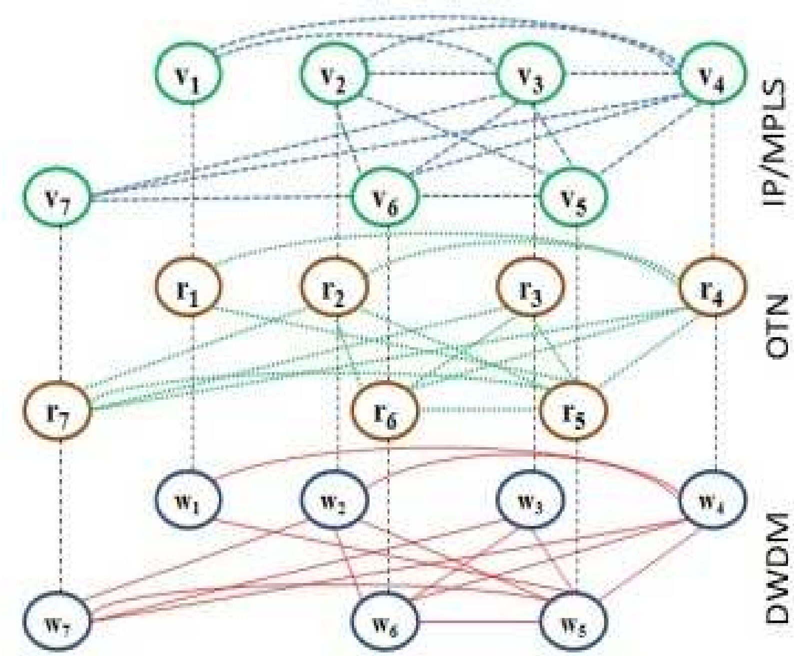
A Study on Layer Correlation Effects Through a Multilayer Network Optimization Problem

Iyad Katib and Deep Medhi

Presented at ITC 2011
San Francisco, USA
September 2011

Main Contributions and Problem Considered

- IP/MPLS over OTN over DWDM network optimization model.
- Three-layer modeling.
- OTN sublayer technological constraints explicitly considered.
- Layers' modularity.
- Comprehensive study.
  - Varying layers' costs and parameters to understand the correlation effects between the layers.



Presentation Outline

- Introduction.
  - OTN Overview.
  - Motivation.
  - Related Work.
- IP/MPL and OTN Layer Correlation Effects.
  - Scope of Study.
  - Three-layer Design Model.
  - Study and Results.
  - Summary.

What is OTN?

- **O**ptical **T**ransport **N**etwork.
- A new-generation transmission layer technology.
- Large-granule broadband service transmissions.
- A "digital wrapper" layer.
- Efficient multiplexing and switching of high-bandwidth signals.

OTN Signals

- Optical Data Unit (ODU) layer.
- ODU_k Multiplexing.

U_k Signal	Bit-Rate (Gbps)	Max. U_ks in a wavelength
U_0	1.25	80
U_1	2.5	40
U_2	10	10
U_3	40	2
U_4	100	1

Research Motivation

- Problems with 2-layer architectures.
  - IP/MPLS over point-to-point WDM.
    - EOE conversion.
    - Routers' capacity heavily consumed by forwarding services.
    - More time to detect failure at WDM.
  - IP/MPLS over WDM (with OXCs).
    - No explicit consideration for the technological constraints of the middle layer.
- Our approach:
  - Three-Layer IP/MPLS over OTN over WDM.
    - Separates the logical from the physical topologies.
  - Explicitly consider the OTN layer.

