Performance Evaluation of Optimal Interconnection-based Routing Algorithms in Multi-operator Telecommunication Network

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Abstract

This paper is concerned with the analysis of optimal routing problem in the heterogeneous environment of telecommunication networks, where more than one operator is responsible for all the network controls. The objective is to evaluate candidate routing algorithms which allow a given network to optimize specified objective functions. Based on the framework of interconnection, four routing algorithms are proposed, namely, (i) shortest path routing with no interconnection charge, (ii) cost-based shortest path routing with interconnection charge, (iii) resource-based shortest path routing with interconnection charge and (iv) dynamic alternative routing with interconnection charge. Discrete-event simulation of practical network scenarios are given to show how these routing algorithms perform comparatively in terms of both engineering grade-of-service indicators and business measures (i.e. call blocking, network utilization as well as mean values of servicing cost, network revenue and obtainable profit). The obtained results suggest that the dynamic alternative routing with interconnection charge is the most preferrable routing algorithm when the network has light loads. Alternatively, under heavy loads, it is found that the resource-based shortest path routing with interconnection charge is the best.

I. Introduction

In the emerging information era, telecommunication networking has been widely recognized as a necessary driving force to achieve a better quality of life for the global society as a whole. For countries around the world, their telecommunication infrastructures were in the past mainly designed, built and maintained by a monopolized state organization. This type of financing framework has been proved successful.

However, recent increase in people's demand for universal telecommunication services made this limited state-own business meet its own limitations. To overcome this constraint, telecommunication markets have been transformed from the state monopoly into the more open framework in which private companies were invited to participate. This indispensably leads to the telecommunication network environment with multiple operators. An example of multi-operator network is depicted in Fig. 1.

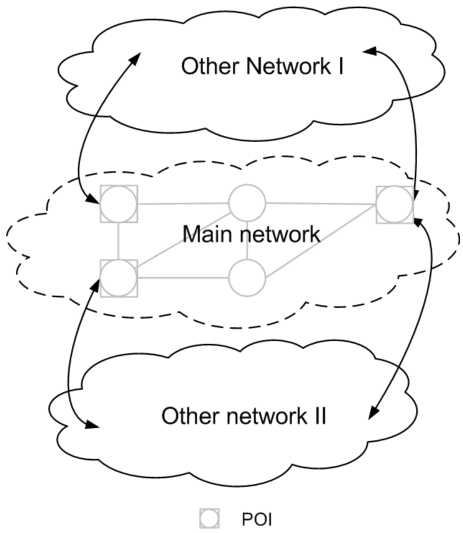

Fig. 1. Main network interconnected with other clouds.

On one hand, viable competition amongst operators sharing a single market raises the question on how each operator can manage its own network's internal mechanisms to maintain its competitiveness. On the other hand, with the nature of networking, each operator needs to cooperate with the others in order to guarantee the overall connectivity for customers. A mutual framework that may allow both competition and cooperation to coexist exists under the concept of interconnection tariff.

Interconnection is defined in different ways in the different regulatory and policy regimes that deal with it. A good recent definition is included in the 12 July 2000 proposed by the European Commission Directive on Access and Interconnection [11]. Interconnection means the physical and logical linking of public electronic communications networks used by the same or a different undertaking in order to allow the users of one undertaking to communicate with the users of the same undertaking, or to access services provided by another undertaking. Services may be provided by the parties involved or other parties who have accesses to the network. By this definition, an interconnection policy affects directly the telecommunication service model as well as business chances to all operators.

Interconnection of telecommunication network has been important for a century, but never more so than today. Competition is the key to growth and innovation of today's telecommunication markets. Interconnection is a critical factor for the viability of competition. An operator with readily available interconnections can have the advantageous power, which may be excercised to obstruct as well as to support other operators in the market. So, the benefits of providing telecommunication services are heavily dependent on how these interconnections have been managed [1], [2].

