitive form of distributed computing
- IoT uses the Edge Computing

Edge Computing

- The origins lie
  - in **content distributed networks (CDN)**
  - that were created in the late 1990s
  - to serve web and video content from edge servers that were deployed close to user
- Example: Netflix, Utube
- CDN focus on Data not Processing
- Edge Computing focus on both Processing and Data

IoT

- Describes physical objects (or groups objects)
  - with sensors, processing ability, software, and other technologies
  - that connect and exchange data with other devices and systems over the Internet or other communications networks
  - Do a whole one collaborative work
- Crowd souring Google map traffic, Building/Campus for energy efficiency

IoT

- IoT can be used for Smart home, Smart Speaker, Elder Care
- Smart health care, Manufacturing, Transportation
- Agriculture, Environmental Monitoring
- Internet of Battle field of things, Ocean of Things

IoT : Characteristics

- Source of Data : Sensors, Camera, Microphone, Monitors
- Sources may be mobile, ubiquitous, battery powered, all may not be directly connected to cloud
- Collection of Data and Storing of data
  - Network, Delay
  - How to send data to server for storing efficiently
- Processing of Data
  - Resource management
- Action based on Decision on Data Processing
- Many IoTs action : timely manner

User App Data Distribution in Edge Computing

Cost-Effective App Data Distribution in Edge Computing, IEEE Trans Parallel Dist. System, Jan 21

Edge Data Distribution: Intro

- Cloud computing is the practice of
  - using a network of remote servers hosted on the internet
  - to store, manage, and process data,
  - rather than a local server or a personal computer.
- Latency influenced by
  - the number of router hops, packet delays
  - introduced by virtualization in the network,
  - or the server placement within a data center,
  - has always been a key issue for cloud migration.
- Other conventional network paradigms
  - cannot handle the huge increase in the network latency and congestion
  - caused by the resources at the edge of the cloud.

