Virtual-Pod-Assisted Routing and Resource Assignment in Elastic All-Optical Intra-Datacenter Networks

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Peng, L. et. al., "Virtual-Pod-Assisted Routing and Resource Assignment in Elastic All-Optical Intra-Datacenter Networks," IEEE Access, 5, pp.406-420.

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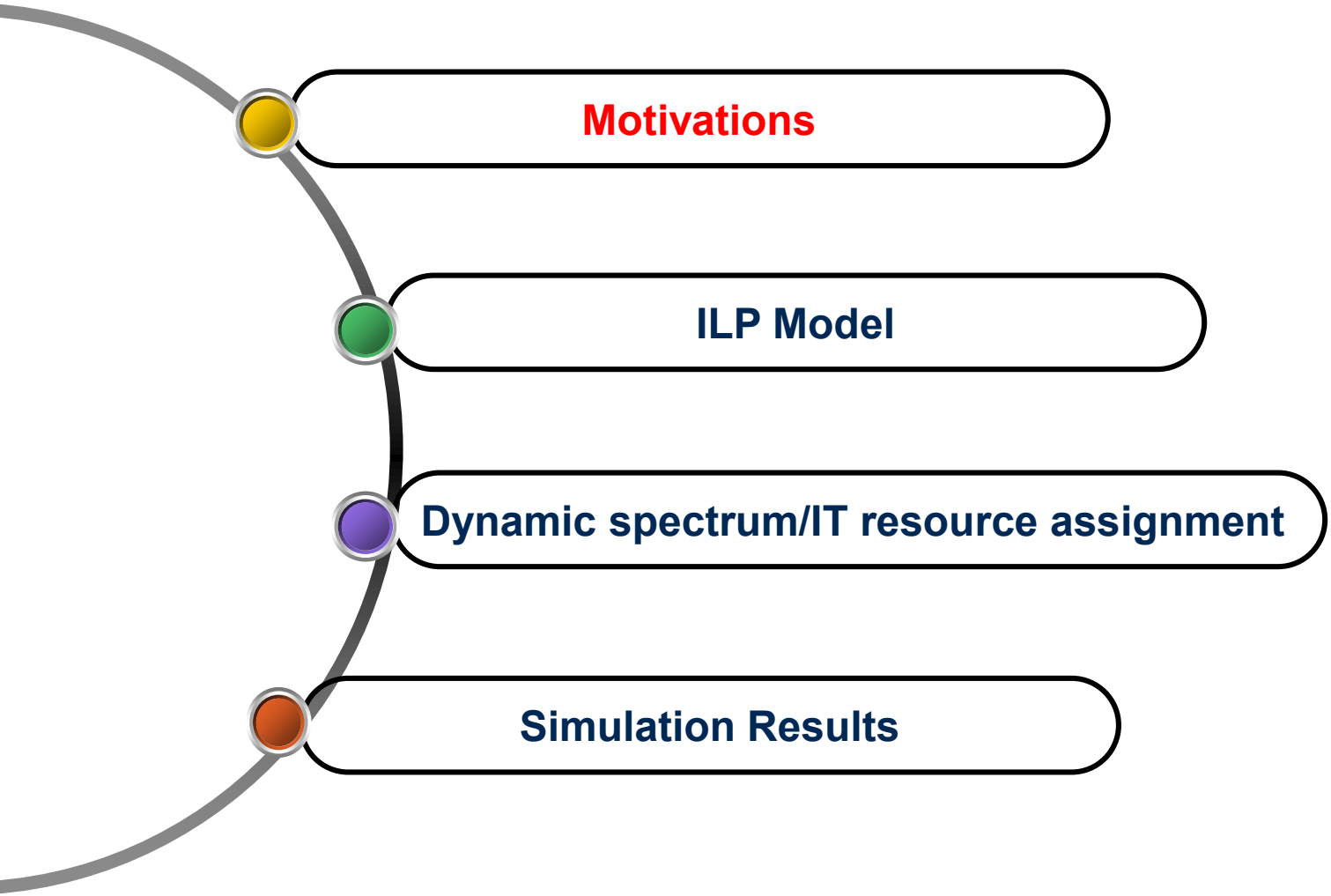

Motivations
ILP Model
Dynamic spectrum/IT resource assignment
Simulation Results

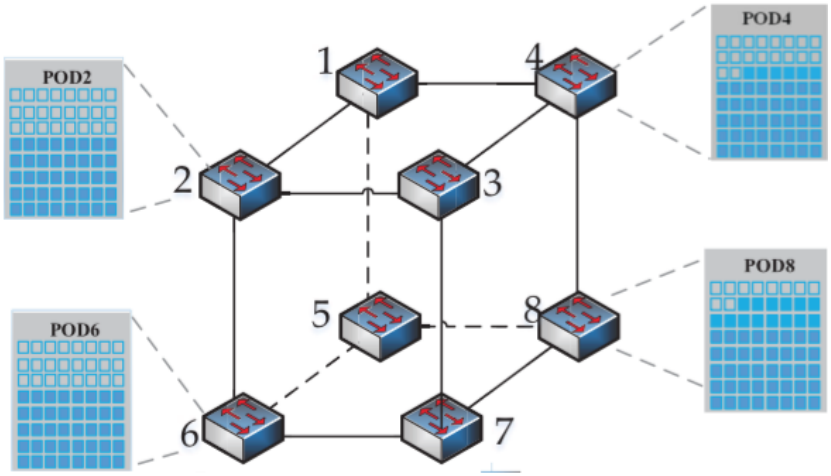
Motivation

- **The service requests of intra-datacenter networks are different from that of traditional transport networks**
  - Traffic in traditional networks is between dedicated node pairs that only require sufficient transmission bandwidth
  - Intra-DCN service requests, require IT resources and transmission bandwidth
  - Any intra-DCN node that can provide the required IT resources can serve as a destination node (i.e., anycast)