¿From the engineering viewpoint, interconnection routing may be considered a key mechanism to control telecommunication network dynamics. Upon an arrival of new customer demanding for a connection across a telecommunication network, the embedded network routing module has to make two-step decisions. The first step is to decide on whether to admit or to reject that customer's request. Given the admission of customer, the second step is then to choose the most appropriate path from the customer's origin to its intended destination. Never before has routing problem a need to incorporate the interconnection constraint of multi-operator networking environment.

In the literature, there exist many interesting research work focusing on routing problems within networks owned by a single operator (e.g. [3], [4]). As a multi-operator, multi-domain environment becomes critical in providing an end-to-end telecommunication connectivity, the problem of routing in such multi-domain network has then been addressed (e.g. [5], [6]). In [5], a minimum cost routing algorithm has been proposed, where the cost function is defined in terms of the quality of service (QoS) index like end-to-end packet transmission delay. Along the same line of investigation, in [6], fairness has been additionally included in the formulation of QoS routing. However, to the best our our knowledge, there has not been any work on routing literature that takes into account the explicit cost of interconnection.

In this research, a new performance evaluation study has been carried out for optimal routing algorithms in a multi-operator telecommunication network. Routing performance is herein characterized by both the engineering and business measures. The study has considered main grade of service (GoS) indicators including the customer blocking probability as well as the percentage utilization of network resources. Further, mean network revenue, servicing cost and achievable profits have been taken into account.

The objective of this research is to investigate candidate routing algorithm which allow a given network operator the maximum possible profit. In doing so, the well-known shortest path algorithm is applied and the algorithm's cost function is newly defined by taking into account the routing cost within the considered network as well as the cost of routing calls across the networks owned by different operators. Interconnection concept has been used to model the cost of routing traffics across network operators.

The remainder of this paper is organized as follows. Section II presents the problem formulation where the definition of network and cost characteristics is given. In Section III, three optimal routing algorithms and an adaptive routing algorithm are proposed for multi-operator networks with interconnection concept. To evaluate the performance of these algorithms, Section IV gives the explanation of network experimental settings. The obtained results of network simulation are then discussed in Section V. Finally, Section VI gives the summary of findings in this paper.

II. Problem Formulation

In a multi-operator regime, the networks of different operators are connected with each other via so-called *point of interconnection* (POI). When an operator needs to send traffics from their network to the other networks, they are required to route traffics through available POI's. The cost of a telecommunication connection is therefore consisted of both the internal cost incurred within the operator's own network and the access cost due to fees that need to be paid to the other operators for utilising their network resources.

A. Network Characteristics

In this paper, the focus is on analysing the routing performance from the viewpoint of a given network operator, whose telecommunication infrastructure is referred to as *main network*. The exact topology and capacity of main network is presumeably made known to the operator's network engineers. Furthermore, it is assumed that the engineers have a complete controllability over the choices of route management within their main network. However, in order to reflect the reality of internetworking, it is not assumed that the engineers have controls over the networks belonging to the other operators. Routing traffics to other networks can only be requested via a set of POI's agreed upon by interconnecting operators. For this reason, the other network is viewed as a black box or a network cloud (e.g. see Fig. 1). The network cloud can be characterised by the maximum number of connections that can be routed simultaneously through each POI and the corresponding interconnection charges. The scope of this research is on the voice service, being the main source of revenue, and therefore each connection requires a fixed channel bandwidth per link.

A network is represented by an undirected graph $G(M_n, E)$, as an example in Fig. 2. Here, M_n is the set of nodes of operator n, where $n = 0$ indexes the main network and $n = 1, 2, 3, \ldots$ indexes the other networks. Let E denote the set of undirected links. Each link can be represented by a tuple (r_i, r_j), where r_i and r_j denote respectively the originated and terminated nodes of that link. A route between each node pair can be represented as a sequence $R = (r_1, r_2, \ldots, r_k)$, where r_1 and r_k are the originated and terminated nodes of the route, and $r_2, \ldots, r_{k-1}$ are transit nodes. An interconnection is made via POI nodes $\{r_i | r_i \in M_0$ and $r_i \in M_{n\neq 0}\}$.