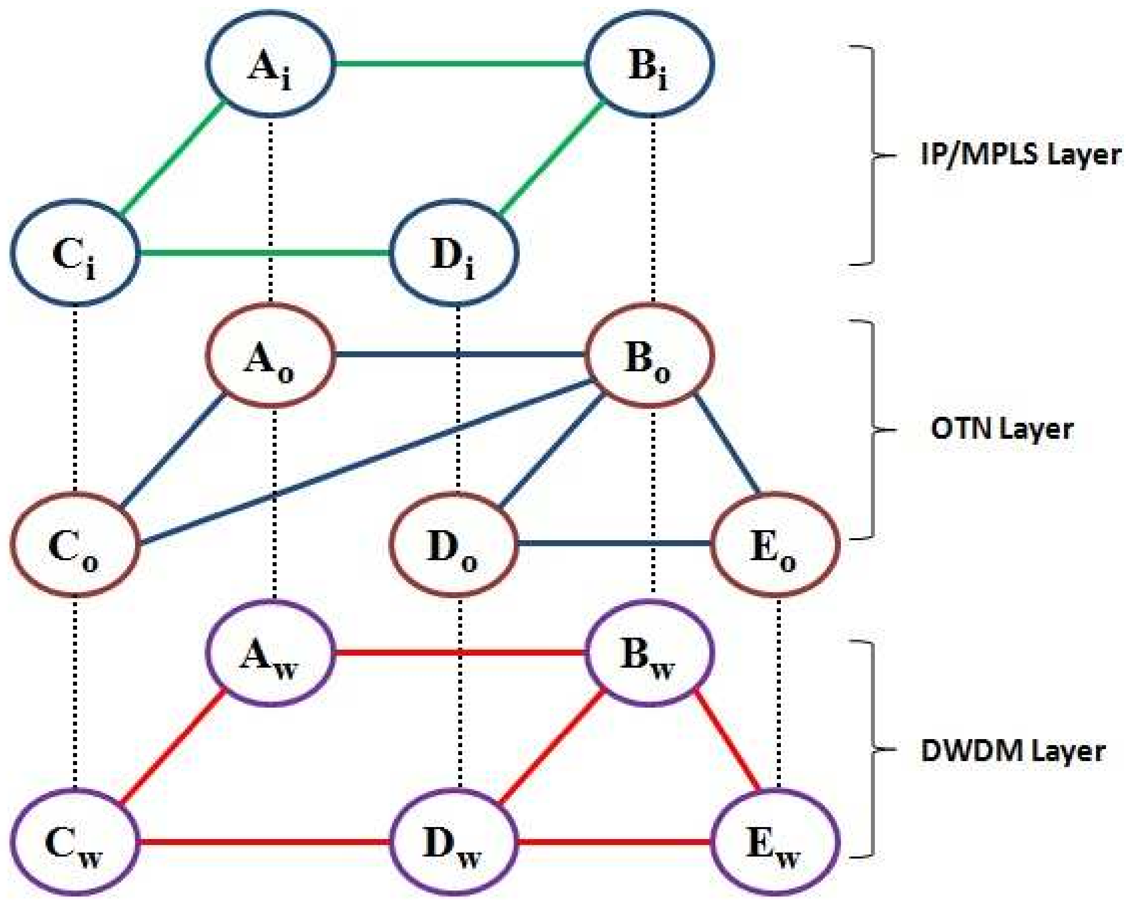
Related Work I

- OTN:
  - G.709 Hierarchy Optical Transport Core Network Design, Requirements and Challenges. [Nee Ben Gee(2009)]
  - Interworking of IP and OTN networks – making IP over OTN a reality. [Nowell(2009)]
  - Optical transport networks: From all-optical to digital. [Puglia(2009)]

Related Work II

- Multilayer Networks:
  - IP over SONET. [J. Manchester(1998)]
  - Cost comparison of IP/WDM vs. IP/OTN for European backbone networks. [I. Tsirilakis(2005)]
  - Survivable MPLS Over Optical Transport Networks: Cost and Resource Usage Analysis. [W. Bigos(2007)]
  - Dynamic LSP Routing in IP/MPLS over WDM Networks. [S. Koo(2006)]
  - Two design problems for the IP/MLPS over WDM networks. [E. Kubilinskas(2005)]
- The OTN layer has not been explicitly considered.
- No work found on Three-Layer networks in which the technological constraints of the middle sub-layer are explicitly considered.

Model: Key Concept



Notations I

Indices:

D: Set of demands between source-destination pairs of the IP/MPLS layer.

P_d: Set of candidate paths for demand $d \in D$.

E: Set of links in the IP/MPLS layer.

Q_e: Set of candidate paths at the OTN layer for $e \in E$.

G: Set of links in the OTN layer.

Z_g: Set of candidate paths of DWDM layer for for $g \in G$.

F: Set of links at the DWDM layer.

$K = \{1, 2, 3\}$: Set of modular interfaces of OTN link g.

Constants:

h_d: Volume of demand $d \in D$.

δ_{edp}: =1 if link e belongs to path p realizing demand d; 0, otherwise.

γ_{geq}: =1 if link g belongs to path q realizing capacity of link e; 0, otherwise.

ϑ_{fgz}: =1 if link f belongs to path z realizing capacity of link g; 0, otherwise.

M: Module size for IP/MPLS layer.

U_k: Module size for OTN layer capacities $k \in K$.

N: Module size for DWDM layer link capacities.

η_e: Cost of one capacity unit of module M of the IP/MPLS layer link e.

β_{gk}: Cost of one capacity unit of module type U_k of the OTN layer link g.

α_{gkz}: Routing cost of the DWDM layer.

b_f: Number of modules N to be installed on link f in the DWDM layer (non-negative integral).

Notations II

Variables:

x_{dp}: IP/MPLS flow variable realizing demand d allocated to path p (non-negative, binary).
m_{eq}: OTN flow variable allocated to path q realizing capacity of link e (non-negative integral).
s_{gkz}: DWDM flow variable allocated to path z realizing capacity of link g of interface k (non-negative integral).
y_e: Number of modules M to be installed on link e in the IP/MPLS layer (non-negative integral).
w_{gk}: Number of modules U_k to be installed on link g in the OTN layer (non-negative integral).

Constraints

$$\sum_{p=1}^{P_d} x_{dp} = 1, \qquad d \in D \qquad (1)$$

$$\sum_{d \in D} h_d \sum_{p \in P_d} \delta_{edp} x_{dp} \leq M y_e, \qquad e \in E \qquad (2)$$

IP/MPLS layer

$$\sum_{q \in Q_e} m_{eq} = y_e, \qquad e \in E \qquad (3)$$

Demand on OTN layer

$$M \sum_{e \in E} \sum_{q \in Q_e} \gamma_{geq} m_{eq} \leq \sum_{k \in K} U_k w_{gk} \qquad g \in G \qquad (4)$$

Capacity of OTN layer

$$\sum_{z \in Z_g} s_{gkz} = w_{gk}, \qquad k \in K \quad g \in G \qquad (5)$$

Demand on DWDM layer

$$\sum_{g \in G} \sum_{k \in K} U_k \sum_{z \in Z_g} \vartheta_{fgz} s_{gkz} \leq N b_f, \qquad f \in F \qquad (6)$$

Capacity of DWDM layer

Objective Function

- Optimization problem (**P**) can be written as:

$$\text{Minimize} \quad \sum_{e \in E} \eta_e y_e + \sum_{g \in G} \sum_{k \in K} \beta_{gk} w_{gk} + \sum_{g \in G} \sum_{k \in K} \sum_{z \in Z_g} \alpha_{gkz} s_{gkz}$$

subject to the set of constraints (1)–(6).

- Optimal Solution gives the minimum numbers of capacity modules (IP/MPLS layer), and OTN signals (OTN layer).

Scope of Study

When DWDM capacity is fixed:

- How do the IP-cost and size of *M* influence the types and numbers of U_k signals at the OTN layer?
- What role does the size of *M* play on each layer and on the overall cost?
- How does the cost of each U_k scenario affect the final types and numbers of U_k s needed to satisfy a given set of demands?
- How does increasing the demands load affect the OTN layer?

