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Forecasting on Inter-office Facility Based on Congestion-Sensitive Internet Traffic Flow

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ABSTRACT

Traffic congestion has become inevitably exuberant at the edge nodes of metro- and/or wide-area networks due to the triple play transports of voice, data and video information globally supported on the bricolage of modern Internet. Commensurately, the local exchange carriers improvise necessary infrastructure at the physical-layer level across the entire turf of the service area. Pertinent to this context, the scope of this study is to evaluate the conjectural impact on trunk terminations (and related facility) that decide the forecasts on network access line (NAL) requirements at the traditional circuit-switches (of T1-hierarchy) located in the premises of a central office (CO) where the changing trends in traffic patterns of telecommunication transports are encountered. For optimal engineering designs of interoffice facility, the dynamics of such NAL requirements is modeled in terms of traffic profiles measured in terms of centum-call-second metric at CO terminations.

Keywords: *Internet, Interoffice Facility, Network-access Lines, Telco Turf Engineering*

1. INTRODUCTION

Commensurate with the growth in Internet proliferation, the information traffic seen on access lines provisioned in the local exchange turf, (which was originally supported by traditional T1-hierarchy), now gets shifted to digital subscriber lines (x DSLs); as such, the extent of traffic intensity experienced currently at circuit-switches in the premises of a central office (CO) is not at the same level as pre-x DSL era. Notwithstanding of traffic diversions to x DSL, still in vogue and operational across several Class-5/4 office locations of telecommunication company (Telco) services is the T1-hierarchy plus its associated network access line (NAL) facility. However, with growing trends in x DSL on the access side, trimming of NAL requirements is evidently warranted to engineer the cost-reduction on retrofits as well as on reducing maintenance expenses of T1 hierarchy paraphernalia.

Thus, with the advent of x DSL penetration (supporting Internet with triple-play transports of voice, data and video) in a service area, the infrastructure at the CO premises of modern Telco is set to cater for intense incoming and outgoing high-speed data transmissions at its switch terminals. Correspondingly, a loss in traffic intensity at the traditional T1 line-terminations of the CO switches can be anticipated, which calls for dynamic reductions in NAL requirements on ad hoc basis. Hence, the scope of this paper is to evaluate the conjectural impact on trunk terminations (and related facility) that decide the forecasts on NAL requirements at the traditional circuit-switches (of T1-hierarchy). Relevant logistics pursued thereof conforms to matching the NAL design to the traffic-flow specified in terms of centum call second (CCS) metric [1-3]. Considering an anticipated extent of trunk-side traffic (on NAL) facing a downward trend, it is attempted here to analyze following specific considerations of underlying engineering versus changes needed at the trunk-side in infrastructure planning of the inter-office facility (IOF) for economical CO operations:

- Evaluating the degree of inverse proportionality between x DSL penetration versus T1-sizing
- Introducing CCS-specific parameters in the inverse proportional relation
- Developing an algorithm that comprehensively leads to estimating (or forecasting) the anticipated fractional reduction in trunk-lines, for a given percentage increase in x DSLs and validating the computed results using example calculations performed with available data pertinent to some real-world wire centers across the country.

2. THE INFRASTRUCTURE OF INTER-OFFICE FACILITY (IOF): AN OVERVIEW

The techno economic aspects of a modern CO facility form a vivid portrait of a complex system as a result of [1]: (i) Intricate and advanced technology improvised to meet the economics-centered consumer options and (ii) a gamut of varying traffic statistics supported across the CO-switch and its associated network infrastructure.

Notwithstanding the fact that, even the Telco operation of yesteryears had a complex profile of certain dimension, modern Telco operations are even more set to forge ahead in assuming additional complex attributes. This stems from the situation that the originally equipped (traditional) circuit-switch are redesigned in the present contexts of Telco services and supplanted with multiples of newer technology so as to provide access to a variety of subscriber-generated traffics across the networks of typical Telco infrastructures illustrated in Figures 1 and 2.

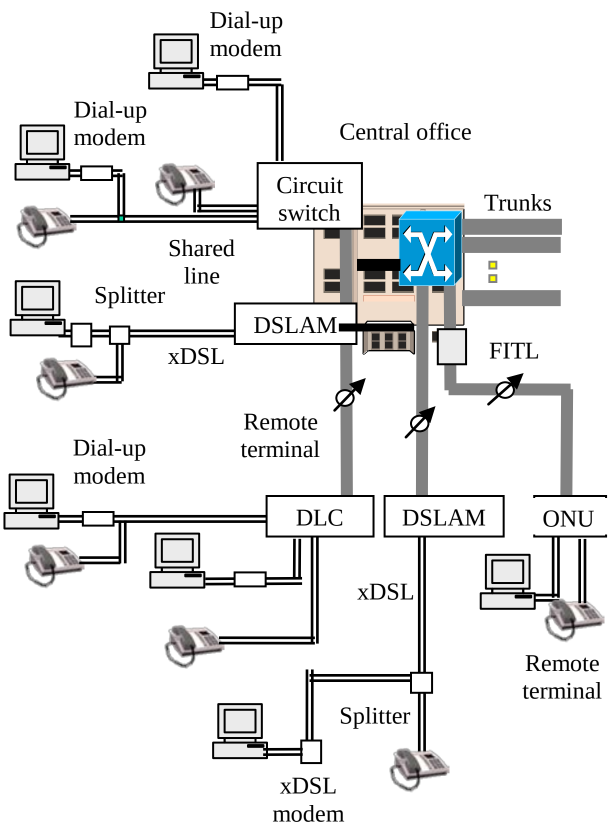

Fig 1: Typical telephone and data access methods at a local switching office (CO/RT) level. (DLC: Digital loop carrier; DSLAM: DSL access modem; FITL: Fiber-in-the-loop; ONU: Optical network unit)