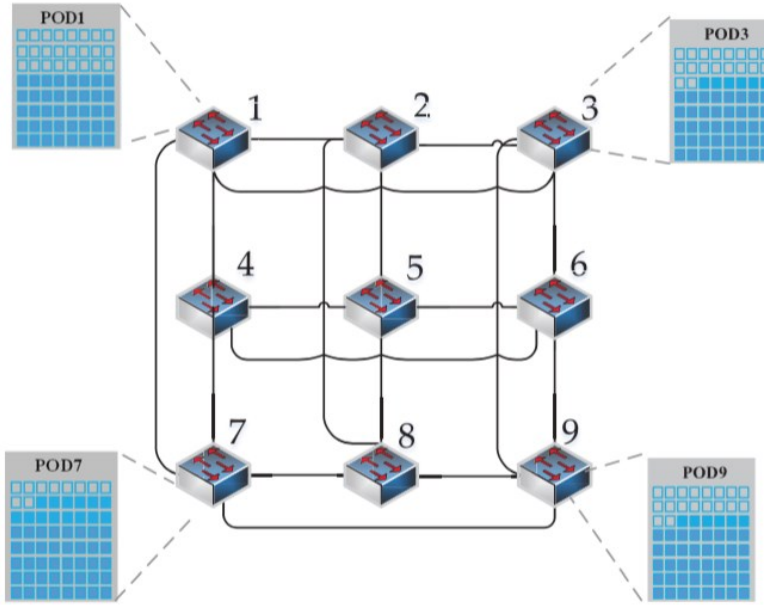
- **Routing and spectrum/IT resource assignment (RSIA)**

Intra-DCN architectures

- **N-cube topology**
- **Torus topology**



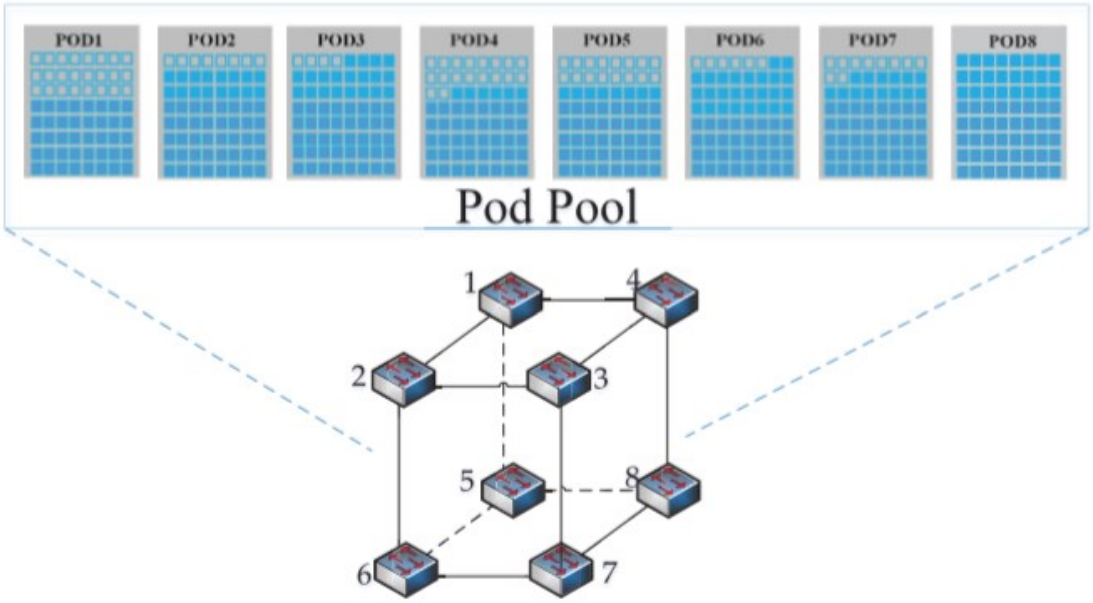
A 3-cube elastic intra-DCN architecture.