Study and Results

Parameters Values:

α_{gkz} 10 % of the U1 cost.

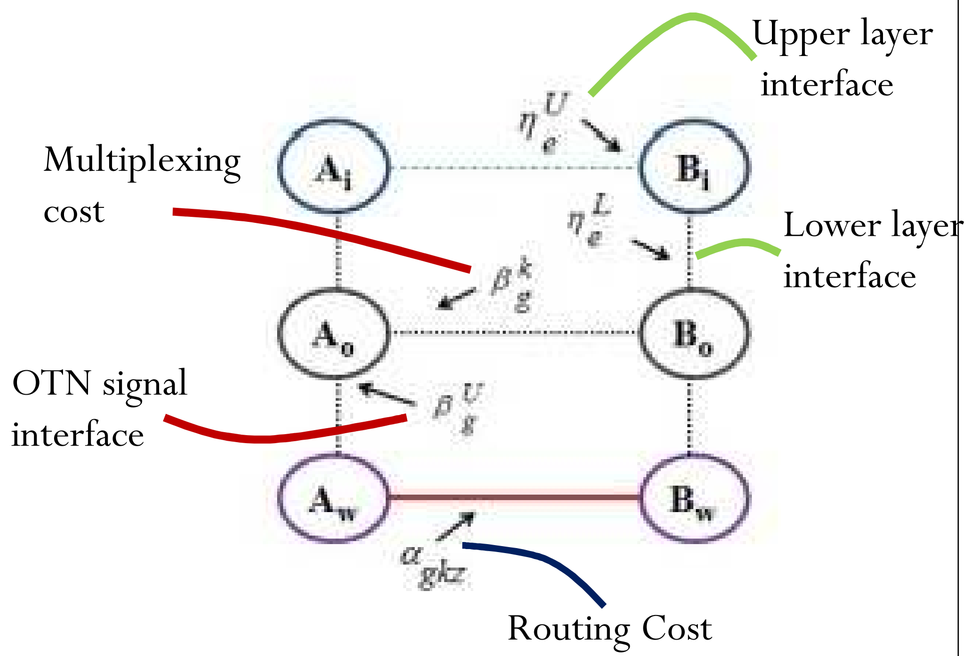
U_1, U_2, and U_3 are considered.

Cost ratio of network elements:
Transponder, IP/optical interface, OXC:
8, 0.5, 1 → case1

Another cost ratio of network elements:
1, 8, 0.5 → case3

IP cost reduced by 50% → case2

Cost Model:



U_k-cost relationships

UK-cr1: $2\ U_k = U_{k+1}$
UK-cr2: $3\ U_k > U_{k+1}$
UK-cr3: $3\ U_k = U_{k+1}$

	Unit Cost Values		
Cost Notation	Case1	Case2	Case3
IP-cost (η_e)	3	9	17
U_k-cost (β_{gk})	3/6/12, 3/7/18, 3/9/27	2/4/8, 2/5/12, 2/6/18	2/4/8, 2/5/12, 2/6/18

Avoid unrealistic U_k-cost relationships:

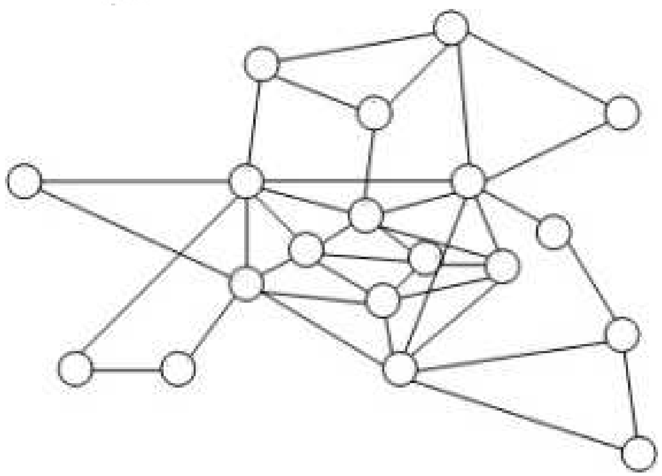
$U_k = U_k+1$
E.g. $1U_1 = 1U_2$ (equal cost of two different signals)

or $4U_k = U_k+1$
E.g. $4U_2 = U_3$ (follows a multiplexing rule)

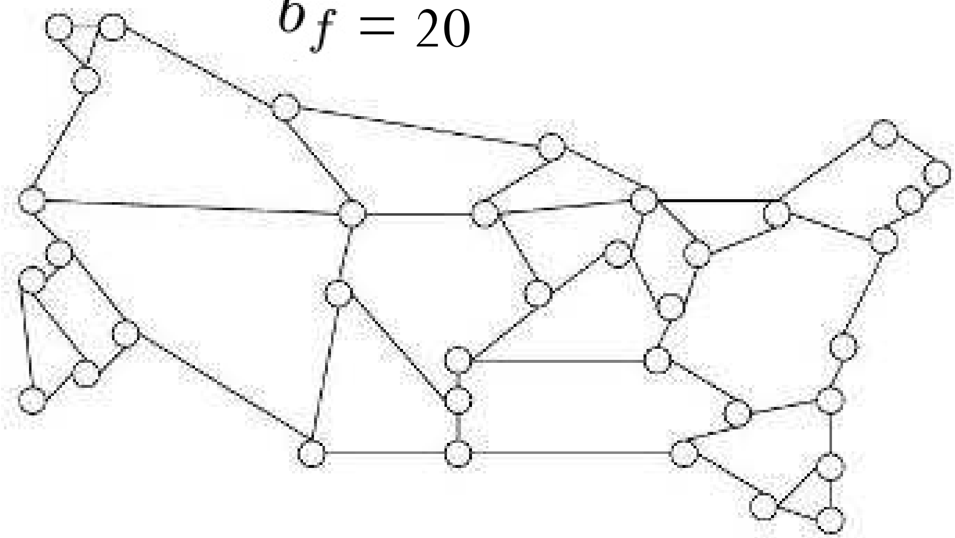
or $4U_k > U_k+1$
E.g. $4U_2 > U_3$ (U_2 will never be used)

