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TITLE

TRANSMISSION CAPACITY METRIC FOR SPF ROUTING IN ISO 10589

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TRANSMISSION CAPACITY METRIC FOR SPF ROUTING IN ISO 10589 (U)

by

Claude Bilodeau

CRC REPORT NO. 96-004

April 1996
Ottawa

Industry Canada Industrie Canada

The work was developed under the NATO CSNI project which was sponsored in Canada by the Department of National Defence through the Defence Communications Program.

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COMMUNICATION RESEARCH CENTRE, INDUSTRY CANADA
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ABSTRACT

The ISO 10589 IS-IS protocol relies on the SPF algorithm to route traffic to destinations. By default, metric values associated with the capacity of the circuits are understood by every IS in a domain and used in performing the default path cost calculations. This report shows that such approach will normally lead to sub-optimal routing.

Two indicators are developed to assess the routing bias introduced by various throughput-based routing metric functions. Numerical results are presented for selected suites of 2-hop and 3-hop topologies, composed of HF, UHF and/or SHF radio subnetworks.

RÉSUMÉ

Le protocole ISO 10589 s'appuie sur l'algorithme SPF pour effectuer le routage de l'information vers les destinataires. A l'intérieur d'un domaine donné, il est coutume que chaque système intermédiaire admette des valeurs de métriques adjointes au débit disponible des circuits et que celles-ci soient utilisées, par défaut, dans le calcul des coûts de parcours. Cette étude démontre qu'une telle approche produit un routage non-optimal.

Deux indices mathématiques sont proposés pour évaluer le biais introduit par des fonctions de calcul de métriques adjointes au débit disponible des circuits. Des exemples numériques sont présentés pour des ensembles choisis de topologie de parcours comprenant deux et trois liaisons radio HF, UHF et/ou SHF.

EXECUTIVE SUMMARY

The CSNI project adopted open systems interconnect (OSI) principles in developing an open architecture that could accommodate diverse users and a broad array of deployed systems and subnetworks. Central to this approach, the ISO 10589 intermediate system to intermediate system (IS-IS) protocol provides the intra-domain routing information exchange between the CSNI nodes.

ISO 10589 specifies that the shortest path first (SPF) algorithm must be executed by the routers for calculating the optimal path to a destination system within a routing domain. The algorithm combines the metric (cost) values of the links by simple addition. By convention, the default metric values are intended to measure the capacity of the circuits. Higher values indicate a lower capacity. The path having the lesser metric (cost) sum is selected in preference to paths having a greater metric sum. By metric sum is understood the sum of the metrics along the path to the destination.

This report shows that the use of the SPF algorithm with capacity metrics will normally lead to sub-optimal routing, the main reason being that the transmission capacity of serial links is non-additive by nature; i.e. the throughput achieved on a path composed of several hops can never be better than the throughput available from the slowest link.

Two mathematical expressions are proposed to measure the degree of "incorrectness" introduced in applying the SPF algorithm with capacity metrics. The expressions are useful for comparing the routing bias introduced by various capacity-based metric functions and selecting the one offering the least amount of bias within a specified network topology.

These results are particularly relevant since one of the main objective of the CSNI project was to assess the effectiveness of dynamic routing in heterogeneous radio subnetworks.

FOREWORD

The work described in this report was performed under the collaborative Communications Systems Network Interoperability (CSNI) R&D project.

Very briefly, CSNI is a five-year project initiated at the end of 1991 and includes six participating nations (Canada, France, Germany, The Netherlands, The United Kingdom and The United States) with the Shape Technical Centre also as a participant.

The principal CSNI objective is to develop, test and demonstrate multiservice (voice, data, messages) communications across mixed media transmission networks (HF, VHF, UHF, SHF) employing open systems principles and Commercial Off-The-Shelf (COTS) products to the greatest extent possible. R&D results from the project are made available to the international standards community for consideration in the promulgation of emerging standards.

The CSNI project organization, R&D schedule, demonstration testbed and overall major project accomplishments are summarized in [3].

Table of Contents

Transmission Capacity Metric for SPF Routing in ISO 10589

1.0 Introduction

The ISO 10589 intermediate system to intermediate system (IS-IS) standard [1] specifies that for route calculation between systems the shortest path first (SPF) algorithm must be used. The standard also specifies four routing metrics, corresponding to the four possible orthogonal qualities of service defined by the QoS Maintenance field of the ISO 8473 (connectionless-mode network service) protocol [2]. Only the default metric needs to be understood by every IS in a domain. ISO 10589 does not really define the default metric except to say that (para. 7.2.2):

> "... the (default metric) value may be associated with any objective function of the circuit, but by convention is intended to measure the capacity of the circuit for handling traffic, for example, its throughput in bits-per-second."

This document discusses the difficulties of using the SPF algorithm with a default metric based on the transmission capacity of the circuit. It will be shown that such approach will normally lead to sub-optimal routing.