The Telco facility in general, is comprised of a set of local switching hardware (both at the premises of CO and its remote terminal, RT). Relevant engineering economics is governed by the investment cost (expended on line terminations, trunks and processors) as well as by maintaining the traffic-load supported across the CO, (which implicitly depicts the revenue metric on possible return-on-investment (ROI) to the Telco business). With the advent of traditional CO facility being revamped to accommodate new versions of access technology (such as x DSL) on incoming traffic side [2, 3], concurrently it has become necessary to achieve an enhanced capacity for the outgoing traffic (facilitated by IOF). Further, considering the nature of modern telecommunication traffic load handled at CO premises, its classical profile of being just a voice-traffic is no longer valid, thanks to coexisting triple play transports, (each of which having its own peak-hour characteristics) accessed through CO facility.

Further, the wire line voice traffic across a CO is affected by the diversion of telephone conversations met through cellular telephony; in addition, the extent of data traffic originally accessed via dial-up modems and presented at the CO circuit-switch has now declined because, the users have either opted for a high-speed access via x DSL or churned to cable-modem or direct-satellite access services. In both cases, the load (otherwise seen at the circuit-switch), is unavailable for handling at the CO-switch and its trunk facility.

The net effect of the aforesaid considerations on line-terminations can be seen manifesting as a downward trend in the CCS profile monitored at CO premises [3]. Consequently, this trend is also felt at the trunks and in the IOF that supports the outgoing traffic. That is, a "head-count" on active trunk terminations and the associated call-processing time would incline to show a negative slope.

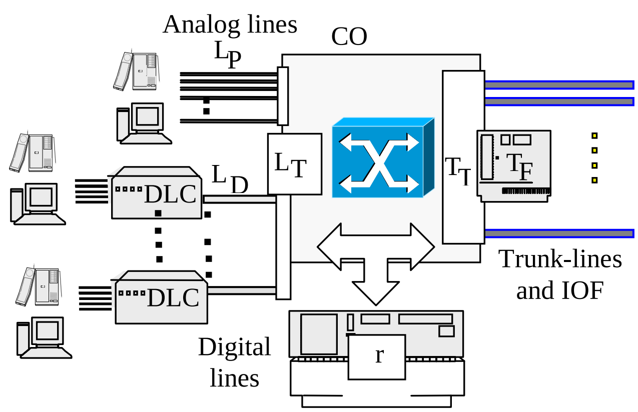

Fig 2: Technology-specific central office (CO) parameters that can be engineered to meet customer demand and for optimal revenue earning. (DLC: Digital loop carrier; L_P: Number of analog lines; L_D: Number of digital lines; T_T: Trunk terminations; L_T: Line terminations; T_F:Trunk facility; and, r: Call-processing capacity)

Foreseeable engineering efforts consistent with anticipations to increase or reduce the number of trunks are essential to optimize the cost versus revenue profile of CO premises that faces the aforesaid changing trends in traffic/ CCS patterns at the switch. Such trunk-sizing efforts should, however be done prorated basis; as well as, it should be commensurate with needs that arise as a result of visibly changing traffic/CCS load pattern. Any overestimate on the reductions will hamper the CO performance in handling the information traffic; and, an underestimate will burden the CO economically due to possessing unused spare capacity on the trunk-side. The implication of aforesaid considerations, in general, suggests the need for a cost-saving economics by prudently reducing the number of trunks required at the CO, in question. Alternatively, the trunks that will be released as a result of reduced traffic (that is, any spare capacity) can be shifted for use by wire centers

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that need additional trunk facilities [4]. However, all such efforts should be done cautiously and judiciously lest CO performance will be under-rated or spare-lines will be left over unused in the operational turf. Hence, it is pertinent and necessary to monitor as well as track trunk requirements (plus the associated switch terminations and relevant IOF) in envisaging CO-specific economics and exercising related cost-saving (both CAPEX and OPEX) strategies envisioned via T1-sizing.

Further, as a lead effort proactive to any expansion scenario of provisioning xDSLs to customers, it is meaningful to observe relevant impacts of such xDSL implementations on the CCS supported at the incoming side of each circuit-switch so that, the extent of trunks required at the outgoing section of a CO could be reasonably justified and prudently trimmed. In addition, any observable impact thereof, should be simultaneously viewed (as indicated before), as the consequence of two other (implicit) influences, namely, the proliferation of alternate Internet access methods and cellular phone demography in the service area, all of which could potentially "snatch" away the existing CCS-load at a CO switch facility.