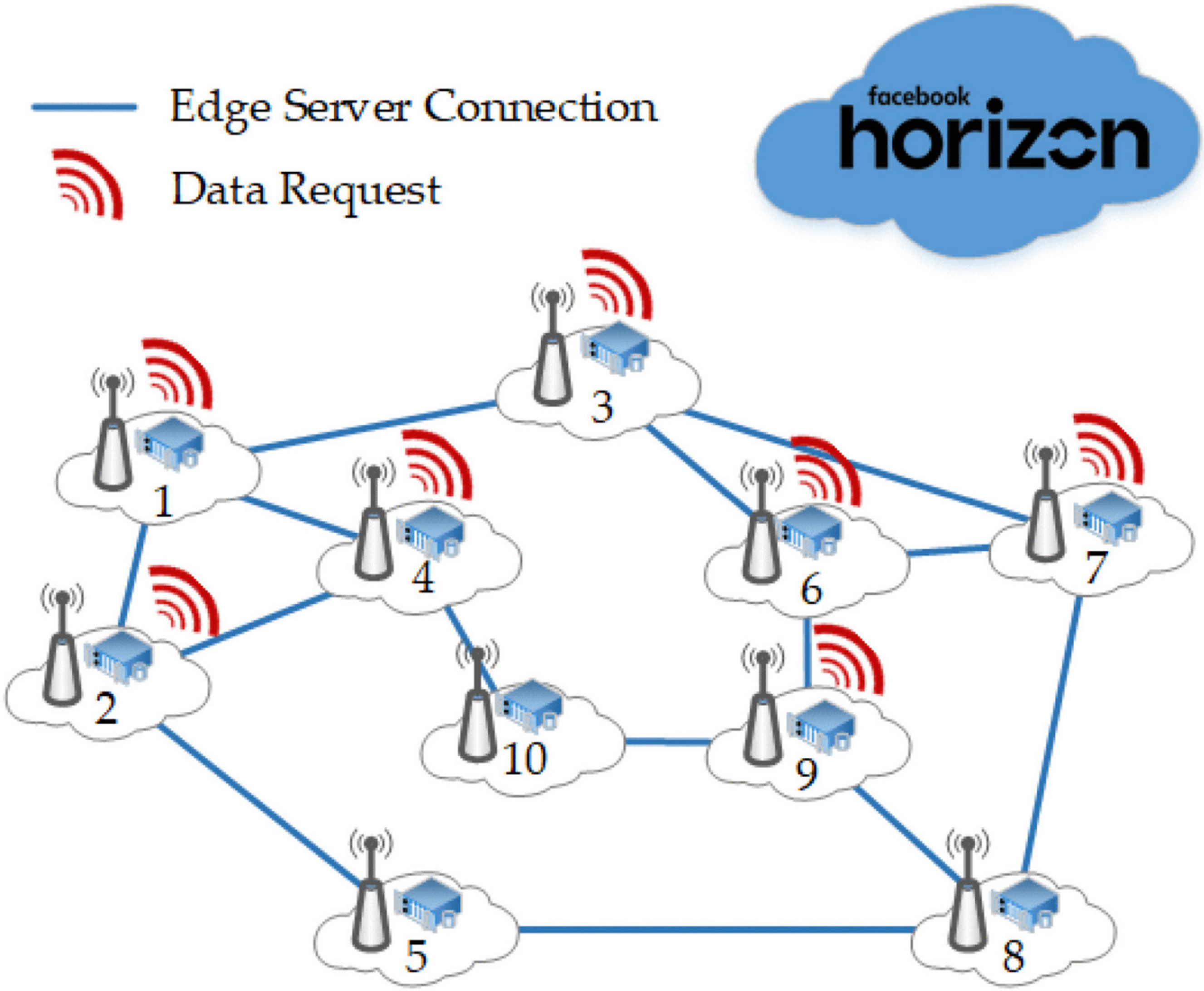
Edge Data Distribution: Intro

- edge computing
  - which is essentially the process of decentralizing the computer services
  - with the help of edge servers deployed at the base stations.
- From an app vendor’s perspective,
  - caching data on edge servers
  - considerably reduce both the latency for their users to fetch data and the volume of their app data transmitted between the cloud and its users.
  - Thus, reducing the transmission costs.

An Industry Example: Facebook Horizon

- Facebook Horizon: VR application
- Facebook Horizon can benefit greatly
  - from distributing most popular VR videos and VR games onto the edge servers.
- VR applications are very latency sensitive
  - thus caching these data onto edge servers
  - will increase VR performance, experience and sensitivity.
- Cost-Ineffective app data distribution
  - Can thereby cost Facebook Horizon significantly more.

An Industry Example: Facebook Horizon



Problem Definition: EDD

- N edge servers in a particular area and model as graph G.
  - For each edge server v, graph G has a node v.
  - For each of the linked edge servers (u,v), graph G has a corresponding edge $e_{(u, v)}$.
- $G(V,E,W)$ to represent the graph
  - where V is the set of nodes or edge servers in the graph,
  - E are the set of edges in the graph, and
  - W is the set of weights corresponding to the edges.
- Let R denote the set of destination edge servers in graph G.