This report contains 6 sections, including this introduction. Section 2.0 describes the problem in general whereas some specific examples are given in Section 3.0. In Section 4.0, an attempt is made to assess the routing bias introduced by various Metric vs. Capacity functions under a selected suite of 2-hop and 3-hop topologies. Two indicators are developed and used to select the best function. Detailed numerical results are given in the Annex A following Sections 5.0 and 6.0, the conclusion and reference sections, which complete the core of the report.

2.0 SPF Routing based on Circuit Capacity Metric: a Fallacy?

ISO 10589 defines a *link* as the communication path between two neighbours. For the purposes of this document, the term *path* is used when the communication flow is between systems that may or may not be neighbours, i.e. systems spaced by one or more hops.

If $M_i(n)$ designates the routing metric associated with the transmit[1] circuit of link i, the cost P_N resulting from N serial links can be expressed by:

1. Two routing metrics are needed to describe the link state: one in each traffic direction.

$$P_N(n) = f(M_1(n), M_2(n), \ldots, M_N(n)) \tag{1}$$

where $f(\ )$ is a path metric generation function having the objective of producing a metric value representative of the quality of service offered via the N link route. In (1), all variables are signals or sequences of the discrete time n. One of the simplest and most obvious choices for $f(\ )$ is:

$$f(x_1, x_2, \ldots, x_N) = \sum_{i=1}^{N} x_i \tag{2}$$

Substituting (2) in (1), with $x_i = M_i(n)$, we obtain

$$P_N(n) = M_1(n) + M_2(n) + \ldots + M_N(n) \tag{3}$$

which shows that at any given instant n, the metric values are combined by simple addition. This is the function used in the CSNI router as the 10589 standard specifies that for route calculations the shortest path first (SPF) algorithm must be used. This algorithm is based on the total metric sum of the links.

The standard defines four routing metrics, corresponding to four orthogonal qualities of service: default metric, delay metric, expense metric and error metric. The simple equal-weight summing operation described by (3) is certainly appropriate when calculating the cost P resulting from multiple link delays or monetary expense, or to some extent link error situations. However, if the default metric is to represent the capacity of the circuit (e.g. its throughput) then the use of (3) may lead to serious routing problems. The main reason is that the transmission capacity of serial links is non-additive by nature, that is, the throughput achieved on a path composed of several hops can never be better than the throughput available from the slowest link.

A more appropriate combining function for calculating the cost P associated with N serial links using the capacity metrics $M_{c,i}$ might be:

$$f(x_1, x_2, \ldots, x_N) = \mathrm{MAX}(x_1, x_2, \ldots, x_N) \tag{4}$$

where MAX( ) returns the maximum value among the set of N elements. As with (2), x_i represents a metric value $M_i(n)$. Using (4) in (1):

$$P_{c,N}(n) = \mathrm{MAX}(M_{c,1}(n), M_{c,2}(n), \ldots, M_{c,N}(n)) \,. \tag{5}$$

It would appear desirable to modify the Dijkstra algorithm to make use of (5) instead of (3) when computing the default-cost paths. However, this approach will not be further investigated since the goal of the CSNI project is mainly to test the applicability of the OSI models and existing standards to the military communication systems internetworking environment. Some of the difficulties of using (3) instead of (5) in calculating the best cost path based on capacity metrics will be shown in the next sections and can only lead to sub-optimal routing.

3.0 Capacity Metric Calculation

The block diagram representation of Figure 1 shows the functional relationship between the capacity of the circuits and the mathematical operations to be performed on these inputs to yield the output path cost P_c. For the remainder of this discussion, it will be assumed that the capacity metrics of the various subnets along a path are combined using a function $f(\ )$ such as (3), as required by the ISO 10589 protocol.

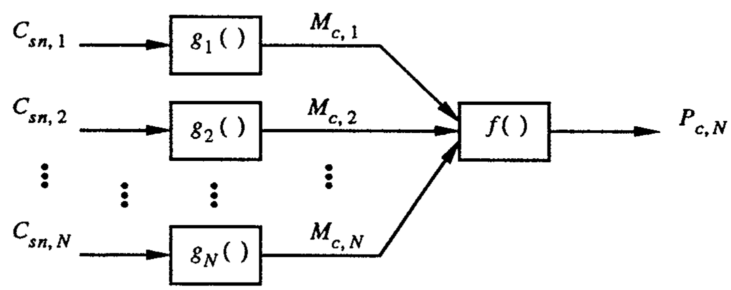

FIGURE 1. Functions used in path cost calculation

For each subnet a "link metric generation function $g(\ )$" is needed to relate the subnet free capacity C_{sn} to a metric value M_c. Two sets of equations will be discussed in the next subsections. Both make use of the following definitions:

Free Capacity:	Total link capacity (nominal capacity) minus the current total throughput achieved over the link.
Nominal Capacity:	Total link capacity i.e. the maximum total throughput that can be achieved over the link.