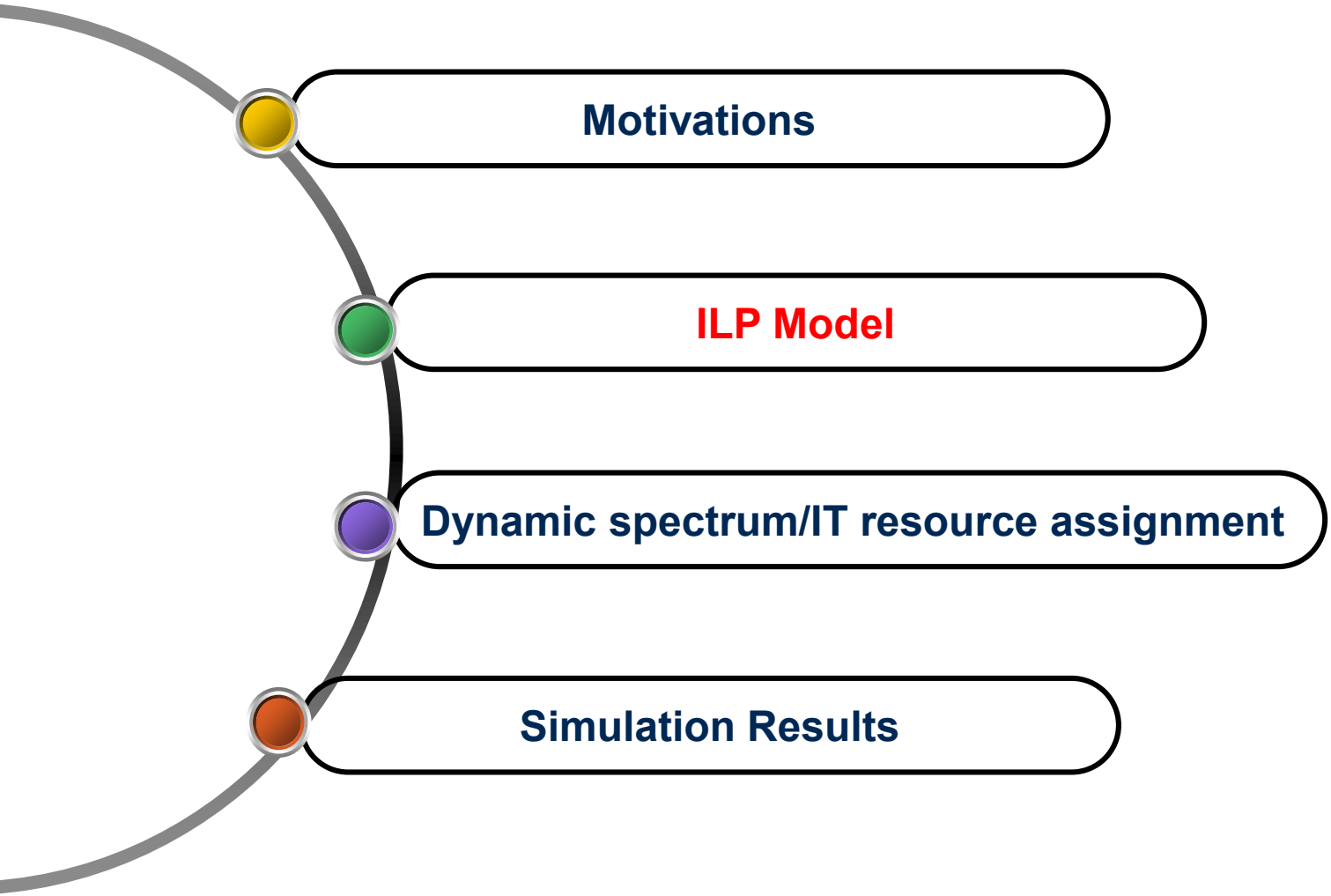


A 3-by-3 Torus elastic intra-DCN architecture.

Virtual-pod pool intra-DCN architectures

- Flexible number of destination nodes
- Destination node is not preset
- IT units of different pods can be shared

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ILP MODEL FOR STATIC ROUTING AND SPECTRUM/IT ASSIGNMENT (RSIA)

- ANYCAST ILP MODEL FOR INTRA-DCN STATIC RSIA
- UNICAST ILP MODEL FOR INTRA-DCN STATIC RSIA

ANYCAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Given**
  - *V* : Set of intra-DCN nodes.
  - *L* : Set of intra-DCN links.
  - *R*: Set of service request indices,1,2,…,*N*.
  - Service-request (SR) is represented as SR (SRC, BW, IT)
  - *LKi* : Set of links that start or end at node *i*.

- **Objective**
  - Minimize maximum number of required spectrum slots, and the maximum number of required IT units of all the destination nodes.

Minimize F+I

ANYCAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Parameters**
- *SRCi*: Source node of service request *i*.
- *BWi*: Number of spectrum slots required by service request *i*.
- *ITi*: Number of IT units required by service request *i*.
- *Fmax* : Total number of required spectrum slots by all the intra-DCN service requests. It is calculated as the sum of the required spectrum slots of all the service requests.
- *G*: Guard band required in units of spectrum slot unit between two spectrally neighboring elastic optical channels.

ANYCAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Variables**
- *PLmin*:Abinaryvariable.Thevalueisequalto1ifthe lightpath for service request *i* traverses physical link *mn*; zero, otherwise.
- *PNmi* : A binary variable. The value is equal to 1 if the lightpath for service request *i* traverses physical node *m*; zero, otherwise.
- *FNmi* : A binary variable. The value is equal to 1 if *m* is the final physical node, i.e., destination node, traversed by the lightpath for service request *i*; zero, otherwise.
- *fi*: Starting spectrum slot index of service request *i*.
- $\beta_{i,j}$: A binary variable that takes value one if $fi < fj$; zero, otherwise.
- *F*: Maximum index of required spectrum slots among all the fiber links of the entire intra-DCN.
- *I*: Maximum number of required IT units among all the
- destination nodes of the entire intra-DCN.

ANYCAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- Constraints

$$\Sigma_{mn \in LK_{SRC_i}} PL^i_{mn} = 1, \quad \forall i \in R \tag{1}$$

$$\Sigma_{m \in N} FN^i_m = 1, \quad \forall i \in R \tag{2}$$

$$FN^i_m \leq PN^i_m, \quad \forall i \in R, \ \forall m \in V \tag{3}$$

$$\Sigma_{mn \in LK_w} PL^i_{mn} = 2PN^i_w - FN^i_w, \quad \forall i \in R, \quad w! = SRC_i \tag{4}$$

$$PN^i_m + PN^i_n \geq 2 * PL^i_{mn}, \quad \forall i \in R, \ \forall m, n \in V, \ \forall mn \in L \tag{5}$$

$$F \leq F_{max} \tag{6}$$

$$F \geq f_i + BW_i + G, \quad \forall i \in R \tag{7}$$

$$F \geq \Sigma_{i \in R} PL^i_{mn} * BW_i, \quad \forall mn \in L \tag{8}$$

$$\beta_{i,j} + \beta_{j,i} = 1, \quad \forall i, j \in R \tag{9}$$

$$f_i + BW_i + G - f_j \leq F_{max}(1 - \beta_{i,j} + 2 - PL^i_{mn} - PL^j_{mn}), \quad \forall i, j \in R, \ \forall mn \in L \tag{10}$$

$$\Sigma_i FN^i_m * IT_i \leq I, \quad \forall i \in R, \ \forall m \in V \tag{11}$$

$$IT_i \leq I, \quad \forall i \in R \tag{12}$$

UNICAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Given**
  - *V* : Set of intra-DCN nodes.
  - *L* : Set of intra-DCN links.
  - SD : Set of intra-DCN source-destination node pairs.
  - *LKi* : Set of links that start or end at node *i*.

- **Objective**
  - Minimize maximum number of required spectrum slots, and the maximum number of required IT units of all the destination nodes.

Minimize F+I

UNICAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Parameters**
- *BWi*: Number of spectrum slots required by service request *i*.
- *ITsd* : Number of IT units required by node pair sd.
- *Fmax* : Total number of required spectrum slots by all the intra-DCN service requests. It is calculated as the sum of the required spectrum slots of all the service requests.
- *G*: Guard band required in units of spectrum slot unit between two spectrally neighboring elastic optical channels.

UNICAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- **Variables**
- PLsd : A binary variable. The value is equal to 1 if the mn lightpath for node pair sd traverses physical link mn; zero, otherwise.
- *PNsd*: A binary variable. The value is equal to 1 if the lightpath for node pair sd traverses physical node m; zero, otherwise.
- *fsd*: Starting spectrum-slot index for a service request between node pair *sd*.
- $\beta sd\,1, sd\,2$: A binary variable that takes value one if $fsd1 < fsd2$; zero, otherwise.
- *F*: Maximum index of required spectrum slots among all the fiber links of the entire intra-DCN.
- *I*: Maximum number of required IT units among all the
- destination nodes of the entire intra-DCN.