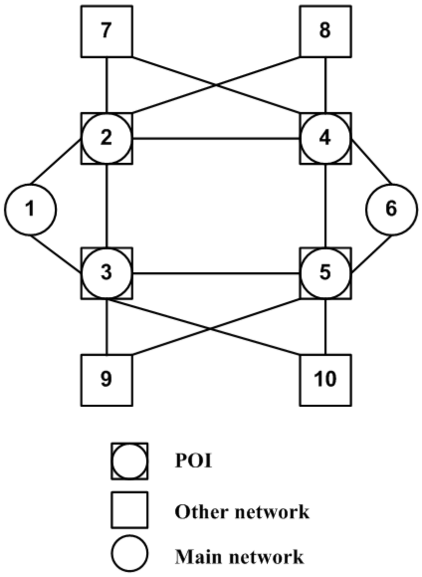

Fig. 2. Example of main network interconnected with other clouds.

B. Cost Characteristics

In the state-own, monopoly telecommunication service regime, the business model is comprised of two main players, i.e. a network operator and users. Price and cost structure is relatively simple with only two parties involved. In this paper, the focus is on a new price and cost structure that is applicable to the multi-operator network. Here, the price and cost are calculated per call. Once the network accepts a call, the call is placed along a suitable route R. The ongoing call generates a revenue with a given pricing rate (per call or per usage time). This paper defines the total cost of routing a call in terms of link cost and node transit cost.

1) *Link cost* is the cost incurred on each link along the route. For the link between nodes r_i and r_j, let $L(r_i, r_j)$ denote this type of cost per connection. Link cost can be classified into 4 categories according to the ownership of nodes r_i and r_j as follows.
   a) *Internal cost* is the cost of placing a connection on the link between nodes r_i and r_j within the main network, i.e. when r_i, $r_j \in M_0$. The internal cost is derived from the installation and maintainance cost of the operator. In practice, internal cost $L(r_i, r_j) \geq 0$.
   b) *Originate cost* is the cost incurred at POI when the main network requests to send its traffic to the other network. The originate cost $L(r_i, r_j)$ is calculated at the interconnection link, where the link's originating node r_i is in the main network but the link's termination node r_j is in another network. So, the originate cost is referred to as $L(r_i, r_j) \geq 0$, where $r_i \in M_0, r_j \in M_{n\neq 0}$.
   c) *Terminate cost* is the cost incurred at POI when a call from another network requests for a termination inside the main network. Similar to the originate cost, the terminate cost $L(r_i, r_j)$ is obtained from the interconnection charge and calculated at the interconnection link. However, the terminate cost is the cost of the other network, but the revenue of the main network. Thus, the terminate cost is counted as a negative cost. The terminate cost is referred to as $L(r_i, r_j) \leq 0$, where $r_i \in M_{n\neq 0}$ and $r_j \in M_0$.
   d) *(Null) external cost* is the cost of using a link whose originating node r_i and terminating node r_j are both located in the other networks, i.e. $r_i, r_j \notin M_0$. Since all the operations inside other networks are hidden behind POI's, the external cost $L(r_i, r_j) = 0$ from the viewpoint of main network.
2) *Node transit cost* is the cost incurred on each transit node along the route. This cost is different from the link cost in that it takes into account the information of the route origination and route destination. For a route $R = (r_1, \ldots, r_k)$, we define the transit cost $T(r_i)$ of passing a call over a node $r_i (i = 2, \ldots, k)$ as follows.

$$T(r_i) = \begin{cases} \alpha_n, & r_{i-1} \in M_0, r_i \in M_{n\neq 0}, r_k \in M_{m\neq n} \\ -\beta_n, & r_{i-1} \in M_n, r_i \in M_0, r_k \in M_{m\neq 0} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

   In (1), $\alpha_n \geq 0$ is the fee that needs to be paid to operator n when the main network passes its traffic through that operator, i.e. when the traffic is originated in the main network and destined to an operator m which is different from the operator n (being asked for a network transit). Further, $\beta_n \geq 0$ is the fee that can be collected from operator n who wants to pass its traffic through the main network though the traffic is destined to another operator $m \neq 0$.