3.1 Capacity Metric Calculation based on a Linear Equation

To suit the CSNI network environment, the following linear equation was originally proposed by the The United Kingdom participating organization:

$$M_c = 63 - C_{sn}/300 \qquad (6)$$

where M_c is the capacity (default) metric of the link and C_{sn}, expressed in bits per second, is an estimate of the free link capacity available to the subnetwork. This equation is shown in Figure 2.

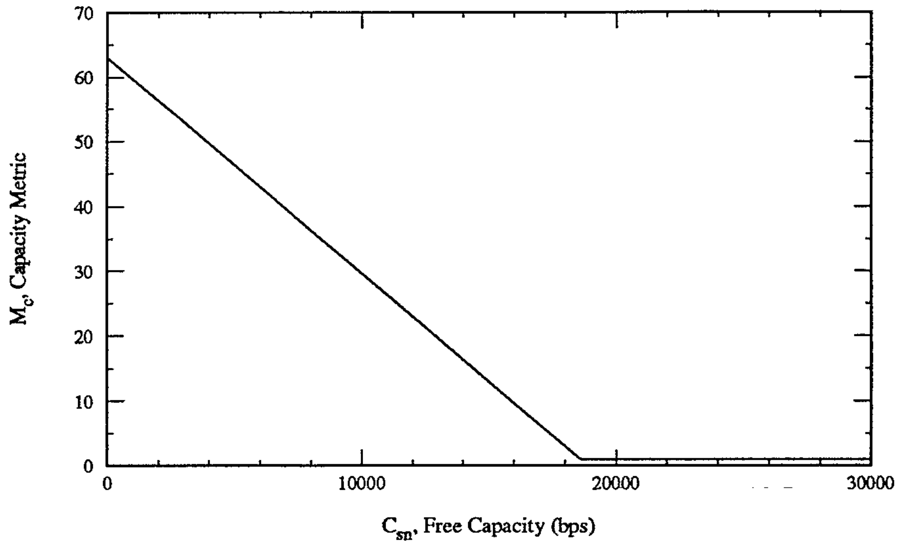

FIGURE 2. Capacity metric calculation based on a linear equation

To be ready for use by the ISO 10589 routing function, the metric values of (6) must be mapped to 6 bit quantities, by an expression similar to:

$$M_c = \begin{cases} \mathrm{NINT}(63 - C_{sn}/300) & , 0 \le C_{sn} \le 18600 \\ 1 & , C_{sn} > 18600 \end{cases} \qquad (7)$$

where NINT( ) is the nearest integer function. The slope of (6) indicates that it takes a net capacity change of 300 bps for the metric value to change by 1. This rate of change is the same for all CSNI subnet types.

A difficulty in using (6) "as is", is that the algorithm may not always provide the proper path routing when used over multiple subnet hops. Consider the network topology illustrated in Figure 3, where inter-node communications are provided by HF subnetworks. When neglecting the link protocol overheads, we have:

$$0 \le C_{sn} \le 2400 \text{ bps} \qquad (8)$$

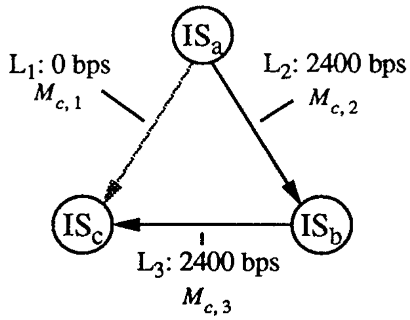

FIGURE 3. Example of routing through HF subnetworks

Equations (7), (8) and the data provided in Figure 3 can be used to calculate the total cost of each one of the two possible paths between the intermediate systems IS_a and IS_c. These are:

path 1, $IS_a \rightarrow IS_c$, (single hop, L_1) $\quad P_{c,1} = M_{c,1}\big|_{C_{sn}=0} = 63;$

path 2, $IS_a \rightarrow IS_b \rightarrow IS_c$, (dual hop, L_2-L_3) $\quad P_{c,2} = M_{c,2}\big|_{C_{sn}=2400} + M_{c,3}\big|_{C_{sn}=2400} = 55 + 55 = 110.$

This example shows that this algorithm fails to select the high capacity path $IS_a \rightarrow IS_b \rightarrow IS_c$ as the best path. In fact, the algorithm will never select a two hop path if a single path exists, regardless of the capacity metric values of the HF links[1]. The algorithm fails because the capacity metrics do not have additive properties as discussed in Section 2.0.