UNICAST ILP MODEL FOR INTRA-DCN STATIC RSIA

- Constraints

$$\Sigma_{mn \in LK_s} PL_{mn}^{sd} = 1, \quad \forall sd \in SD \tag{13}$$

$$\Sigma_{mn \in LK_d} PL_{mn}^{sd} = 1, \quad \forall sd \in SD \tag{14}$$

$$\Sigma_{mn \in LK_w} PL_{mn}^{sd} = 2PN_w^{sd}, \quad \forall sd \in SD, w! = s, d \tag{15}$$

$$PN_m^{sd} + PN_n^{sd} \geq 2 * PL_{mn}^{sd}, \quad \forall sd \in SD, \ \forall m, n \in V, \ \forall mn \in L \tag{16}$$

$$F \leq F_{max} \tag{17}$$

$$F \geq f_{sd} + BW_{sd} + G, \forall sd \in SD \tag{18}$$

$$F \geq \Sigma_{sd \in SD} PL_{mn}^{sd} * BW_{sd}, \quad \forall mn \in L \tag{19}$$

$$\beta_{sd1,sd2} + \beta_{sd2,sd1} = 1, \quad \forall sd \in SD \tag{20}$$

$$f_{sd1} + BW_{sd1} + G - f_{sd2} \leq F_{max}(1 - \beta_{sd1,sd2} + 2 - PL_{mn}^{sd} - PL_{mn}^{sd}), \quad \forall sd \in SD, \quad \forall mn \in L \tag{21}$$

$$\Sigma_{s \in V} IT_{sd} \leq I, \quad \forall sd \in SD \tag{22}$$

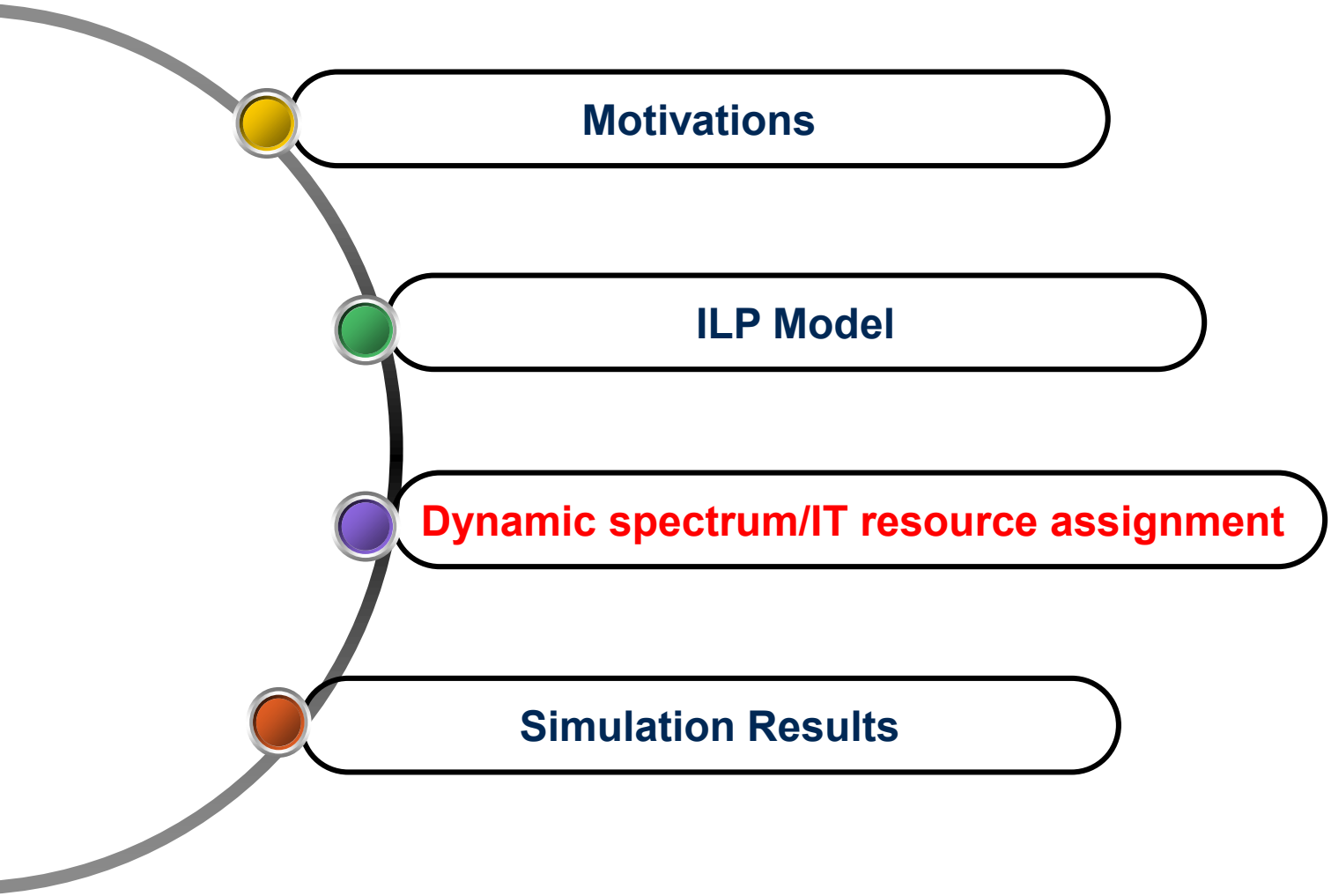
Complexity comparison for two ILP models

TABLE 1. Complexity comparison for a 3-Cube and a 3-by-3 Torus intra-DCN topologies based on the actual numbers of variables and Constraints given by Gurobi ILP solver. No. of service requests = 12.

Model Name		Rows(Variables)	Columns(Constraints)
3-Cube	*Anycast*	428	2108
	Unicast	506	2086
3*3 Torus	*Anycast*	578	3003
	Unicast	482	2862

TABLE 2. Results comparison for anycast ILP model and unicast ILP model. SRs = 12 means the number of service requests is 12.