Finally, by taking into account both link cost and node transit cost, the total cost $C(R)$ of placing a call over a route $R = (r_1, \ldots, r_k)$ can be obtained from

$$C(R) = \sum_{i=2}^{k} \left(L(r_{i-1}, r_i) + T(r_i) \right) \quad (2)$$

III. Routing Algorithms

The routing algorithms investigated in this paper are based on the well-known shortest path algorithm where the distance is defined as either the number of hops or the route cost in (2). When the number of hops is used, the routing algorithm is aimed at minimising the total resource usage. When the route cost is used, the aim is to minimise the routing cost and hence maximising profits.

A. nISPR

This algorithm is called *shortest path routing with no interconnection charge*. It selects the best path to minimise the total routing cost. Interconnection with the main network is allowed without charges. Therefore, both originate and terminate costs are set to 0. However, no transit calls are allowed. This routing algorithm can occur in the country where private companies are not allowed to transfer calls amongst themselves. Instead, they are obliged to pass every call destined to other operators via the network owned by the state company without any interconnection charges.

B. Cost-based ISPR

This algorithm is called *cost-based shortest path routing with interconnection charge*. The aim of this routing algorithm is to choose the route R such that the total cost $C(R)$ in (2) is minimised for every call upon the arrival of that call. All interconnection and transit calls are allowed and charged.

C. Resource-based ISPR

This algorithm, *resource-based shortest path routing with interconnection charge*, is aimed at selecting the route with the minimum number of hops. Therefore, the resource-based ISPR tries to minimise the total network resources needed to provide connections. Like the cost-based ISPR, interconnection and transit calls are allowed and charged.

D. IDAR

Dynamic alternative routing with interconnection charge is a distributed and adaptive routing technique, by which each individual node can learn from its locally obtainable network status and adapt its routing preferences accordingly. IDAR is here proposed as an extension from the original dynamic alternative routing (DAR) algorithm [12]. Due to DAR's simplicity, analysability as well as proved efficiency, DAR has also been extended to take into account the packet-switched, multiservice environment [13] and smooth rerouting scenarios [14].

The nature of DAR is to try to route an incoming new call to the route that has been previously used successfully first. If such an attempt is failed, then an alternative route will be tried randomly. By this random selection of routes, DAR has a learning mechanism which allows it to adapt to changing network conditions. Since DAR has been originally proposed for a telephone core network, DAR is designed only for a network with fully connected, or *full mesh*, topology.

In this paper, IDAR extends the DAR concepts in two ways. First, the network topology needs not be full mesh. Second, interconnection concept is taken into account. Fig. 3 gives a summary of IDAR operations. Here, for each pair of origin and destination, the set of all possible routes between them is classified into groups. All the routes in each group have the same cost for making a connection. In Fig. 3, x denotes the group index where $x = 1, 2, \ldots$ refer to the group with the smallest cost, next smallest cost, and so on.