3.2 Capacity Metric Calculation based on a Non-Linear Equation

To circumvent the problems discussed in Section 3.1, the following inverse function was proposed by The United States participating organization:

$$M_c = MaxC_t / C_{sn} \tag{9}$$

where $MaxC_t$ is "the largest nominal capacity for the various subnet capacities". A value of $MaxC_t = 12000$ bps is suggested. This value is somewhat arbitrary and was obtained by multiplying the raw nominal throughput of the CSNI SHF subnet (48 kbps) by a representative or average loading of one fourth. It is assumed that the nominal SHF subnet capacity is limited to 12000 bps per user and is fixed for each subnet member. In reality, $MaxC_t$ could reach a raw throughput of 48000 bps since nothing prevents the DSCS subnetwork protocol[2] from granting all the tokens to a single user when no other net mem-

1. This conclusion can be extended to other sets of homogeneous subnets using the same topology.
2. See [3] for an overview of CSNI subnetworks.

ber is reserving them. In any case, the intent of (9) is to introduce a steep metric change when the available free capacity is low, and a much reduced metric change otherwise. Equation (9) is plotted in Figure 4 for three of the CSNI subnets:

- HF, $0 \le C_{sn} \le 2400$ bps;
- UHF, $0 \le C_{sn} \le 4800$ bps;
- SHF, $0 \le C_{sn} \le 12000$ bps.

The equation can be mapped to 6 bit quantities by an expression like:

$$M_c = \mathrm{MIN}(63, \mathrm{NINT}(MaxC_t/C_{sn})) \qquad (10)$$

where the function $\mathrm{MIN}()$ returns 63 (the maximum metric value allowable in ISO 10589) or $\mathrm{NINT}(MaxC_t/C_{sn})$, whichever is less, and $\mathrm{NINT}()$ is the nearest integer function.

Equation (9) will provide the proper path routing for the example given in Section 3.1. However, it is not difficult to find other cases where the algorithm does not produce the desired result. For example, if we let $L_1 = 1250$ bps in Figure 3 and keep $L_2 = L_3 = 2400$ bps as before, this algorithm fails to select $L_1 - L_2$ as the best path.

Another problem with (9) is the much compressed range of metric values. Regardless of the subnet types, the free capacity values above 1200 bps are confined to the narrow metric range $1 \le M_c \le 10$. A minimal metric change of 1 within this range has a significant impact on the routing decision and warrants an update of the intermediate systems' routing information tree. However, as the available free capacity of a subnet goes

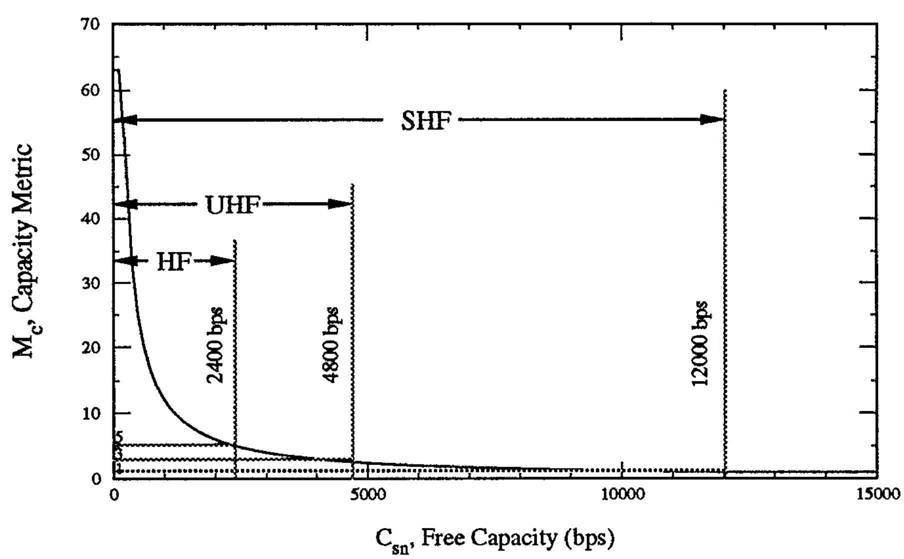

FIGURE 4. Capacity metric calculation based on a non-linear equation

down ($C_{sn} < 1200$ bps, $10 < M_c \leq 63$), the same small metric changes may cause many unnecessary updates.

Despite these inconveniences, this algorithm appears to be superior to the one discussed in Section 3.1 because it will generally provide better multihop path selection.

4.0 Capacity Metric and Routing Bias

It has been pointed out in the previous sections that the use of a routing metric based on free link capacity leads to sub-optimal routing. Despite this limitation, it is recognized that some capacity-based metric calculations can provide better path routing than some others, depending on the topology selected. A number of equations have been proposed by different participating organizations in an attempt to define the CSNI default routing metric based on free link capacity. Although none of these equations can possibly be optimum for all topologies, this section will present nevertheless some numerical data useful for comparing the proposals and assessing to some extent, the routing bias introduced by these equations under a selected suite of 2-hop and 3-hop topologies.