Model Name	SRs = 12		SRs = 16		SRs = 20	
	F	*I*	*F*	*I*	*F*	*I*
3-Cube-Anycast	209	76	209	76	289	76
3-Cube-Unicast	209	76	209	76	289	76
*3 * 3 Torus-Anycast*	150	40	189	52	248	58
*3 * 3 Torus-Unicast*	257	114	277	118	405	118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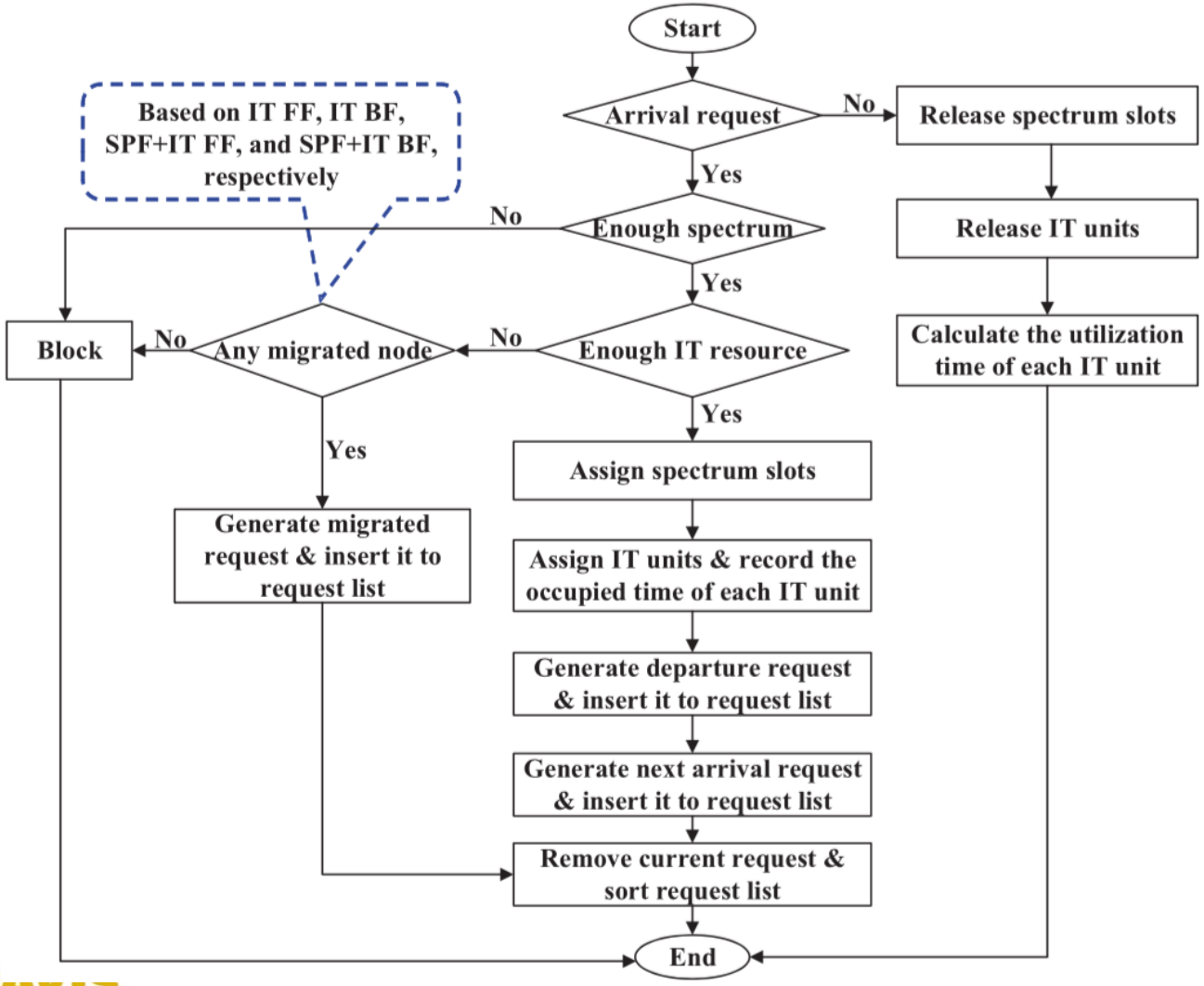
V-POD-ASSISTED ALGORITHMS FOR DYNAMIC RSIA

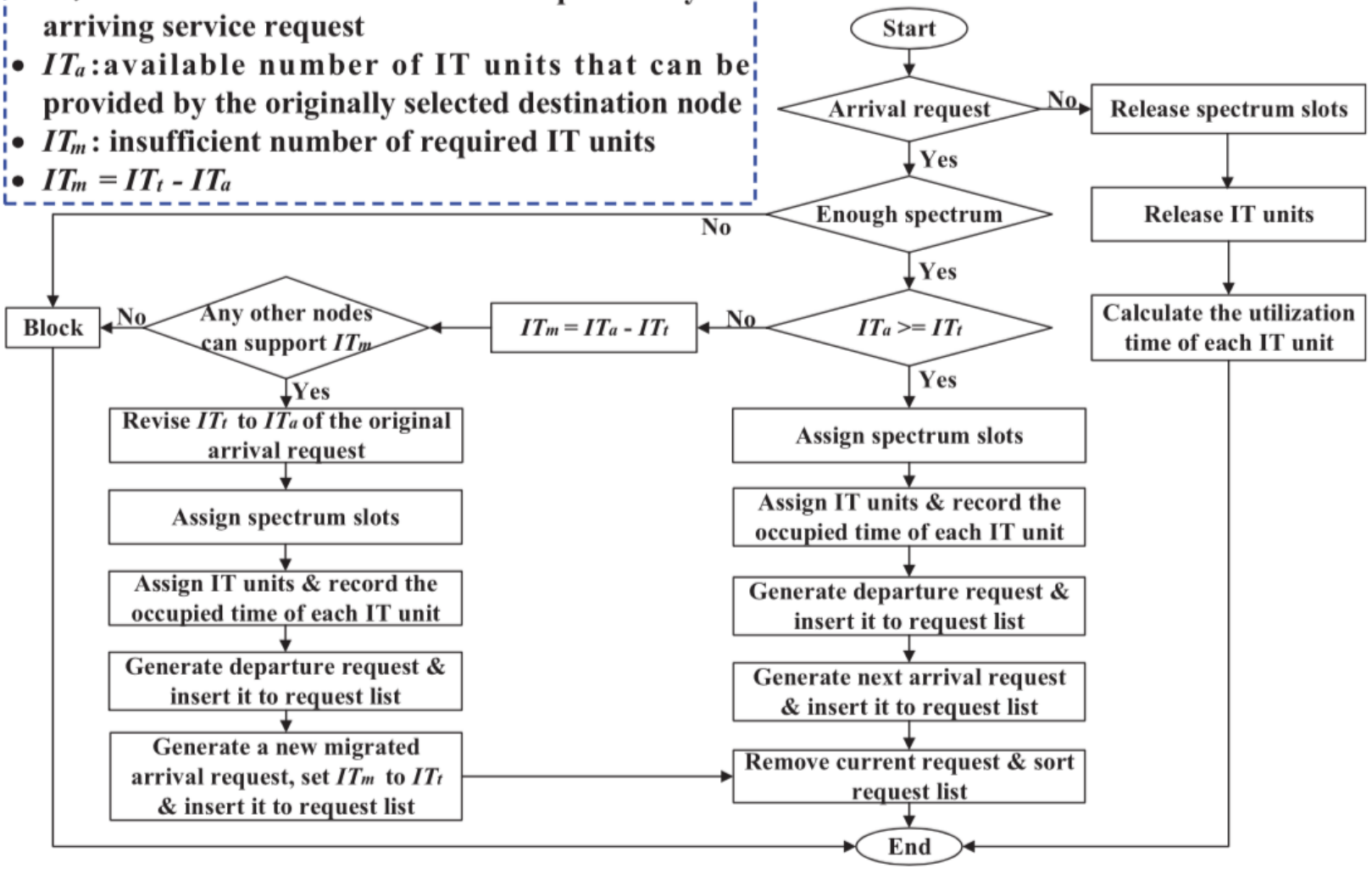
- **Full migration**
- **Partial migration**