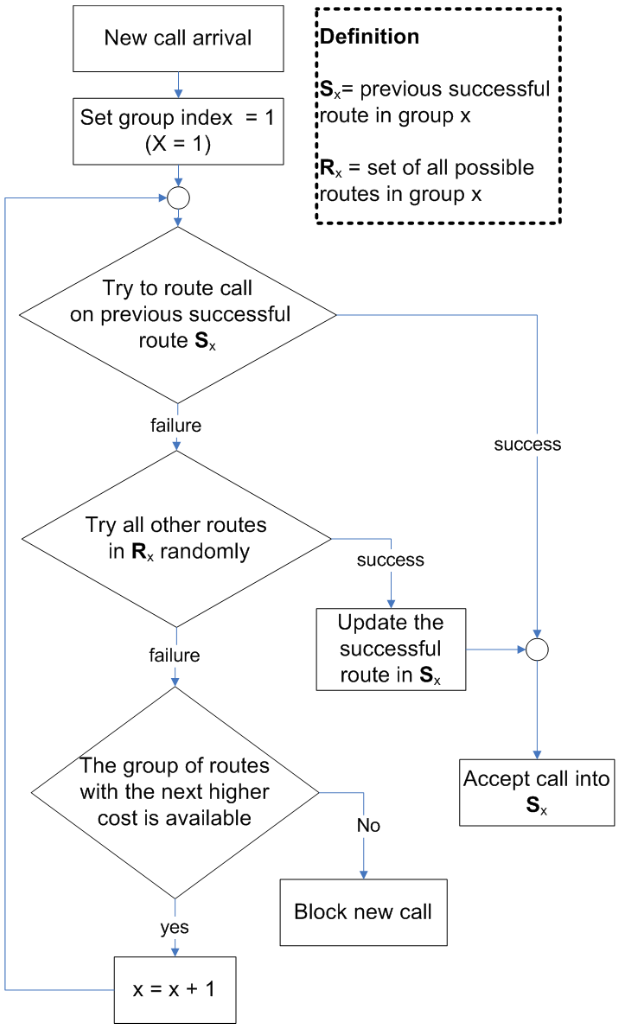

Fig. 3. Dynamic alternative routing with interconnection (IDAR)

IV. Multi-operator Network Example

To investigate the performance of the routing algorithms proposed in Section III, a simple network scenario with 10 nodes and 3 different operators as shown in Fig. 2 has been considered. Here, $M_0 = \{1, 2, \ldots, 6\}, M_1 = \{7, 8\}$ and $M_2 = \{9, 10\}$.

As a standard assumption, calls are assumed to arrive at each origin-destination pair according to independent Poisson processes whose mean rate has been varied. Each link has the capacity of 30 channels. Call holding times are exponentially distributed with normalised mean to 1 unit time. Revenue rate is 10 units per success call. The internal, originate and terminate costs are set to 1 unit per channel per link. The transit cost is set to 3,5,6 units per channel per link for M_0, M_1, M_2, respectively. Discrete-event simulation has been carried out with 50,000 call arrivals (per each investigated case). All the results has been measured with 95% confidence intervals, as estimated by the method of batch means [10].

V. Simulation Results

Network simulation results are depicted in Figs. 4–11.

From the obtained results, it is worth noting that nISPR returns the lowest overall utilization of network for every loading. The reason is that, as seen in Fig. 4, nISPR allows no transit calls, all of which resort to blocking. Hence, given that the main network uses nISPR and network has a large portion of transit call request, then this type of transit blocking may lead to the sharp decrease in otherwise obtainable revenue.

On the other hand, IDAR results in the relatively high overall utilization and high profit per success call especially under light loads. This is due to the added adaptibility of IDAR. In IDAR, the routes within the same group of cost have the chance of being selected, where this chance is inversely proportional to the call blocking probability on the