4.1 Selected Topology

A generic topology is shown in Figure 5-a and was used for the 2-hop routing analysis. Table 1 lists the various configurations for which the results apply. Similarly, Figure 5-b shows the generic topology used for the 3-hop routing analysis and Table 2 lists the 3-hop topology suite. For each topology, a link (Link-0) going directly (1 hop) from the source to the destination is used as a reference to measure the routing bias values.

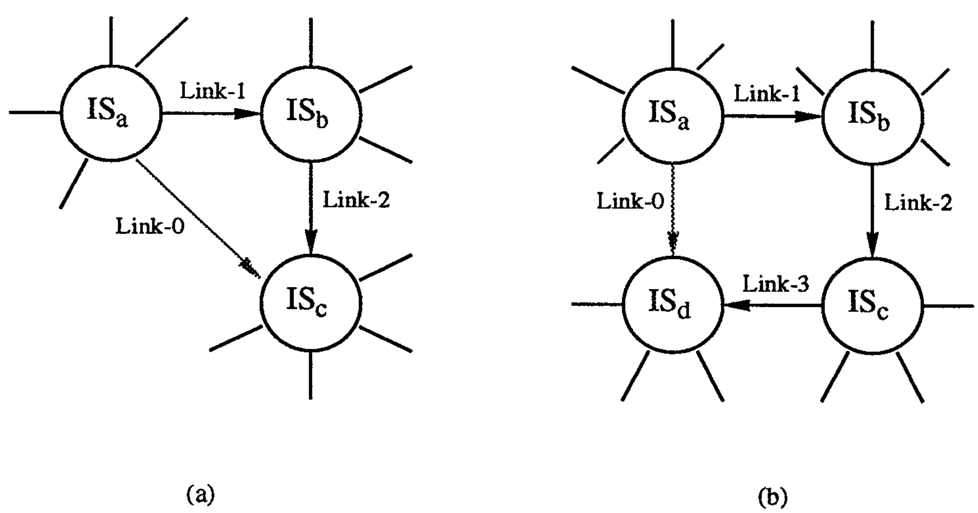

FIGURE 5. Generic 2-hop and 3-hop topology

TABLE 1. Two-hop Topology Suite

TOPOLOGY	2-HOP PATH		REFERENCE LINK
	LINK-1	LINK-2	LINK-0
1	HF	HF	HF
2	HF	UHF	HF
	UHF	HF	HF
3	HF	SHF	HF
	SHF	HF	HF
4	UHF	SHF	HF
	SHF	UHF	HF

TABLE 2. Three-hop Topology Suite

TOPOLOGY	3-HOP PATH			REFERENCE LINK
	LINK-1	LINK-2	LINK-3	LINK-0
1	HF	HF	HF	HF
2	HF	UHF	HF	HF
	UHF	HF	HF	HF
	HF	HF	UHF	HF
3	HF	SHF	HF	HF
	SHF	HF	HF	HF
	HF	HF	SHF	HF
4	HF	UHF	SHF	HF
	HF	SHF	UHF	HF
	UHF	HF	SHF	HF
	UHF	SHF	HF	HF
	SHF	HF	UHF	HF
	SHF	UHF	HF	HF

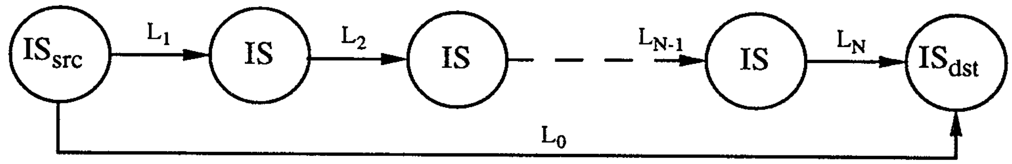

FIGURE 6. Generic N-hop topology

4.2 Bias Functions

In this section, two functions are proposed to measure the degree of "incorrectness" introduced in calculating the best cost path based on capacity metrics.

But first, consider the generic N-hop topology shown in Figure 6 where a source intermediate system, IS_{src}, has only two paths to choose from to reach a destination, IS_{dst}. The first path is the direct link L_0 whereas the second path is composed of the links $L_1, L_2, ..., L_N$. Let P_0 be the routing cost of the direct link and P_I the cost of the indirect path. The SPF algorithm will always select the path having the lesser cost to route a packet toward IS_{dst}. For example, if $P_I > P_0$ then the direct path L_0 will be chosen. Such a decision implies that the free link capacity c_0, available across the direct path L_0, should be higher than the free link capacity c_I, available across the indirect path, otherwise, the SPF algorithm does not really select the best path. If that were to be the case i.e. if the path selected were not the path having the largest free link capacity then, we here state that the routing decision is *biased.* Table 3 defines the conditions for a routing decision to be biased. Note that when the free link capacity is the same on both paths, the selection of a path over the other is rather irrelevant since both offer the same free capacity.