3. A NAÏVE APPROACH ON IOF-SPECIFIC T1-SIZING

In the contexts of alternate high-speed transits facilitated for Internet traffic, the inevitable T1-sizing encountered directly implicates the IOF techno economics. Relevantly, certain canonical hypotheses can be suggested toward trunk-sizing forecasts specific to penetrating x DSL, vis-à-vis the growing trend of other Internet access methods and proliferation of cellular telephony in the service area. These hypotheses can then be adopted to relate the growth in ADSLs versus the trunk (T1) size requirements at a CO facility.

Proposed here thereof are three naïve models: In the first model (Model I), the aforesaid impact of alternate traffics on T1-sizing can be hypothesized as a simple inverse proportion relation characterized by the following equivalence concept: "The actual provisioning of a single ADSL will equivalently impact inversely $(1/24)^{th}$ of a T1". This statement is based on an approximate heuristics that a wire-pair extended to a subscriber as an ADSL is the wire-pair lost on the DS0 voice-line service; and, as well known, 1 DS1 (T1) is made of 24 DS0s.

The second model (Model II) can be posted on similar considerations of equivalency between ADSL growth-to-(T1-sizing), except with an exponent factor Γ imposed on the inverse relation. Introducing such a factor can be, for example, based on an intuitive reasoning as follows: Suppose the broadband market pushes the subscriber demands by a percentage increase of, say, 40 % while opting for a broadband/high-speed access. (This assumed 40 % presumably includes both x DSL as well as other Internet access methods like cable-modem facilitated as high-speed/broadband options). That is, an augmentation of (say 40%) anticipated in broadband/high-speed provisioning can be set by a factor equal to, $\alpha = (1/0.4) = 2.5$. However, it can be further surmised that, for every end-user who opts for and migrates to broadband/high-speed access, only a fractional reduction in trunk-size (that supports T1-hierarchy) may be required. This can be justified as follows: No reduction in the extent of trunks (at an end-office serving the T1 traffic) is warranted for those traffics, which will not require an interoffice trunk for onward transmission. Hence, filtering out such traffics, only a partial reduction (say, 70 %) would sustain. Expressing this fraction as β (equal to 0.7 denoting 70 %), a net factor, $\Gamma = \alpha \times \beta$ (= 2.5 × 0.7 = 1.75) can be arrived at under the presumed considerations that the associated statistics of α and □ are mutually independent; and, this factor Γ (= 1.75, in the present example) can be indicated for applications towards the impact scenario on the number of x DSLs in an end-office versus any trunk down-sizing contemplations. Thus, $\Gamma = (\alpha \times \beta)$ with $(1/\alpha)$ denoting the fraction of subscribers in the service area opting for high-speed access via x DSL and/or other services and β is the fraction of the transport not dependent on interoffice facility.

4. LOGISTIC APPROACH OF T1-SIZING

In both versions of canonical models (Model I and II) explained above, the impact of x DSL growth on trunks can be viewed as an "incremental effect". That is, a fractional change in the cause (namely, ADSL growth) would influence a fractional sizing of trunks in an inverse proportional manner. In other words, by denoting the ADSL-growth impact as a variable parameter, x, and the corresponding trunk-size reduction parameter by a variable, y, the following (normalized) logistic fractional increment relation can be validly specified:

$$\Delta y/y = -\Gamma\, \Delta x/x \qquad (1)$$

where Γ is a constant of proportionality depicting an extent of weighing on the trunk-size versus x DSL-growth relation. The negative sign indicates that the effect on trunk-sizing is of decreasing (inverse proportion) trend. Integrating the relation of equation (1), the following result is obtained:

$$y = k_o x^{-\Gamma} \qquad (2)$$

Where k_o is the constant of integration, which can be determined explicitly by knowing some reference values for y and x. Denoting those reference values as y_o and x_o respectively, equation (2) reduces to:

$$(y/y_o) = (x/x_o)^{-\Gamma} \qquad (3a)$$

In differential form, equation (3a) can be rewritten as:

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$$(1 + d\, y/y_o) = (1 + dx/x_o)^{-\Gamma} \qquad (3b)$$

Pertinent to the canonical models under discussion, a logistic heuristic is additionally implied in equations (3). Correspondingly, presented in Figure (3) are graphs depicting the fractional change (dx/x_o), (expressed in %) versus (dy/y_o) as determined by the relation of equation (3b). The results furnished in Figure (3) further show that Model I (with $\Gamma = 1$), for example, implies a relative impact (influencing a downward trend) on the trunk facility as 66.6 % (from a reference level of 100 %), if the x DSL growth is up by 50 % from the reference status. For the same x DSL growth (of 50 % above the reference level), the second model (Model II with $\Gamma = 1.75$) however, proposes a relative trend down to 49.1 % from the 100 % reference. In other words, Model II is more prudent and projects a greater impact on T1-sizing (than the relevant projection by the first model). This is because Model II approach takes into account of customer specific routing of broadband/high-speed traffics. (For example, if $\beta = 0.4$, it means that 60% of the service is presumably borne by other competitive local exchange carriers (CLECs) like multiple system operators (MSOs). In effect, the net impact factor on T1-sizing (on decrement basis) as deduced earlier (via Model II) is $\Gamma = \alpha \times \beta$ ($\equiv 2.5 \times 0.7 = 1.75$). On the contrary, the Model I recommends Γ equal to 1 (implicitly suggesting no implications of those considerations pertinent to α and β of Model II).