Network Topologies and Demands

19-node per layer EON
$b_f = 10$

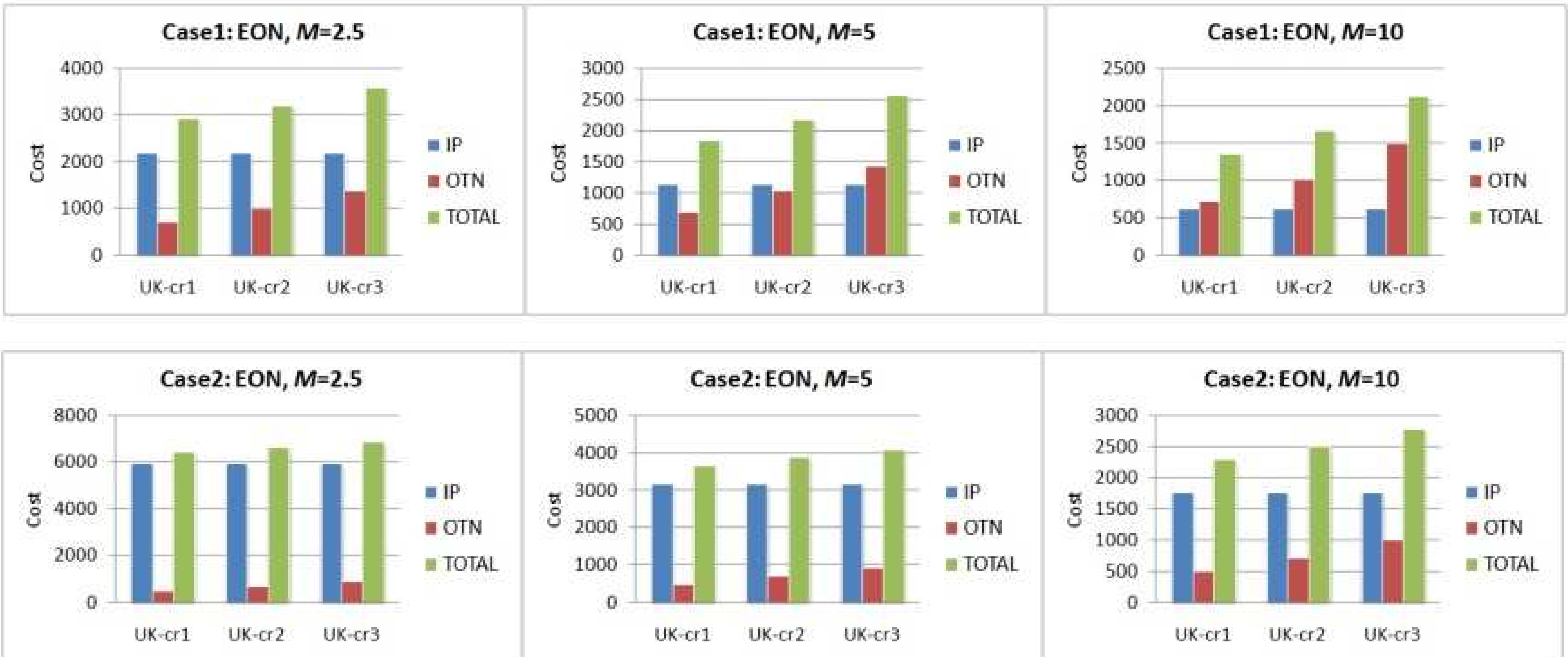


36-node per layer Sprint
$b_f = 20$



Network	No. of Nodes per Layer	No. of Physical Links (F)	Total load	No. of D	Avg. Load/d
EON	19	35	855	171	5
SPRINT	36	54	3,150	630	5

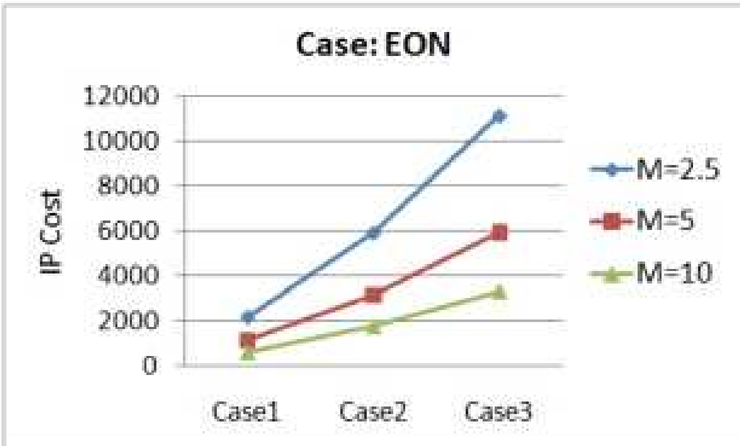
Interrelated Cost of Both Layers

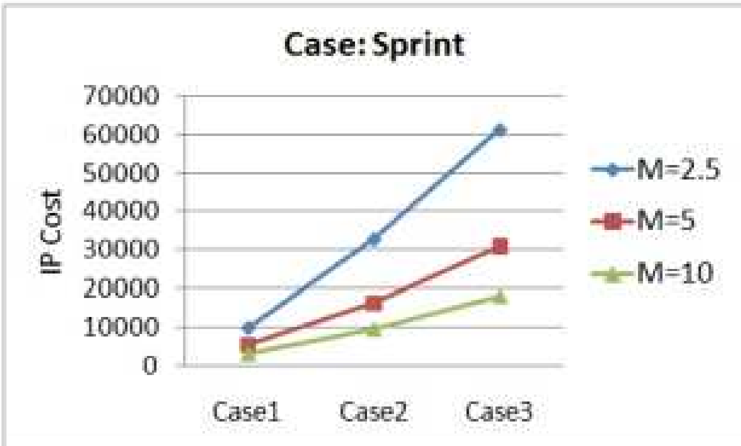


The influential cost depends on the relationship between the IP-cost and the U_k cost, and on the value of *M*.