TABLE 3. Definition of routing bias

	$P_I < P_0$	$P_I = P_0$	$P_I > P_0$
$c_I < c_0$	biased	biased	-
$c_I = c_0$	-	-	-
$c_I > c_0$	-	biased	biased

The first bias function to be defined, δ, simply detects the presence or absence of a bias. Let $c_1, c_2, ..., c_N$ be the free capacity of the N-hop path formed by the links $L_1, L_2, ..., L_N$ respectively. Let c_0 be the free capacity of the link directly joining the source and destination ISs. A function $\delta(c_1, c_2, ..., c_N; c_0)$ is defined as follows:

$$\delta \equiv \begin{cases} 1, & \text{when} \left\{ (MIN(c_1, c_2, \ldots, c_N) > c_0) \wedge \left(\sum_{i=1}^{N} M_i(c_i) \geq M_0(c_0) \right) \right\} \text{ is true} \\ 1, & \text{when} \left\{ (MIN(c_1, c_2, \ldots, c_N) < c_0) \wedge \left(\sum_{i=1}^{N} M_i(c_i) \leq M_0(c_0) \right) \right\} \text{ is true} \\ 0, & otherwise \end{cases}$$

where MIN returns the minimum value among the set of N elements and M_i designates the routing metric associated with the transmit circuit of link i. The summations represent the overall cost P_N resulting from the N serial links. A biais is present whenever $p \wedge q$ is true i.e. when both p and q are true.

The second function, ε, is a measure of the capacity bias due to selecting the wrong path:

$$\varepsilon(c_1, c_2, \ldots, c_N; c_0) \equiv |MIN(c_1, c_2, \ldots, c_N) - c_0| \delta(c_1, c_2, \ldots, c_N; c_0)$$

4.3 Routing Bias Indicators

In this section, two indicators are developed to assess the routing bias over a 2-hop path.

Both bias functions described in Section 4.2 are time dependent functions since the free link capacity c_i's will change over time according to the traffic load of the topology, the transmission capability of the subnets and the transmission queue lengths. To reduce the analytical complexity, it will be assumed that the traffic flows within the topology are de-correlated due to the presence of multiple traffic sources and link connections between the nodes of the topology.

As in Section 4.2, let c_o, c_1 and c_2 be the free link capacity of Link-0, Link-1 and Link-2, respectively (Figure 5-a). The values of these c_i's are bound by the transmission characteristics of the subnets $i = 0, 1, 2$ to the range $c_{i,min} < c_i \leq c_{i,max}$. These free link capacities are orthogonal quantities and delimit a rectangular volume in a 3-D space. Each point of this volume represents one possible routing decision among the set (volume) of all possible routing decisions that the router will ever have to make. Each one of these decisions may or may not be biased. The first indicator provides an indication of the fraction of biased decisions taken by the router over the set of all the decisions taken:

$$\text{BiasRatio}_{2\text{-hop}} = \frac{\int\limits_{c_0}\int\limits_{c_1}\int\limits_{c_2} \delta(c_1, c_2; c_0)\, dc_2 dc_1 dc_0}{\int\limits_{c_0}\int\limits_{c_1}\int\limits_{c_2} dc_2 dc_1 dc_0}$$

where δ is the bias detection function described in Section 4.2 and each integral is defined over a range $c_{i,min} < c_i \le c_{i,max}$.

The second indicator is a measure of the average bias resulting from the set of biased decisions:

$$\overline{\text{Bias}}_{2\text{-hop}} = \frac{\int\limits_{c_0}\int\limits_{c_1}\int\limits_{c_2} \varepsilon(c_1, c_2; c_0)\, dc_2 dc_1 dc_0}{\int\limits_{c_0}\int\limits_{c_1}\int\limits_{c_2} \delta(c_1, c_2; c_0)\, dc_2 dc_1 dc_0}$$

where ε is the bias measurement function described in Section 4.2.

4.4 Bias Indicators generalized to N-hop Path

The bias indicators derived in Section 4.3 can easily be extended to a N-hop path topology by considering a $N+1$ dimensional space and the corresponding $N+1$ integration operations. The bias functions developed in Section 4.2 are directly applicable to an N-hop path topology. The derivation of these indicators is straightforward and will not be given here.

4.5 Default Metric Equations

Several organizations participating to the CSNI project have proposed different equations to calculate the CSNI default routing metric based on the free link capacity of the subnets. A list of these equations is given in Table 4. Each equation will be referred to by the arbitrary name given in the first column of the table. Note that the first five equations are listed by chronological order i.e. as they have been introduced over time. The last four equations are here introduced for further comparison. Note also that the throughput ranges selected for equations FR2 and FR3 are derived from an approximation of the values generated by equations CA2 and CA1 respectively.