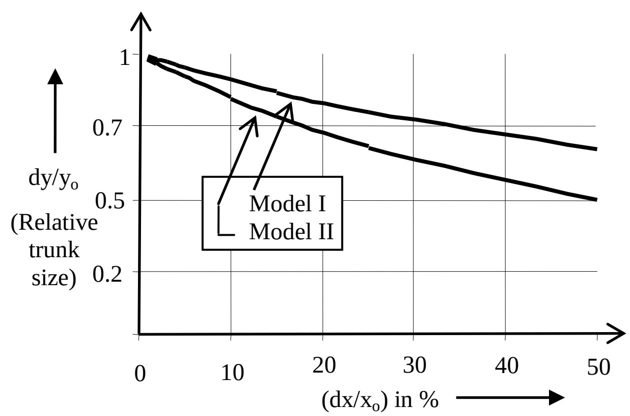

Fig 3: Fractional changes in x DSL growth versus trunk-size at the incumbent local exchange carrier (ILEC) CO: The cause-effect inverse proportion relation conforms to the proposed canonical Model 1 with $\Gamma = 1$ and Model II with $\Gamma = 1.75$.

It should however, be noted that the entities, $\alpha = 2.5$ and $\beta = 0.7$ used in deducing the Model II (as weighting entities on the impact factor for T1 down-sizing), are purely intuitive values based on an arbitrarily assumed, broadband/high-speed market profile and on other CLEC calls, and fractionally supported by the trunks. Such intuitive reasoning adopted in assigning the values for α and β, could be interpreted sometimes intangible, inasmuch as such values could be based on several other coexisting factors, which cannot be accurately quantified in practical Telco operations.

Notwithstanding such a projected opinion as above, the basis of Model II cannot however, be totally ignored. Perhaps the specific numbers suggested (namely, $\alpha = 2.5$ and $\beta = 0.7$) imply only a particular scenario of market situation and CLEC-based traffics trends experienced at a CO facility. That is, $\Gamma = 1.75$ should not, per se, be regarded as a rigid parameter for use in equation (1). More appropriately, Γ should be considered as a range of stochastic variable contained within certain lower and upper bounds. That is, a bounded range of Γ, namely ($\Gamma_{min} \le \Gamma \le \Gamma_{max}$) is more appropriate. Hence, the following is an analytical suite suggested here to arrive at a more stochastically justifiable value for Γ, or at least its bounds.

4.1 T1-Sizing with Stochastical Bounds

Suppose the factor Γ that implicates the extent of T1 down-sizing is taken in a normalized form as γ/γ_o. Then, the parameter Γ in equation (3) can be identically set equal to a value such that, $[1 < (\Gamma = \gamma/\gamma_o) < (\gamma/\gamma_o)_{max}]$ corresponding to a range, ($\Gamma_{min} \le \Gamma \le \Gamma_{max}$). Here, the normalization factor namely, γ_o can be uniquely prescribed and justified on the basis of engineering considerations pertinent to the system under discussion. Typically, on the lower-side when $\Gamma = \gamma/\gamma_o \to 1$, it refers to Model I; and, considering the upper-side, $(\gamma/\gamma_o)_{max}$ specifies a maximum value for γ/γ_o as governed by the associated statistical bounds. Model II as seen earlier rather prescribes a more specific value for $\Gamma = \gamma/\gamma_o = 1.75$ residing within these bounds for an arbitrary set of assumed values for α and β; and, as said earlier, such values are based on the intuitive reasoning of an assumed, near-future, broadband market factor that will push the subscriber demands by a certain percentage increase while opting for the broadband/high-speed access. Therefore, an augmentation of broadband/high-speed provisioning by a factor equal to, $\alpha > 1$ is anticipated to cope with subscriber demand. It is further propositioned in Model II that, for every end-user who opts for and migrates to broadband/high-speed access, only a fractional reduction in the trunk-size (that supports the high-speed traffic) may be required. That is, no reduction in the extent of trunks at an end-office serving Internet routing is warranted for those traffics that may not require an interoffice trunk to reach the switching premises of CLECs. Hence, eliminating such enhanced high-speed options subscribers and traffic diversions, only a partial reduction ($\beta < 1$) sustains in the second model in arriving at the net factor, $\Gamma = \alpha \times \beta$ (with the associated statistics of α and β being mutually independent).