The OTN cost is negligible except in Case1 when the IP/optical interface is relatively cheap, *M* is equal or above the average demand, and U_k-cost: UK-cr3 .

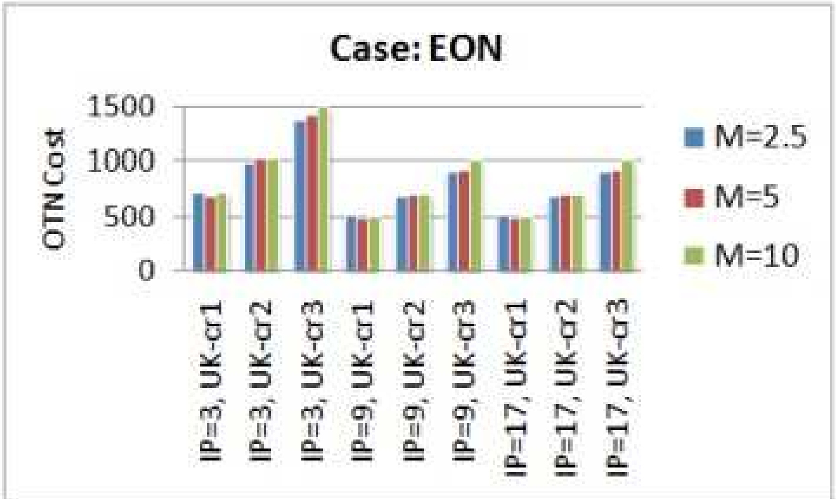
IP Cost

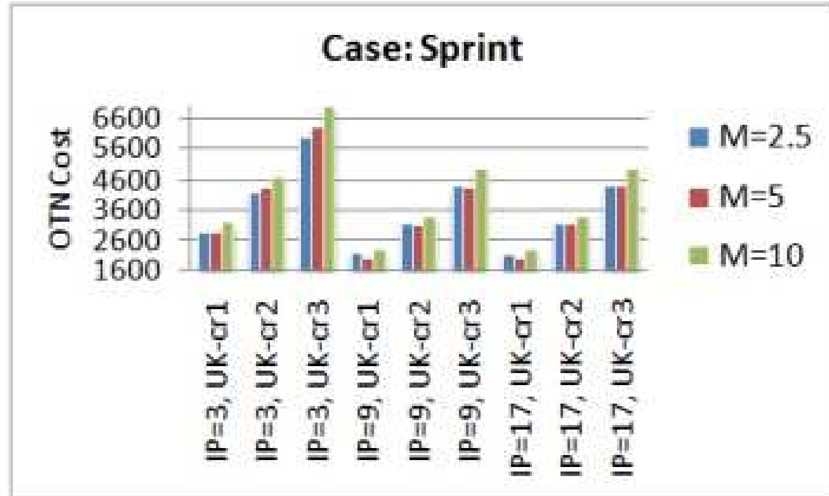




Always M=10 is best to minimize the total IP-cost.

OTN Cost



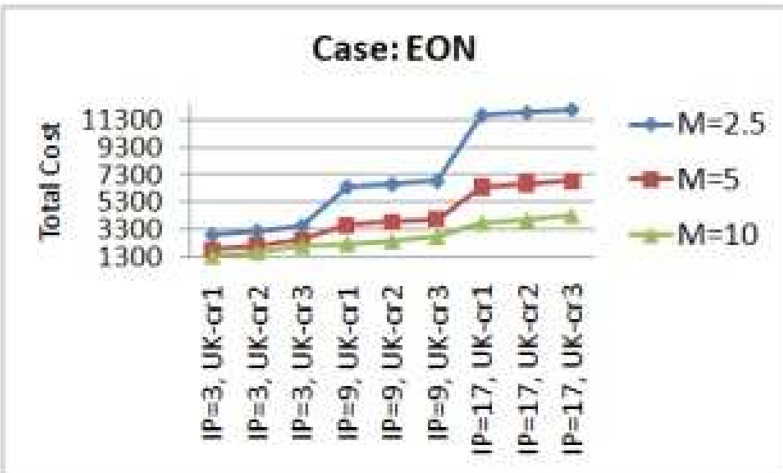


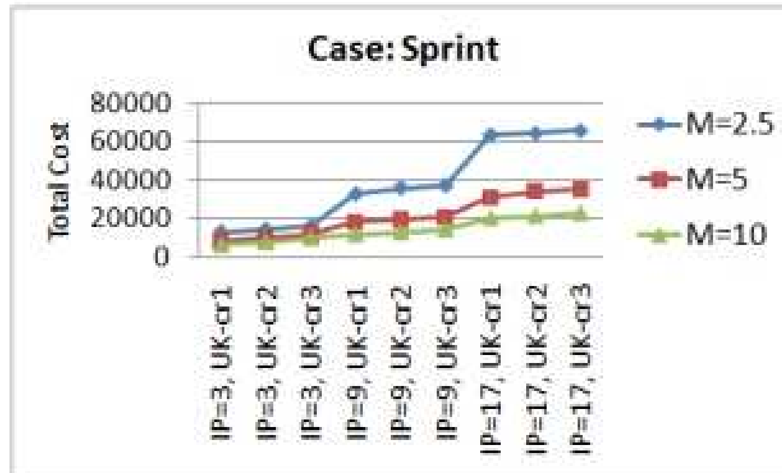
•*M* below or equal the average demand is the best choice when the goal is to minimize the OTN layer cost.

•Note the close cost values of Case2 and Case3.