Problem Definition: EDD

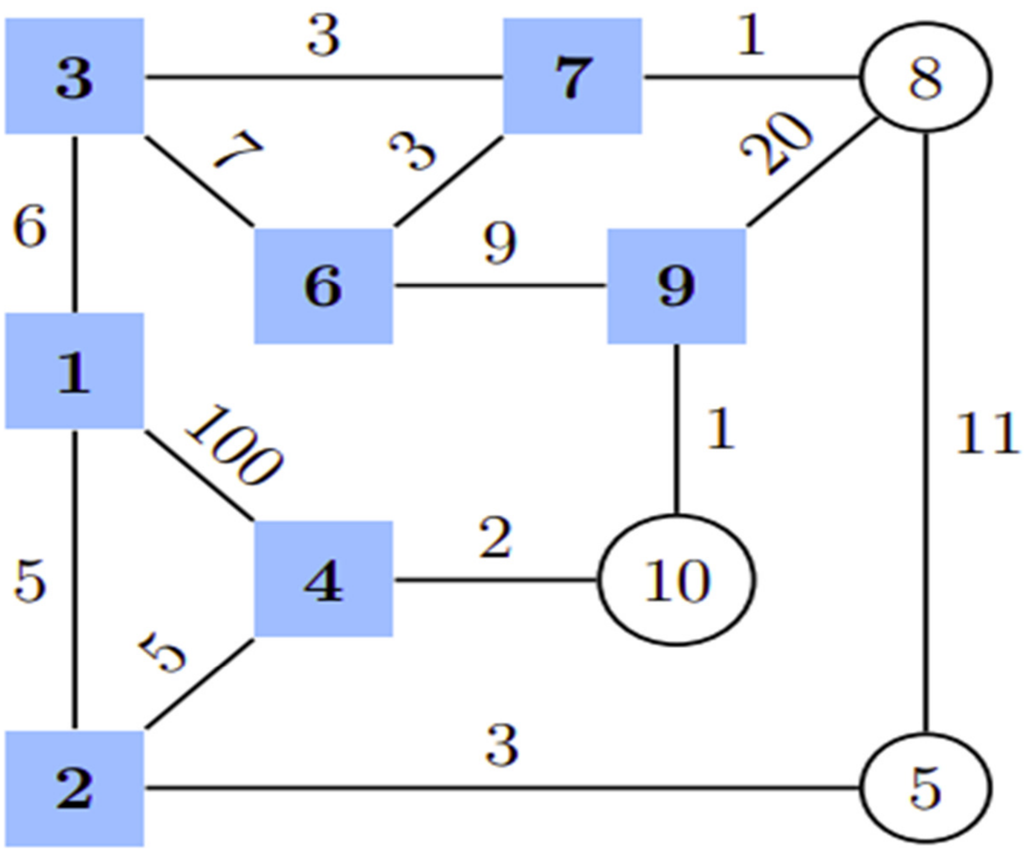
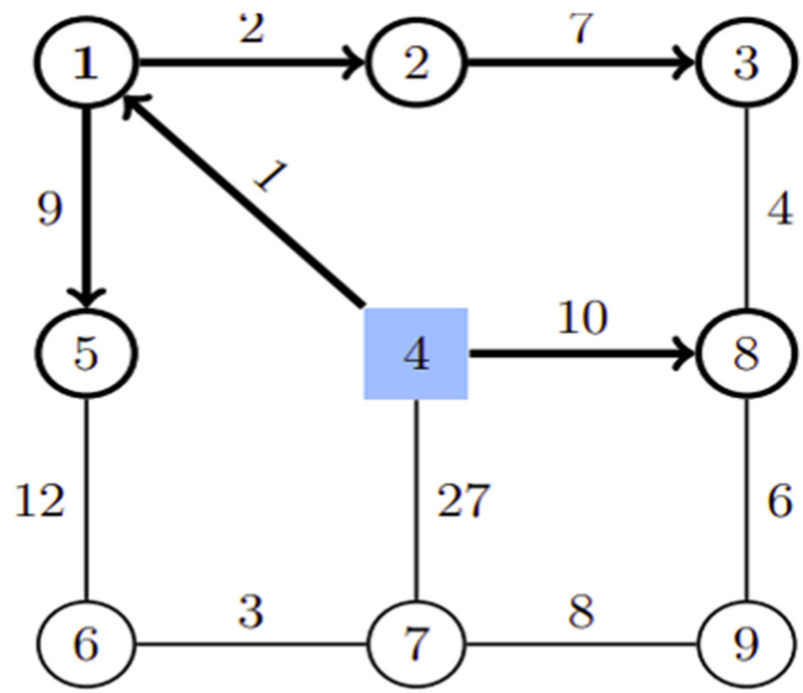


Fig. 4.1: EDD scenario with 10 edge servers

Problem Definition : EDD

- Let L_{limit} be the vendors' EDD length constraint.
- Two Possible Scenario – C2E and E2E.
- We define a ratio λ to specify the constant weight for the cloud to edge server edges.



EDD example to demonstrate L_{limit}

Problem Definition: EDD

$$s_{\mathrm{v}} = \begin{cases} 1, & \text{if } v \text{ is an initial transit edge server} \\ 0, & \text{if } v \text{ is not an initial transit edge server} \end{cases} \tag{1}$$

$$\tau_{(u,\ v)} = \begin{cases} 1, & \text{if data is transmitted through } \mathrm{e}_{(\mathrm{u},\ \mathrm{v})} \\ 0, & \text{if data is not transmitted through } \mathrm{e}_{(\mathrm{u},\ \mathrm{v})} \end{cases} \tag{2}$$

$$Connected(S,\ T,\ u,\ v) = true,\ \forall v \in R,\ \exists\, u, s_{\mathrm{u}} = 1 \tag{3}$$

$$P_{\mathrm{delay}} = \frac{L_{\mathrm{link}}}{s_{\mathrm{medium}}} \tag{4}$$

$$W_{(\mathrm{c},\ \mathrm{v})} = \lambda, \forall\, v \in V \setminus \{c\} \tag{5}$$

$$0 \le L_v \le L_{limit}, L_v \in Z^+, \forall v \in R \tag{6}$$

$$minimize\left(Cost_{\mathrm{C2E}}(S) + Cost_{\mathrm{E2E}}(T)\right) \tag{7}$$