The naïve strategy of Model I and II however, needs a further revision that would allow the inclusion of a range-specified set of random values for the variables ($1 \le$

$\alpha \le \alpha_{max}$) and ($0 \le \beta \le 1$) in lieu of a fixed set of values adopted in the models as indicated above. Relevantly, the underlying considerations are as follows:

4.2 Mixture Formulation on Conjectural Impacts

The joint statistics of (α and β) in essence, decides the value of Γ which in turn, inter-relates the cause-effect considerations of the models under discussion. In other words, the parameter Γ can be regarded as an outcome of the "mixed" entities α and β that are mutually independent. That is, Γ should be regarded as the constituents of a statistical mixture phenomenon, in which the factor α plays a fractional role to an extent of η_1 and β shoulders a part, namely, η_2 so that, $(\eta_1 + \eta_2 + \eta_3) = 1$, where η_3 represents any other influences (designated by ρ) that are governed neither by α nor by β. Corresponding to the set $\{\alpha, \beta, \rho\}$, suppose a normalized counterpart, namely, $\{a/a_o, b/b_o, c/c_o\}$ are specified and the resultant of these mixed influences, namely, γ/γ_o is determined by a statistical mixture formula (due to Lichtenecker and Rother [5-7]) given by:

$$\frac{\gamma}{\gamma_o} = \left(\frac{a}{a_o}\right)^{\eta_1} \times \left(\frac{b}{b_o}\right)^{\eta_2} \times \left(\frac{c}{c_o}\right)^{\eta_3} \qquad (4)$$

Where, the variables are uniformly distributed random numbers (commensurate with Laplacian hypothesis with no prior knowledge on the associated statistics and no bias been imposed). Further, the functional relation of equation (4) can be prescribed with the following statistical bounds:

Lower bound: $[(\gamma/\gamma_o)_{LB}]$

$$= \eta_1 \times (a/a_o) + \eta_2 \times (b/b_o) + \eta_3 \times (c/c_o) \qquad (5a)$$

Upper bound: $[1/(\gamma/\gamma_o)_{UB}]$

$$= [\eta_1/(a/a_o)] + [\eta_2/(b/b_o)] + [\eta_3/(c/c_o)] \qquad (5b)$$

The mixture formula of equation (4) is popularly known as "logarithmic law of mixing" [5-7].

The parameter set $\{a/a_o, b/b_o, c/c_o\}$ depicts the causative mechanisms that are stochastically-justifiable and visibly impact the steps to be pursued in altering the T1-size. Hence, it is appropriate to call this set as an impact parameter set. Further, the corresponding normalizing entities, namely, $\{\gamma_o; a_o, b_o, c_o\}$ can be chosen as reference values correlated to, for example, the prevailing technological and/or market situations. And, the elements of the set $\{\eta_1, \eta_2, \eta_3\}$ that constitute the power-exponents in equation (4) implicitly denote weighting coefficients on the logarithmic values of the impact parameters, $\{a/a_o, b/b_o, c/c_o\}$. That is, taking logarithm on either side of equation (4), it follows that,

$$\log(\gamma/\gamma_o) = \eta_1 \times \log(a/a_o) + \eta_2 \times \log(b/b_o) + \eta_3 \times \log(c/c_o) \qquad (6)$$

Where the base of the logarithm is implicitly absorbed by the coefficients involved. In other words, the base of the logarithms in equation (6) can be appropriately chosen in conjunction with the normalization parameter set $\{\gamma_o; a_o, b_o, c_o\}$.

Now, the "other influences" implicated by the set $\{\eta_3, c/c_o\}$, in practice, may correspond to those traffic diversions significantly felt at CO premises (and observed as the loss of CCS) leading eventually to the viability of T1 down-sizing. Typically, as stated before, the proliferations of cable-modem users in the service area and wireless (cellular) telephony traffic may affect CCS at the CO switches to a significant extent. The resulting traffic (CCS) loss considerations will influence the interoffice trunk facility (like ISP-handled data communications). Hence, it is logical to combine the variables, (b/b_o) and (c/c_o) and specified by a single variable, d/d_o. Correspondingly, η_2 and η_3 can be jointly denoted by, ϕ_2, so that $\eta_1 \equiv \phi_1$ and $(\phi_1 + \phi_2) = 1$. Therefore, equation (4) can be rewritten as,

$$\frac{\gamma}{\gamma_o} = \left(\frac{a}{a_o}\right)^{\phi_1} \times \left(\frac{d}{d_o}\right)^{\phi_2} \qquad (7)$$

Or, alternatively,

$$\begin{aligned}\log(\gamma/\gamma_o) &= \phi_1 \times \log(a/a_o) + \phi_2 \times \log(d/d_o)\\ &= \phi_1 \times \log(a/a_o) + (1 - \phi_1) \times \log(d/d_o)\\ &= \phi_1 \times \log[(a/a_o)/(d/d_o)] + \log(d/d_o) \qquad (8)\end{aligned}$$

Equation (8) can be identically written in the form of a linear relation, Y = mX + C with a set of upper and lower bounds as follows:

Lower bound: $(\gamma/\gamma_o)_{LB}$

$$\begin{aligned}&= \phi_1 \times (a/a_o) + (1 - \phi_1) \times (d/d_o)\\ &= \phi_1 \times [(a/a_o) - (d/d_o)] + (d/d_o) \qquad (9a)\end{aligned}$$

Upper bound: $[1/(\gamma/\gamma_o)_{UB}]$

$$\begin{aligned}&= [\phi_1/(a/a_o)] + [(1 - \phi_1)/(d/d_o)]\\ &= [\phi_1/\{(a/a_o) - (d/d_o)\}] + [(1/(d/d_o)] \qquad (9b)\end{aligned}$$

Where, both bounds are again in linear forms.