- •Reducing the IP/optical interface by 50% does not have a significant impact on the OTN overall cost for the same Uk-cost. (It may effect the signals type and number though).

Total Cost





- *M*= 10 has the best cost performance.
- Note the close performance for Case1.
- As we increase the IP unit cost we see the performance difference is increasing.
  - This is largely because of the increasing IP unit cost that is the dominant cost in most cases.

Table Summary of U_ks

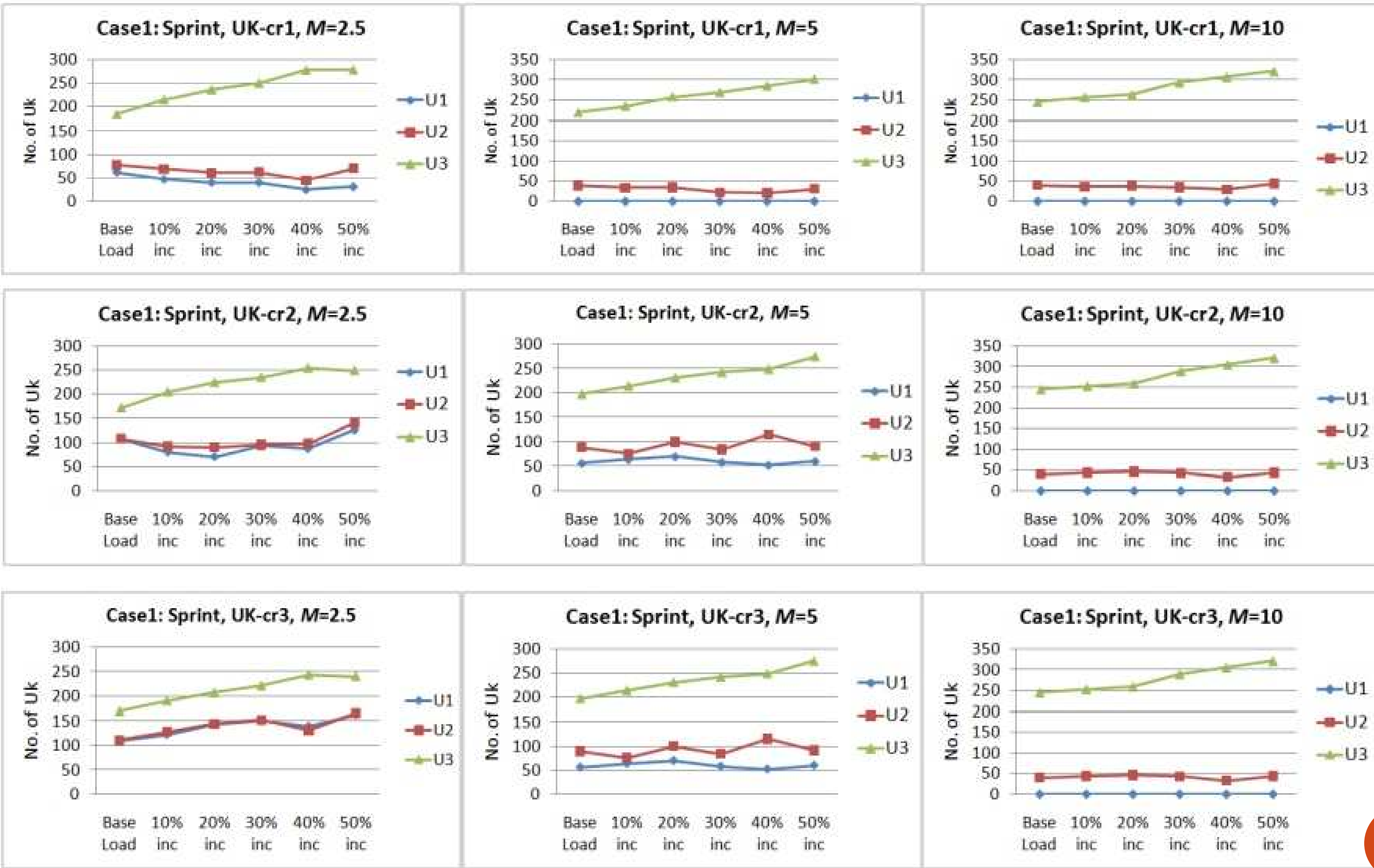
EON

	UK-cr1: 2 $U_k = U_{k+1}$						UK-cr2: 3 $U_k > U_{k+1}$						UK-cr3: 3 $U_k = U_{k+1}$					
	$M = 2.5$		$M = 5$		$M = 10$		$M = 2.5$		$M = 5$		$M = 10$		$M = 2.5$		$M = 5$		$M = 10$	
	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3
U_1	M	H	-	-	-	-	H	$\uparrow$	M	H	-	-	H	$\uparrow$	M	H	-	-
U_2	M	$\downarrow$	M	H	M	H	H	$\uparrow$	H	H	M	H	H	$\uparrow$	H	H	M	H
U_3	H	$\downarrow$	H	$\downarrow$	H	$\downarrow$	H	M	H	M	H	$\downarrow$	H	M	H	M	H	$\downarrow$

Sprint

	UK-cr1: 2 $U_k = U_{k+1}$						UK-cr2: 3 $U_k > U_{k+1}$						UK-cr3: 3 $U_k = U_{k+1}$					
	$M = 2.5$		$M = 5$		$M = 10$		$M = 2.5$		$M = 5$		$M = 10$		$M = 2.5$		$M = 5$		$M = 10$	
	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3	C1	C3
U_1	L	$\downarrow$	-	-	-	-	M	$\downarrow$	L	M	-	-	M	$\downarrow$	L	M	-	-
U_2	M	$\uparrow$	L	$\uparrow$	L	$\uparrow$	M	H	L	$\uparrow$	M	H	M	H	M	H	L	$\uparrow$
U_3	H	$\uparrow$	H	$\uparrow$	H	$\uparrow$	H	$\uparrow$	H	$\downarrow$	H	$\uparrow$	H	$\uparrow$	H	$\uparrow$	H	$\uparrow$