TABLE 4. Default Metric Equations

Eq. Name[1]	$M(c);(c>0)$
UK1	$MIN\left(63, NINT\left(63 - \frac{c}{300}\right)\right)$
US1	$MIN\left(63, NINT\left(\frac{MaxC_t}{c}\right)\right); MaxC_t = 12000$
US2	$MIN\left(63, NINT\left(\frac{MaxC_t}{c}\right)\right); MaxC_t = 24000$
US3	$MIN\left(63, NINT\left(\frac{MaxC_t}{c}\right)\right); MaxC_t = 48000$
FR1	$\begin{cases} 31; & 0 < c \le 500 \\ 15; & 500 < c \le 1400 \\ 7; & 1400 < c \le 2400 \\ 3; & 2400 < c \le 4800 \\ 1; & 4800 < c \end{cases}$
FR2[2]	$\begin{cases} 31; & 0 < c \le 400 \\ 15; & 400 < c \le 800 \\ 7; & 800 < c \le 1700 \\ 3; & 1700 < c \le 4000 \\ 1; & 4000 < c \end{cases}$
FR3[3]	$\begin{cases} 31; & 0 < c \le 200 \\ 15; & 200 < c \le 400 \\ 7; & 400 < c \le 850 \\ 3; & 850 < c \le 2100 \\ 1; & 2100 < c \end{cases}$
CA1	$MIN\left(63, NINT\left(\coth\left(\frac{2c}{MaxC_t}\right)\right)\right); MaxC_t = 12000$
CA2	$MIN\left(63, NINT\left(\coth\left(\frac{c}{MaxC_t}\right)\right)\right); MaxC_t = 10800$

1. The following abreviations are used:
   - UK — The United Kingdom,
   - US — The United States,
   - FR — France,
   - CA — Canada.
2. Throughput ranges derived from CA2
3. Throughput ranges derived from CA1

4.6 Numerical Results

Using the bias indicators developed in Sections 4.3 and 4.4, the default metric equations listed in Table 4 were evaluated numerically for the 2-hop and 3-hop topologies listed in Table 1 and Table 2 respectively. The range of free link capacity assumed over each subnet was set as follows:

	c_{min}	c_{max}
HF	20 bps	2400 bps
UHF	20 bps	4800 bps
SHF	20 bps	12000 bps

To reduce the computation time and still maintain reasonable accuracy of the results, a variable integration step of 3% was used and calculated as $\Delta c_k = 0.03 c_k$. The results are presented in details in Annex A and summarized in Tables 5 and 6. The equations listed under a same group appear in order of increasing value i.e. the best performing equation is listed first, then the second next best, the third and so on. A bias ratio of 0% and an average bias of 0 bps represent the optimum values that any capacity-based metric function could ever achieved.

Of the two indicators developed in this report, the BiasRatio indicator is believe to be the most important one. Once a metric update is made, the metric values are frozen by the intermediate system until the next metric report is received. Any bias will therefore corrupt the routing decisions for the duration of the metric freeze, which in some cases, could severely affect the network throughput performance. The average bias indicator is not a measure of the bias introduced during the whole metric freeze period.

The results are discussed in the next section.

TABLE 5. Metric Equations grouped by BiasRatio performance

TOPOLOGY		BiasRatio (%)				
		[10-12]	]12-15]	]15-18]	]18-21]	>21
2-hop	1	FR2,FR3	FR1,CA2,US1,CA1	US2		US3,UK1
	2		FR2,FR3	FR1,US1,CA2, US2,CA1		US3,UK1
	3	US1	US2,CA2,FR2,CA1	FR3,FR1,US3		UK1
	4	FR1	US2,US1,FR3	CA2,US3,FR2		CA1,UK1
3-hop	1		CA1,FR3,FR2, CA2,US1		US2,FR1	UK1,US3
	2			FR2,CA2,CA1 US1,FR3	US2,FR1	US3,UK1
	3			US1,CA2,CA, FR2,FR3	US2,	FR1,US3,UK1
	4			US1	CA2,FR2,CA, FR3,US2,FR1	US3,UK1

TABLE 6. Metric Equations grouped by Average Bias performance

TOPOLOGY		$\overline{\text{Bias}}$ (bps)							
		[224-250]	]250-300]	]300-350]	]350-400]	]400-450]	]450-500]	]500-600]	>600
2-hop	1	FR2	FR1,US2,US1, FR3,CA2	CA1,US3				UK1	
	2	FR2	FR1,US2	US1,CA2, FR3	CA1,US3				UK1
	3		US2,FR2,US1, CA2,FR1	US3,CA1	FR3				UK1
	4		FR1				US3	US2	US1,FR3,CA2, FR2,CA1,UK1
3-hop	1		FR2,US1,CA2	CA1,US2, FR3	FR1		UK1,US3		
	2			FR2,US1, CA2,US2	CA1,FR3	FR1		US3,UK1	
	3			US2,US1, CA2,FR2	CA1	FR3,FR1	US3	UK1	
	4				US1,US2,CA2, FR1,FR2	CA1,FR3	US3		UK1

5.0 Conclusion

This report illustrates with the help of a few examples the difficulties of using the SPF algorithm with a default metric based on the transmission capacity of the circuit. Such an approach will normally lead to sub-optimal routing, the main reason being that the transmission capacity of serial links is non-additive by nature i.e. the throughput achieved on a path composed of several hops can never be better than the throughput available from the slowest link.