In summary, the extent of impact on the trunk-side is governed in statistical norms by $\Gamma = \gamma/\gamma_o$ of equation (8) with its bounds given by equation (9). Corresponding results on Γ with a pair of bounded-limits can be specified as Model III.

5. SIMULATIONS

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A set of simulations are performed with equations (8) and (9) using uniformly-distributed independent random values in the range (0, 1) assigned to the normalized variables involved. Suppose a set of randomly generated values for $\{a/a_o \in (1, 0); d/d_o \in (1, 0)\}$ with the parameters, $\phi_1 = 0.98$; $\phi_1 = 0.50$ and, $\phi_1 = 0.02$ is considered. Corresponding simulated graphs are presented in Figure 4. These graphs depict the best-fit curves on the results obtained using an extensive ensemble sets of random values prescribed on the set $\{a/a_o, d/d_o\}$.

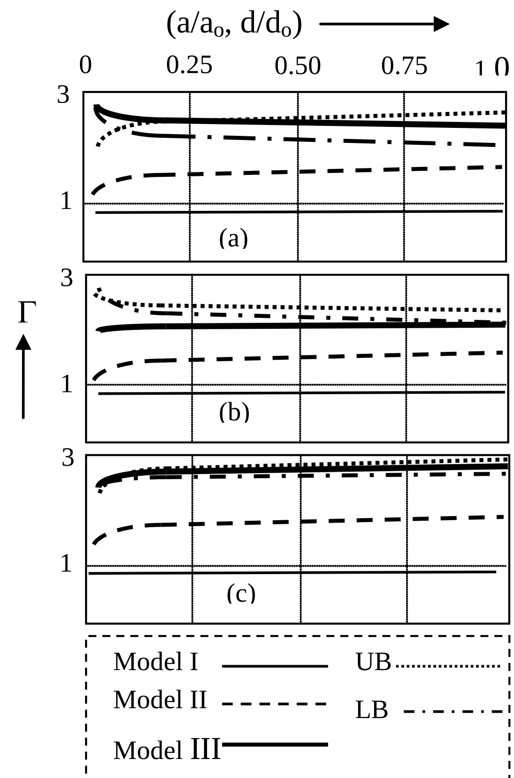

Fig 4: Variation of the impact factor (Γ) versus randomly generated data set $\{a/a_o, d/d_o\}$ in the canonical models (Model I and II) and in Model III

(a) ϕ_1 = 98 % and ϕ_2 = 2 %; (b) ϕ_1 = 50 % and ϕ_2 = 50 %; (c) ϕ_1 = 2 % and ϕ_2 = 98 %.
UB: Upper-bound; LB: Lower-bound

With reference to the example scenario of simulated data presented in Figure 4, the following can be inferred:

- Pertinent to Model III proposed in this study, there are three sample situations assumed (for the same conceptual weightings considered in Models I and II):
- The first case assumes a large influence to an extent of 98 % on (ϕ_1) and only 2 % on (ϕ_2). The statistical nature of variations in Γ for any random set of $\{a/a_o, d/d_o\}$ correspond to bounded conditions as shown in Figure 4(a) with $1 \le \Gamma \le (2 \tau o\ 3)$
- The second case assumes a balanced influence to an extent of 50 % on (ϕ_1) and 50 % on (ϕ_2). In this case, the statistical variations in Γ for any random set of $\{a/a_o, d/d_o\}$ conform again to the bounded conditions of Figure 4(b), with $1 \le \Gamma \le (2 \text{ to } 3)$
- The third case assumes a minimal influence to an extent of 0.02 % on (ϕ_1) and a high impact of 98 % on (ϕ_2). As in the other two cases, the variations in Γ for any random set of $\{a/a_o, d/d_o\}$ are bounded again as shown in Figure 4(c), with $1 \le \Gamma \le (2 \text{ to } 3)$

Pertinent to all three cases as above, it can be observed that the impact exponent Γ lies approximately in the range, $1 \le \Gamma \le (2 \text{ to } 3)$, suggesting that the impact on T1-sizing can be decided by the relation $(1 + dx/x_o) = (1 + dy/y_o)^{-\Gamma}$ with $[1 < \Gamma < (2 \text{ to } 3)]$. Implicitly, it means that the proposed mixture model (Model III) anticipates more prominent impact than the situations indicated by the simple Models I and II.