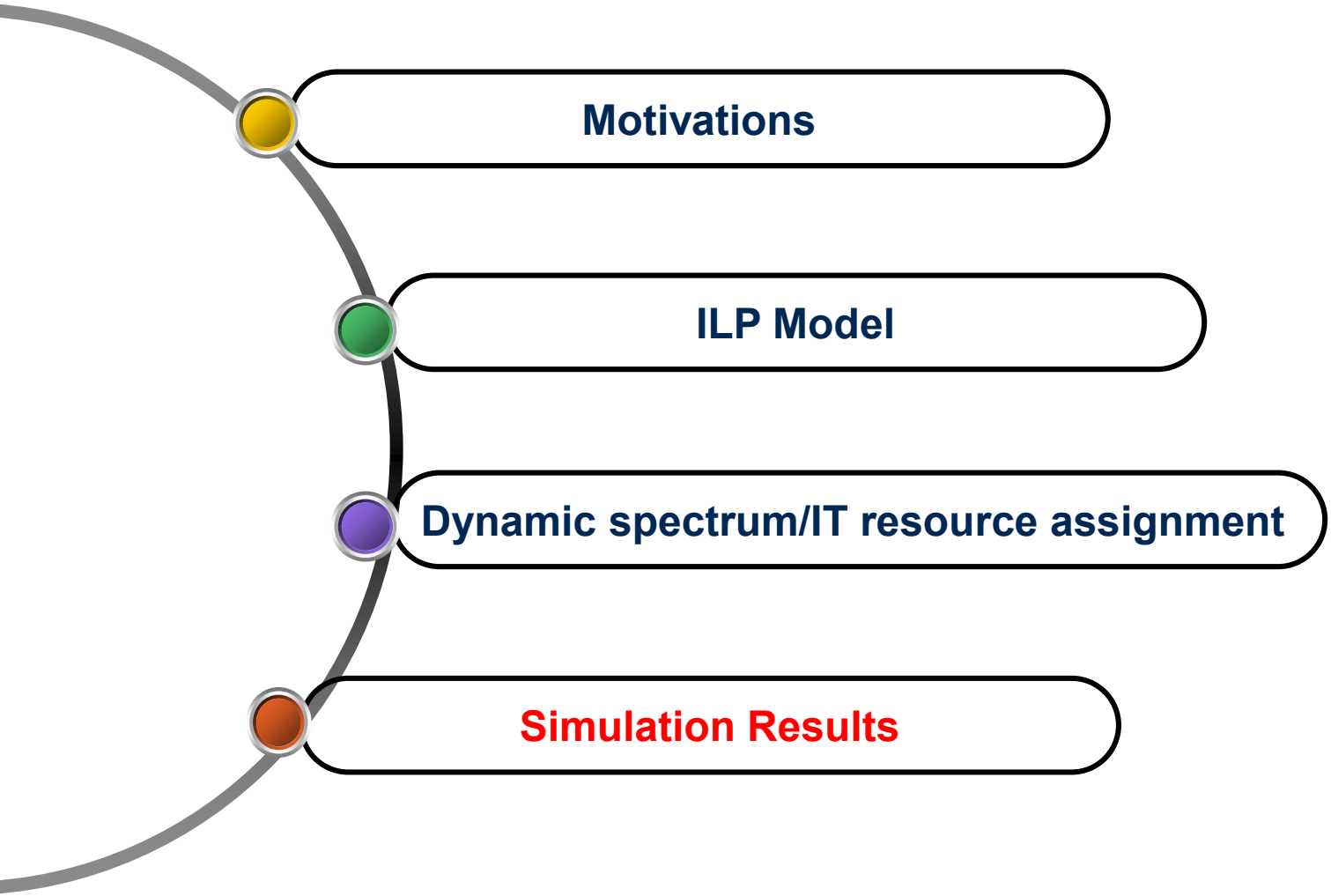
Full Migration Algorithms FOR DYNAMIC RSIA



Partial Migration Algorithms FOR DYNAMIC RSIA

- IT_t : total number of IT units required by an arriving service request
- IT_a :available number of IT units that can be provided by the originally selected destination node
- IT_m : insufficient number of required IT units
- $IT_m = IT_t - IT_a$