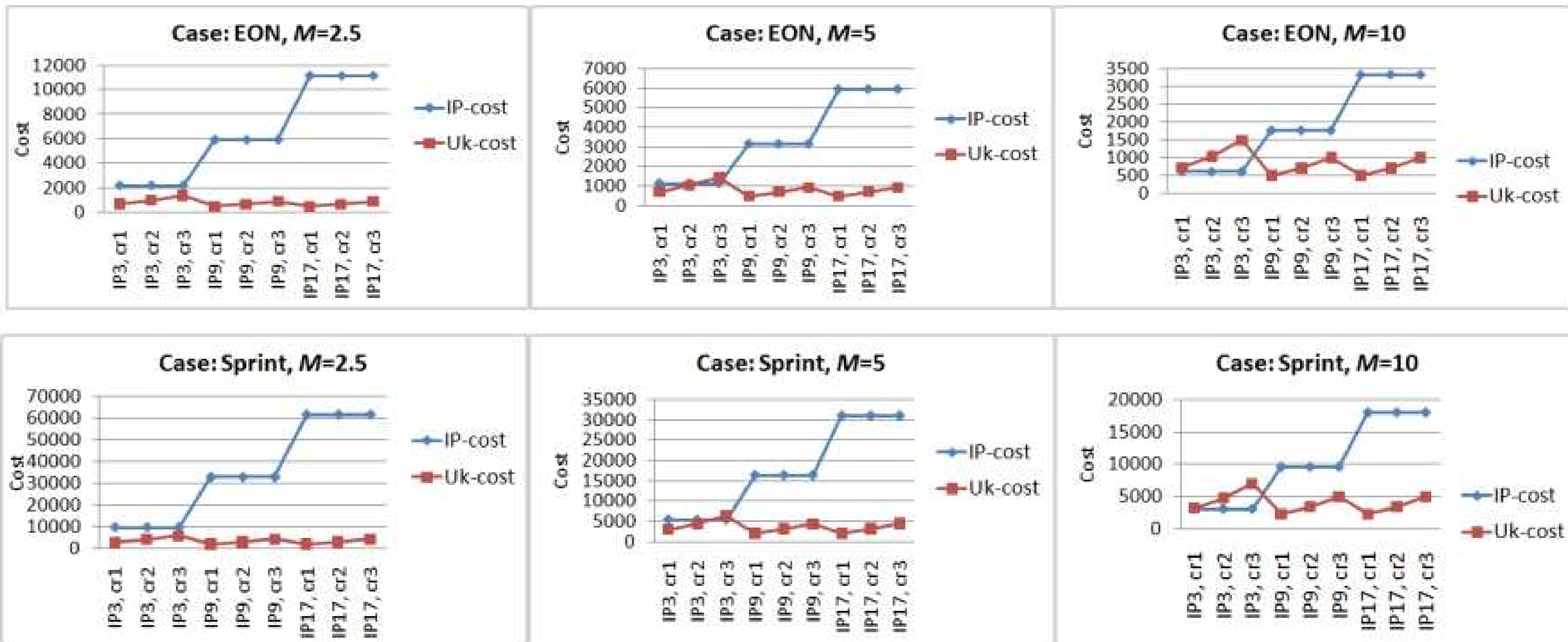
Effects of Load Increase on No. of U_k (Sprint)



Summary

- *M* above the average demand is the best case that minimizes the cost of the IP/MPLS layer and overall network cost.
- *M* below or equal the average demand is the best case that minimizes the OTN layer cost.
- We note the close cost performance of Case2 and Case3, which indicates that reducing the IP/optical interface by 50% does not have a significant impact on the OTN overall cost for the same Uk-cost. However, it may effect the required signals type and numbers.
- The numbers and types of U_k needed to satisfy the demands are noticeably influenced by three elements: the size of *M*, and the Uk-cost, and the demand volume.
- The IP unit cost is not as influential as its size *M*.
- The sum of all U_ks, in terms of bandwidth, is close for each UK-cr scenario. What changes is the types and numbers of U_ks used. Difference is usually within 2%.
- Generally, increasing the demands will lead to either more U_1s or U_2s and certainly more U_3s.