6. COMPUTED RESULTS WITH REAL-WORLD TELCO DATA

Shown in Figures 5 through 8 are ADSL sales data and CCS measured over the period December 1999 through August 2003 at four wire centers identified as A, B, C, and D. Pertinent to relevant details on ADSL penetration (sales) and the CCS variations observed, computed results on Γ (using the test models, Model I, II and III) are presented in Table 1; where Γ denotes the percentage changes (reductions) that could be anticipated in the trunk-side traffic activity.

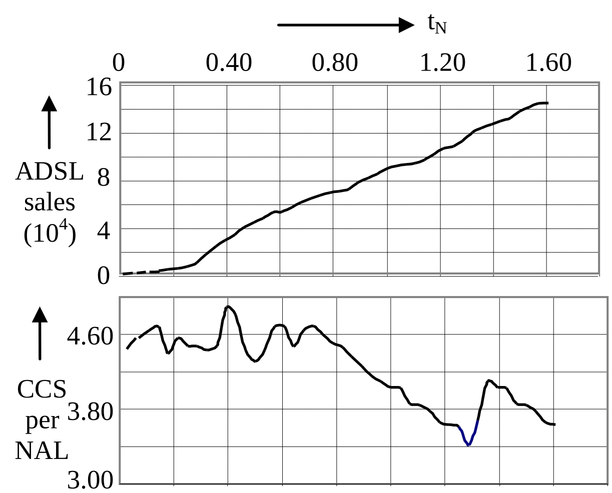

Fig 5: Wire center A data on ADSL sales and CCS variation from December 1999 through August 2003. (t_N: Normalized time t, with $t_N = 1$ depicting 10^{th} month from the start at t = 0)

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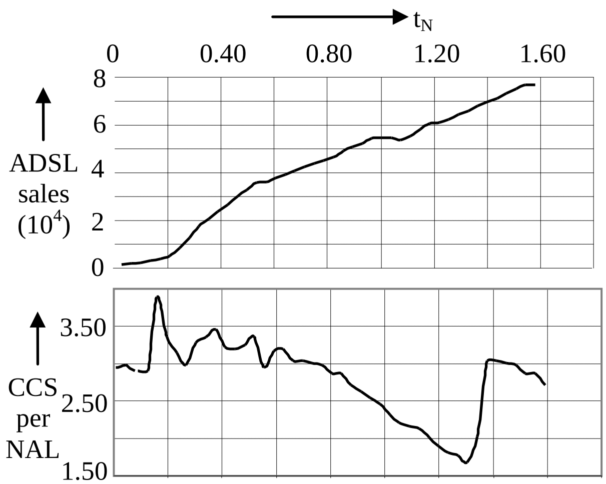

Fig 6: Wire center B data on ADSL sales and CCS variation from December 1999 through August 2003. (t_N: Normalized time t, with $t_N = 1$ depicting 10^{th} month from the start at t = 0)

Table 1: Δa/a versus ΔF/F
Linear regression function: (ΔF/F) = [m(Δa/a) + k]

Wire center	y = (ΔF/F) = [m(Δa/a) + k]	Γ = m
A	1.0488 x – 0.0098	1.0488
B	1.0739 x – 0.0132	1.0739
C	1.0366 x – 0.0262	1.0366
D	1.0325 x – 0.0116	1.0325

The wire centers, A, B, C and D whose data are presented in Figures 5 through 8 are located at large across the United States. (Their explicit names are avoided here due to proprietary reasons). However, the pertinent descriptions of these wire centers are as follows:

A: Wire center with large NAL provisioning and large ADSL penetration
B: Wire center with large NAL provisioning and medium; ADSL penetration
C: Wire center with small NAL provisioning and low ADSL penetration
D: Wire center with medium NAL provisioning and medium ADSL penetration.

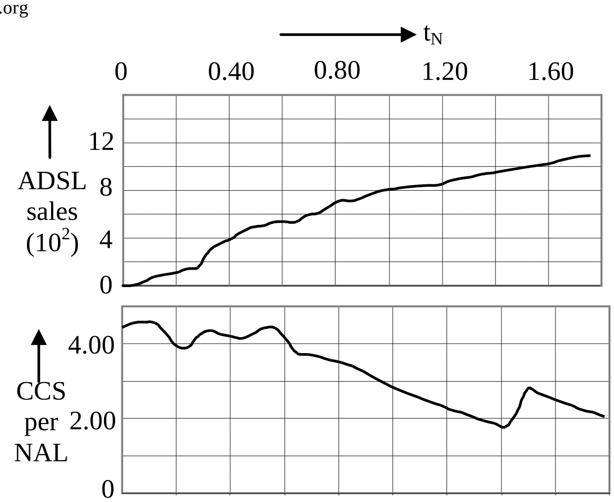

Fig 7: Wire center C data on ADSL sales and CCS variation from December 1999 through August 2003. (t_N: Normalized time t, with $t_N = 1$ depicting 10^{th} month from the start at t = 0)