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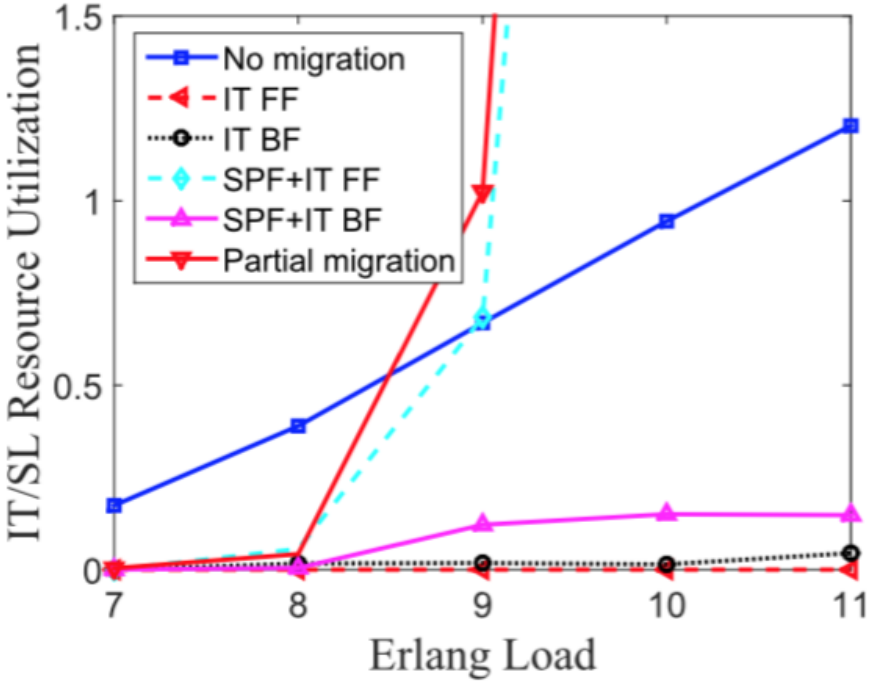
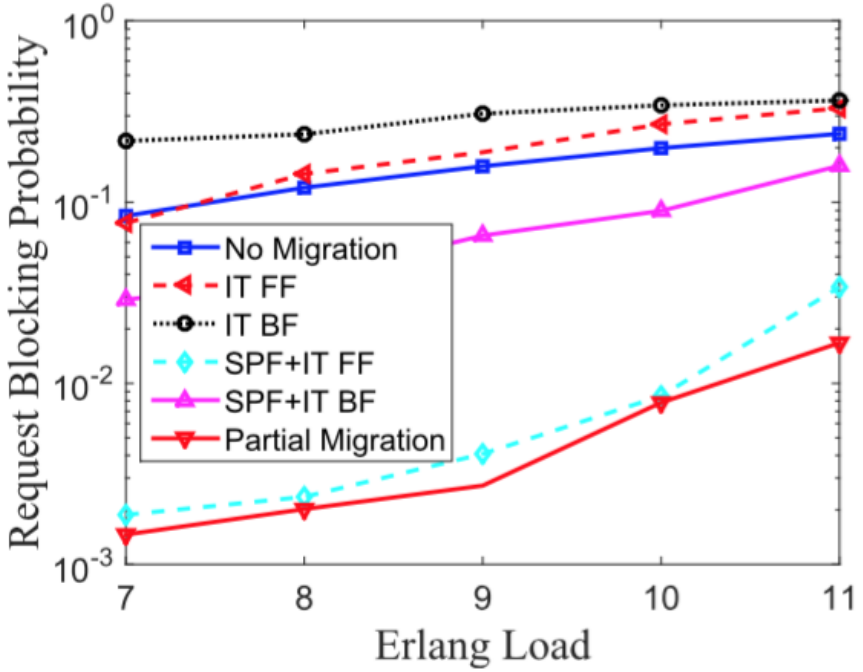
Simulation Results for A 4-cube Intra-DCN

- 4-cube intra-DCN
- 16 pods and 32 optical fiber links
- 400 IT units per pod
- 5 GHz spectrum slot



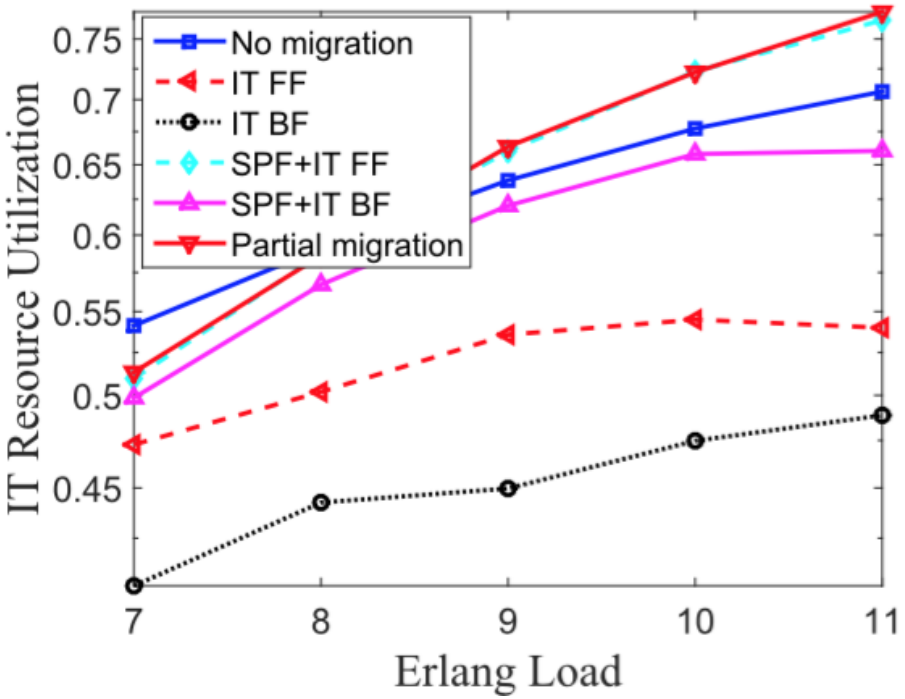
Loss ratio of IT units to spectrum slots.



Service-request blocking probability.