IP-cost vs. U_k-cost

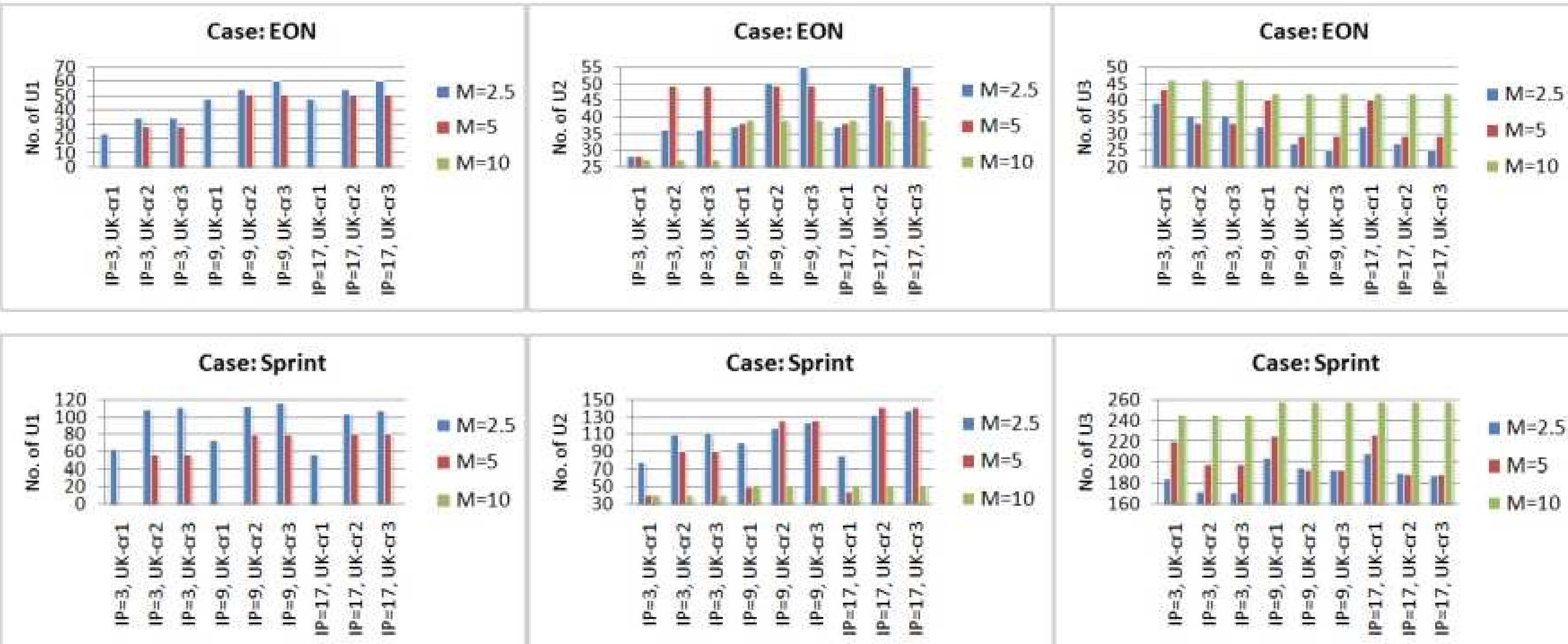


The OTN cost is negligible except in Case1 when the IP/optical interface is relatively cheap:

•M=5, and UK-cr2 and UK-cr3.

•M=10, all UK-cr scenarios.

Numbers of U_ks



U_1 is not used when M=10 and when M=5 and UK-cr1.

U_1 is larger when M=2.5

U_2 is increased as we go from UK-cr1 to UK-cr3.

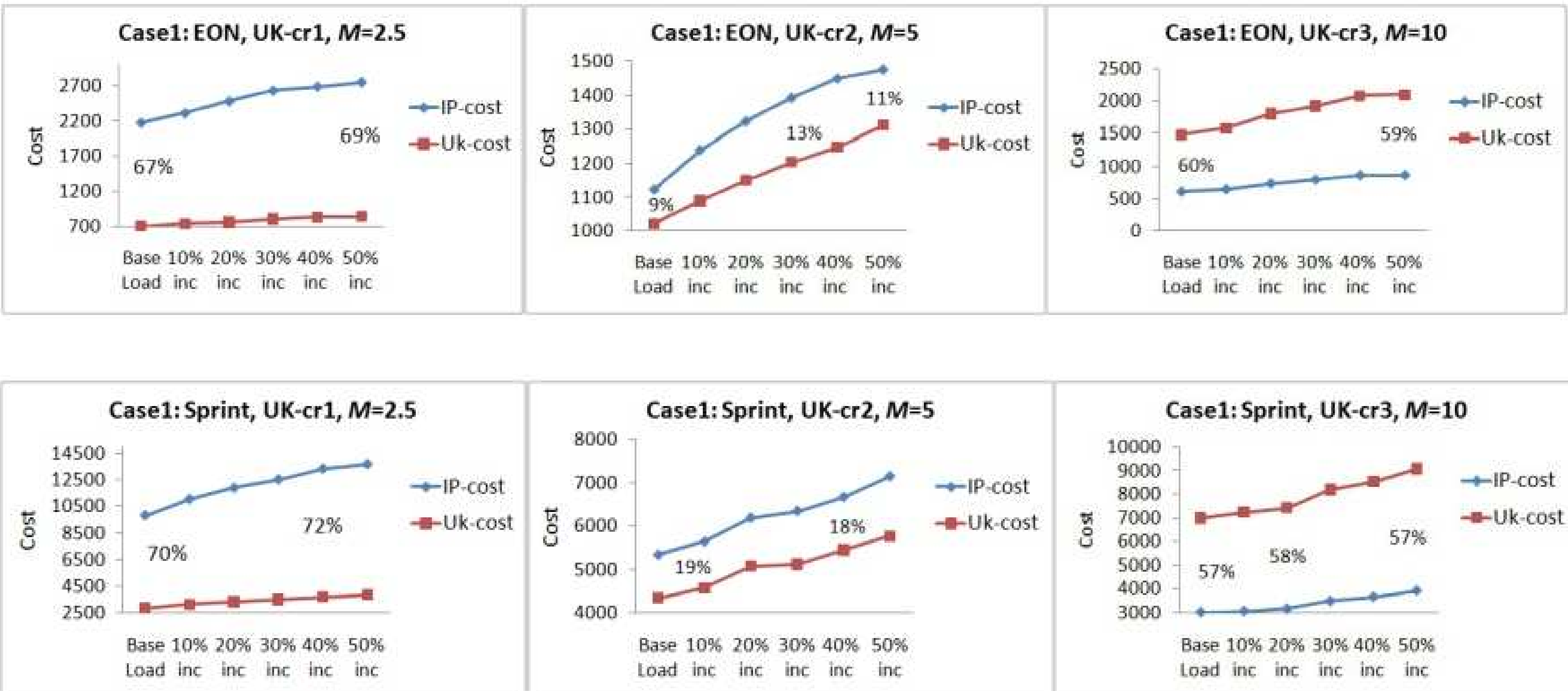
U_2 is lower when M=10.

U_2 is increased as we go from Case1 to Case2 and Case3.

U_3 is increased as we increase M.

U_3 is decreased as we go from Case1 to Case2 and Case3.

Effects of Load Increase on IP vs. U_k Cost



The gap between the IP-cost and Uk-cost remains within ± 2%.

Effects of Load Increase on No. of U_k (EON)