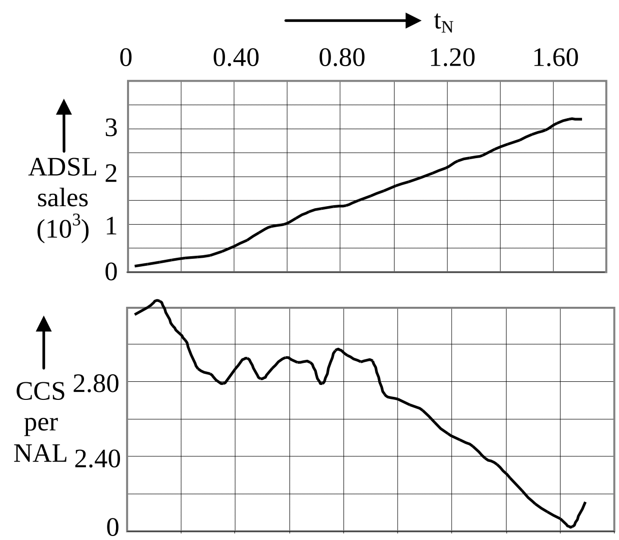

Fig 8: Wire center D data on ADSL sales and CCS variation from December 1999 through August 2003. (t_N: Normalized time t, with $t_N = 1$ depicting 10^{th} month from the start at t = 0)

It can be seen from Figures 5 through 8 that, as ADSL sales grow in a certain service area, correspondingly the measured CCS drops; and hence, an engineering reduction is warranted in NALs. A graphical plot of Δa/a (with 'a' denoting ADSL penetration) versus ΔF/F (with 'F' representing the IOF) should lead to finding Γ. Hence, for the four wire centers indicated above the computed results on Δa/a versus ΔF/F obtained using the data set of the wire centers A, B, C, and D are presented in Table 1: They correspond to linearly-regressed set of lines on the computed data with m as the slope and k as the y-intercept. From the results on Γ indicated in Table 1, they conform to inference developed earlier, namely ($1 \leq \Gamma \leq 2$ to 3); and mostly, the results seen in Table 1 are closer to Model I. The reason is as follows: The data on four wire centers (A to D) correspond to earlier days of ADSL growth in the respective service areas from 1999 through 2003; and as such, the prominence of α and β factors in deciding Γ is not observed inasmuch as there were no significant extent of alternate high-speed local-access other than ADSL prevailed; and, the β-factor alone has insignificantly influenced the formulated Γ values.

7. CONCLUSIONS

On the basis of heuristics presented with reference to the models developed and simulations carried out in this study, the following inferences can be arrived at:

a. The first model (Model I) refers to a simple inverse proportion relation depicting an idealistic situation with minimal impact on the trunk side against any anticipated changes on the traffic intensity supported by the circuit-switch in the CO premises.

b. The second model (Model II), however, proposes a more prudent implication on the impact in question and suggests a cautious approach, which duly accounts for the broadband/high-speed market situation as well as traffic sharing by the CLECs. In spite of some empiricism infused in the model, there is some justification in its prudent outlook implied in projecting a larger impact. This is especially true in view of the declining trend in CCS at a circuit-switch because of x DSL penetration, cable-modem market as well as diversion of voice traffic into cellular telephony. However, Model II lacks statistical attributes in its formalism and as such, it needs a revision to include the extensiveness of the variables. Hence, a third model (Model III) is proposed in this study and tailored to improvise relevant considerations.

c. The statistical aspects considered in Model III avoid empiricism (confined to a rigid set of variables) and justifiably accounts for statistically-bound ranges across the variables involved. That is, the proposed model accommodates a stretch of (random) variables over a range, (unlike a single hypothetical consideration that leads to $\Gamma = 1.75$, as presumed in the second model). Model III leads to an inference, which suggests even a larger impact on the issue (than that proposed in the second model), under the worst-case scenario of Γ tending to an upper bound of 3.

d. The major contribution of the present study governs the method of translating the intuitive reasoning behind the (inverse proportion) logistics of the parameter Γ into a viable algorithm that computes the actual sizing of the trunk-lines (for any given change in x DSL growth). Equations (5 through 9) derived thereof enables relevant computation using a set of practical parameters. This is demonstrated with four sets of data pertinent to wire centers A, B, C, and D. Computed results using appropriate parameters collected from such real-world Telco databases on typical wire centers (of four categories mentioned above) conform to the models developed in this study. Specifically, the simulated results using the data from A, B, C, and D are closely in conformance with Model I (and $\Gamma \approx 1.0$). The reason as mentioned before, is that during the time period of data collected in these wire centers, the non-ADSL versions of high-speed Internet (like cable modem) as well as cellular telephony were not significant in projecting a value for β.

To conclude, the concept of the present study offers a way to determine the statistical range of possible impact of traffic degradation on the circuit-switch that may implicate the size of T1-facility. It provides an explicit means of reducing the percentage of trunk-lines that could be affected because of x DSL penetration. It uses practical, engineering parameters in the algorithm developed. The percentage reduction in the trunks deduced will eventually leave the associated terminals (and/or facility) free (to the extent of reduced traffic intensity estimated); and, such freed (spared) trunk facility could be used for any new demands posed on IOF as proposed by Neelakanta and Baeza [4]. The proposed approach can be extended to the newer generation of IOF supporting optical transports [8].

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