Simulation Results for A 4-cube Intra-DCN

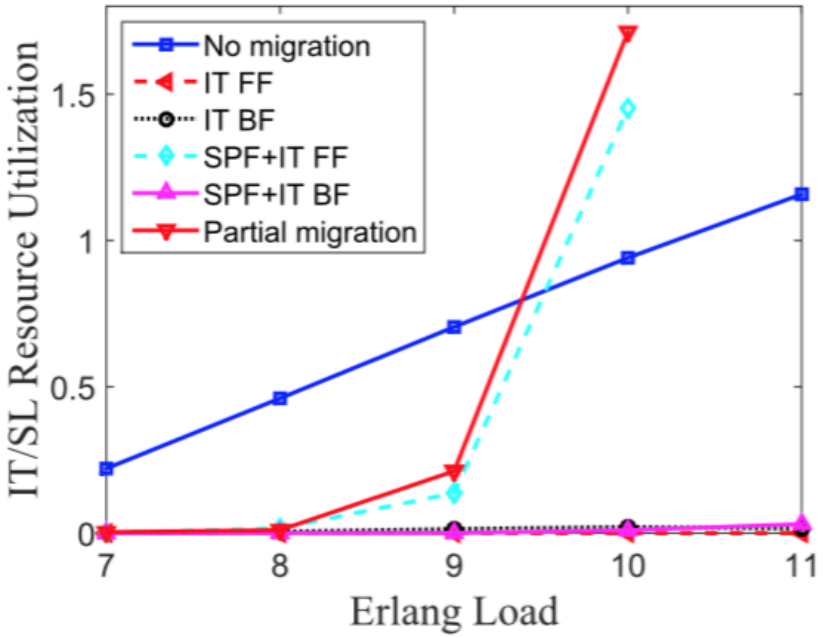
- 4-cube intra-DCN
- 16 pods and 32 optical fiber links
- 400 IT units per pod
- 5 GHz spectrum slot



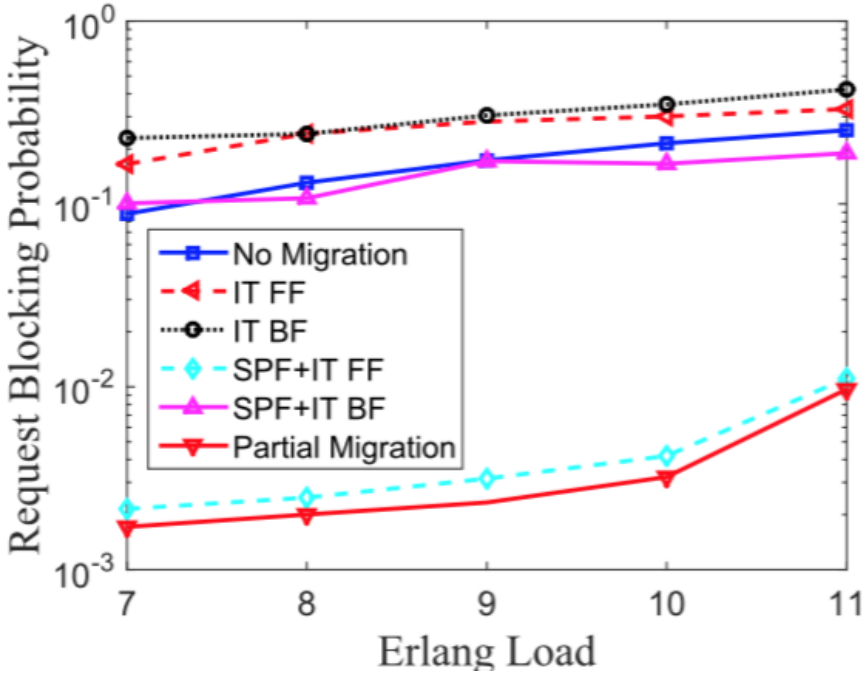
IT resource utilization.

Simulation Results for A 4-by-4 Torus Intra-DCN

- 4-by-4 torus intra-DCN
- 16 pods and 32 optical fiber links
- 200 IT units per pod
- 5 GHz spectrum slot



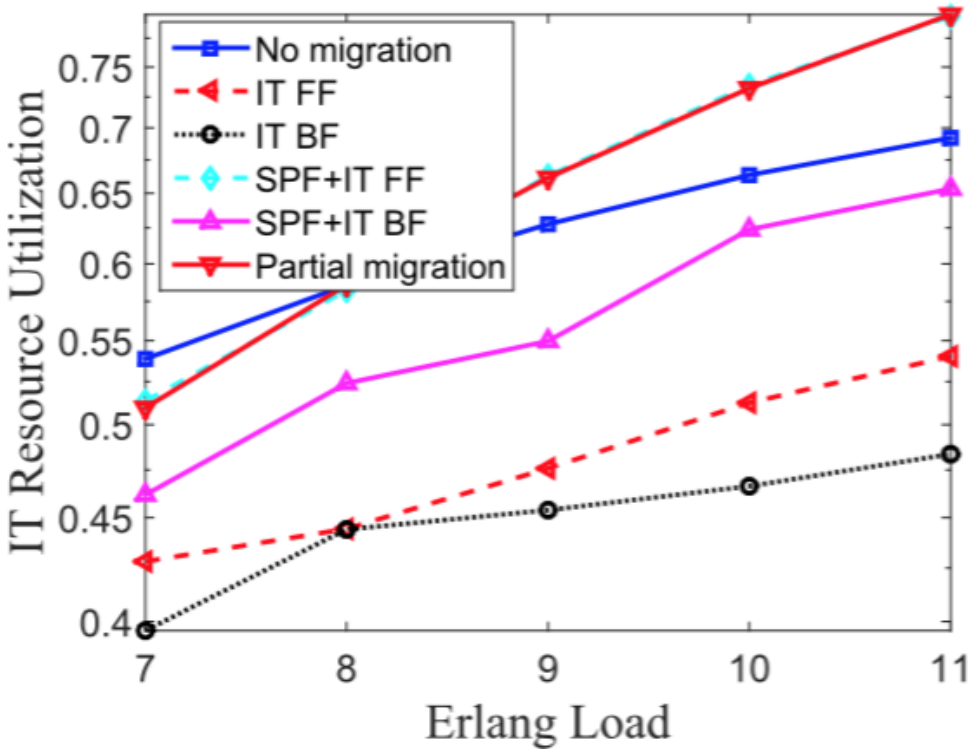
Loss ratio of IT units to spectrum slots



Service-request blocking probability

Simulation Results for A 4-by-4 Torus Intra-DCN

- 4-by-4 torus intra-DCN
- 16 pods and 32 optical fiber links
- 200 IT units per pod
- 5 GHz spectrum slot



Thank You !

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