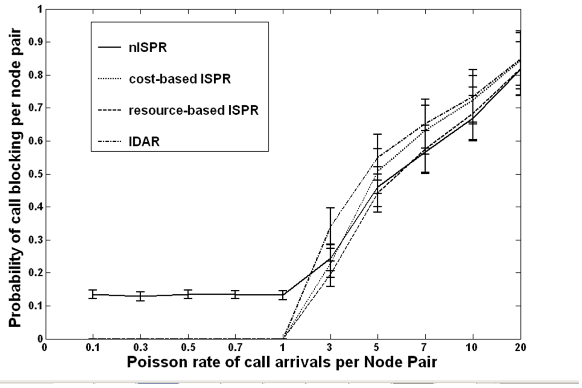

Fig. 4. Blocking probability

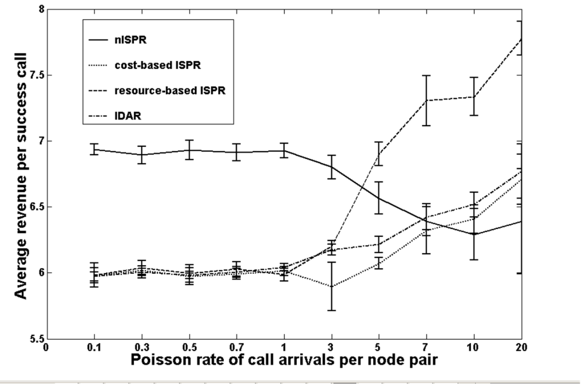

Fig. 7. Revenue per success call

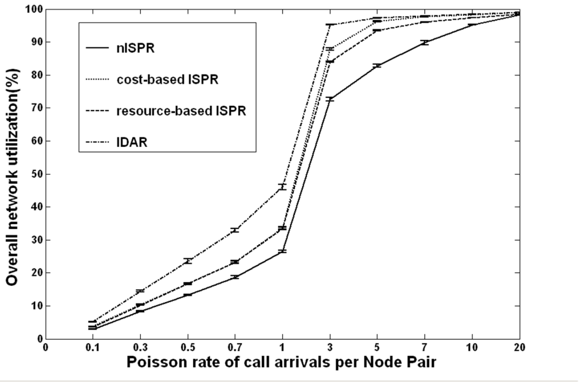

Fig. 5. Overall network utilizaton

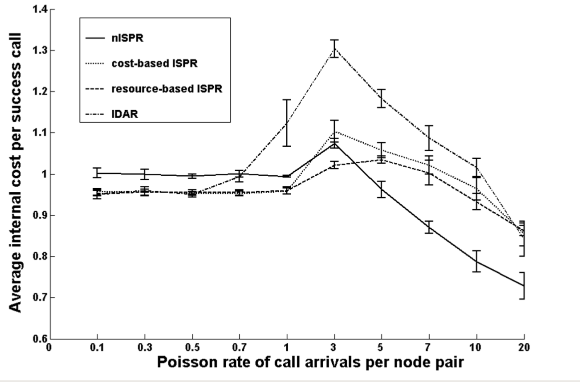

Fig. 8. Internal cost per success call

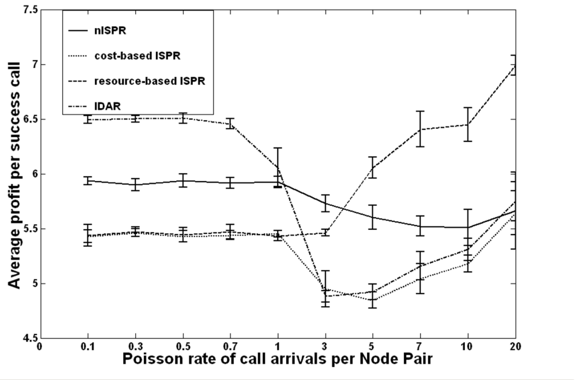

Fig. 6. Profit per success call

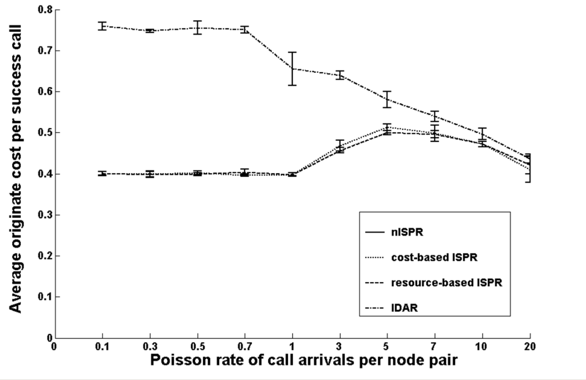

Fig. 9. Originate cost per success call

routes. That is, the lightly loaded route will be selected more frequently than the highly loaded route. As loading of each route changes, IDAR allows this load balancing mechanism to adapt accordingly. This is in contrast with all other shortest path routing algorithms (nISPR, cost-based ISPR and resource-based ISPR), whereby routes with the same cost will be selected in a fixed, sequential order.