Two mathematical expressions were proposed to measure the degree of "incorrectness" introduced in calculating the best cost path based on capacity metrics. Tables 5 and 6 show that the routing bias obtainable with a given metric function is highly dependent of the topology considered, thus the results apply to the two topologies considered.

None of the equations proposed really outperforms the others in all instances. The worst performance is obtained when the metric value is linearly related to the link capacity available to the subnetwork (e.g. Equation UK1). In general, it is preferable that the metric be inversely related to the available capacity. For the functions considered in this document, Equations FR2 and US1 have reasonably low bias values in most cases and are equally recommended.

The approach taken in this report produced useful results for comparing the routing bias introduced by various capacity-based metric functions. There are other important factors to consider if the metric equations are to be assessed globally. For example, the routing traffic generated by an IS certainly depends on the setting of the metric update interval, metric update decision function and the metric variations themselves. For instance, it would be interesting to know if the few discrete metric levels produced by the FRx functions reduce significantly the frequency of link state information regeneration at an IS. This is an area for further study by simulation.

6.0 References

[1] ISO/IEC 10589 :1992 (E), "*Information technology — Telecommunications and information exchange between systems — Intermediate system to Intermediate system intra-domain routeing information exchange protocol for use in conjunction with the protocol for providing the connectionless-mode Network Service (ISO 8473)*", 1st Edition, 30 April 1992

[2] ISO/IEC 8473-1 : 1992 (E), "*Information technology — Protocol for providing the connectionless-mode network service*", 2nd Edition, 1992

[3] STC SP-12, "*Proceedings of the Communications Systems Network Interoperability (CSNI) Symposium on Communications Internetworking*", Shape Technical Centre File Ref. 9980, The Hague, Sept. 1995

ANNEX A — Numerical Estimate of Routing Bias

TABLE A.1 Bias Indicators for 2-hop Topology suite

TOPOLOGY	Eq. NAME	BiasRatio (%)	$\overline{\text{Bias}}$ (bps)
1 (e.g. HF-HF; HF)	UK1	32.8	595
	US1	14.0	294
	US2	16.2	282
	US3	25.3	411
	FR1	13.4	251
	FR2	10.9	224
	FR3	11.7	294
	CA1	14.2	320
	CA2	13.9	296
2 (e.g. HF-UHF; HF)	UK1	41.1	715
	US1	15.4	319
	US2	16.5	298
	US3	23.7	379
	FR1	15.3	283
	FR2	12.2	245
	FR3	14.2	347
	CA1	16.8	365
	CA2	15.4	327
3 (e.g. HF-SHF; HF)	UK1	46.0	765
	US1	11.8	268
	US2	12.5	251
	US3	17.9	315
	FR1	16.5	298
	FR2	13.0	255
	FR3	15.7	370
	CA1	14.9	332
	CA2	12.8	289
4 (e.g. UHF-SHF; HF)	UK1	68.0	1649
	US1	13.9	620
	US2	13.0	510
	US3	15.8	479
	FR1	10.0	300
	FR2	16.3	703
	FR3	14.0	643
	CA1	22.0	954
	CA2	15.7	688

TABLE A.2 Bias Indicators for 3-hop Topology suite

TOPOLOGY	Eq. NAME	BiasRatio (%)	$\overline{\text{Bias}}$ (bps)
1 (e.g. HF-HF-HF; HF)	UK1	24.6	476
	US1	14.4	294
	US2	18.6	318
	US3	24.6	476
	FR1	19.2	364
	FR2	14.2	287
	FR3	13.9	341
	CA1	13.7	314
	CA2	14.2	295
2 (e.g. HF-UHF-HF; HF)	UK1	28.7	544
	US1	15.8	328
	US2	19.3	332
	US3	27.9	513
	FR1	21.0	405
	FR2	15.6	321
	FR3	16.0	381
	CA1	15.6	354
	CA2	15.6	330
3 (e.g. HF-SHF-HF; HF)	UK1	31.2	577
	US1	15.6	325
	US2	18.5	321
	US3	28.0	486
	FR1	22.2	426
	FR2	16.4	339
	FR3	17.3	401
	CA1	15.8	354
	CA2	15.6	330
4 (e.g. HF-UHF-SHF; HF)	UK1	38.6	689
	US1	18.0	373
	US2	20.0	355
	US3	28.8	474
	FR1	20.3	387
	FR2	18.6	397
	FR3	19.6	440
	CA1	19.3	416
	CA2	18.2	381

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