However, as the network load much increases, IDAR's performance becomes similar to the cost-based ISPR. It is here worth noting that, under heavy loadings, the resource-based ISPR gives the best performance. This is perhaps contradictary to the current practice of each operator, whose main objective is to minimise their own servicing cost even though the resultant route may consume more network resources in total.

Of course, from the viewpoint of each operator, such algorithm as cost-based ISPR may be a logical choice of routing. However, based on the numerical results shown here, it is better for each operator to try more to cooperate with all the other operators, especially under critical conditions such as highly surged demands. And hence, a better choice of routing should be based on the objective function that aimes at saving the overall network resouces (no matter if they belong to the

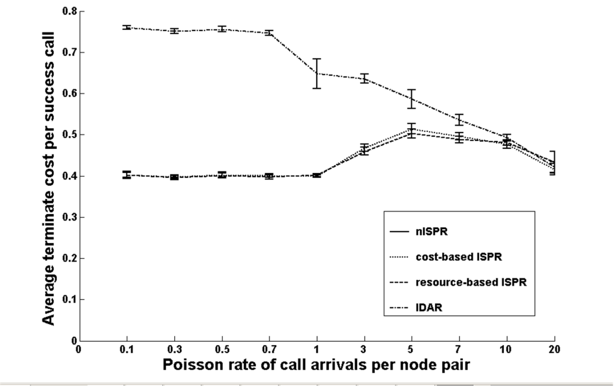

Fig. 10. Terminate cost per success call

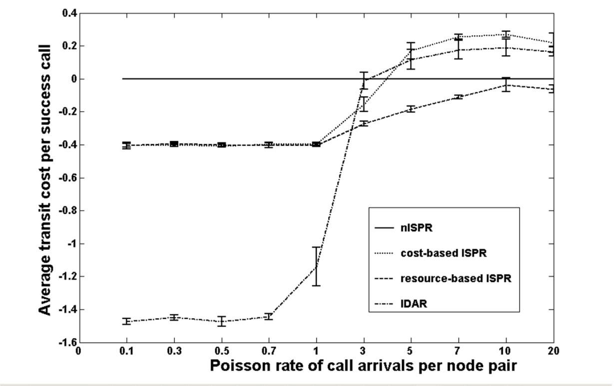

Fig. 11. Transit cost per success call

main network or to the other operators' networks). Given that every operator cooperates, each can help each other absorb their traffic surges and, as a consequence, this cooperation results in the maximum allowable profit in return for every operator.

VI. Conclusion

In this paper, the routing problem in multi-operator network has been addressed in the framework of interconnection. Four routing algorithms have been investigated, namely, (i) shortest path routing with no interconnection charge, (ii) cost-based shortest path routing with interconnection charge, (iii) resource-based shortest path routing with interconnection charge and (iv) dynamic alternative routing with interconnection charge.

These routing algorithms have been compared in terms of call blocking probability, network utilization as well as mean values of servicing cost, network revenue and obtainable profit). The obtained discrete-event simulation results suggest that the dynamic alternative routing with interconnection charge is the most preferrable routing algorithm when the network has light loads. Alternatively, under heavy loads, it is found that the resource-based shortest path routing with interconnection charge is the best.

In this paper, the revenue is charged per call at a fixed rate. However, the formulated evaluation framework is readily applicable to other charging tariffs (e.g. charging by serviced time at a rate dependent on the time of usage). It is then interesting, as a future work, to compare the four routing algorithms herein proposed under such scenarios. It is believed that the results obtained can help network operators to better manage their own resources, and compete as well as cooperate with other operators in the most allowable efficient way.

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