A Nodal Route Switching Network Composed of Standard Modules

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ABSTRACT

This paper presents a form of nodal switchblock, which enables the blocking characteristics and pattern of availability of a small switchblock to be extended to a wide range of larger switchblocks. This principle can be applied so that growth can be achieved without reconfiguring previously established links and terminations. The traffic characteristics of typical implementations are examined and suitable applications for the switchblock in communications networks are suggested.

INTRODUCTION

The switching requirements for low occupancy sources within a network can be subdivided into (a) traffic concentration and (b) route switching. A clear physical as well as theoretical division into these two categories of switching is an essential step towards a system which is adaptable in size range and simple to extend.

The concentration stages present no major problem in system growth since it is merely necessary to provide more standard sized blocks of concentration stages. However, there are problems in providing a form of route switching which can provide an adequate size range and which is simple to extend. Ideally growth should be achievable (a) without altering the blocking probability, (b) over an adequate size range for network requirements, (c) without disturbing the switchblock which already exists, (d) in sufficiently small modular steps. This paper presents and analyses a concept of switching which largely achieves these objectives. The implementation of this concept can be optimised to suit blocking requirements, typical route sizes and switchblock size range.

2. NETWORK TOPOLOGY AND GROWTH PROCESS

The function of the route switching network is that of switching between multi-point routes of defined minimum size. It is assumed that ancillary concentration or access switching stages at local or remote locations provide accessibility to any free paths in the required routes.

The conceptual route switching network is representable in the form of nodes (see figs. 2 and 3) each of which consists of a switching array of at least two stages as shown in Fig. 1 in which the outer switch multiples give N sets of terminations. An array with N = 1, i.e. with no additional multiples, constitutes the smallest or elemental array possessing L inlets and L outlets. Each node is capable of carrying an approximately fixed A erlangs of traffic at the required loss probability determined by the fixed composition of the presently undefined centre stages which may be simply wire links. Any variation in nodal traffic capacity (albeit small) arises from different source traffic distributions, for which one determining factor is the value of N. In the form of switchblock to be presented, the least smooth traffic distribution is likely to occur at the highest utilised value of N. It is generally expedient in practice to fix A at such a worst condition in order to obtain a simple system which does not require subsequent exact traffic calculations or simulations for any intermediate size or growth stage.

FIG. 1 GENERALISED SWITCHBLOCK PER NODE

FIG. 2 1st & 2nd MAIN GROWTH STEPS

FIG. 3 GENERALISED GROWTH PROCESS

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The nodal switchblock consists of a square matrix of $M^2$ nodes, the inlets and outlets of these nodes being multiplied as shown in Fig. 3. The first main growth step, i.e. beyond a single node, is with $M=2$ as shown in Fig. 2. Within the limit of $A$ erlangs per node, the value of $N$ can be 1 or 2, the former permitting an intermediate growth stage but with lower than nominal congestion; these two increments give twice and four times the elemental traffic capacity and number of terminations.

The general case of this growth procedure is represented in Fig. 3. Assuming an even distribution of traffic over the switchblock, it can be seen that the traffic carried per element will be $NA/M$ erlangs, so that $N< M$ without exceeding the $A$ erlang capacity of each node. The switchblock possesses $MN$ inlets and outlets and has a capacity of $MNA$ erlangs throughput. The values of $N$ for any given matrix size $M$ are in practice confined to $N = M$ and $N = M - 1$, as it can be shown that other values produce non-optimum networks in terms of crosspoint quantities.

It will be noted that a path between any inlet and outlet passes through only one node which therefore determines the blocking probability of that connection. It is generally an aim to maintain an even distribution of traffic over a switchblock by means such as choosing terminations for a particular route in a manner which spreads the traffic for that route over different regions of the switchblock. A special feature of the nodal switchblock is that if it is subsequently found that abnormal congestion is occurring in a particular node, it is possible to augment its traffic capacity by paralleling additional standard switching elements across it.

The growth to the next main step of an established switchblock can be accomplished in the manner shown in Figs. 4, 5 and 6, and entails the following procedure:-

(A) If $N = M$ in the existing switchblock, increase $M$ to $M+1$ thus adding $2M+1$ nodes and $2NL$ terminations. This is illustrated by the transition from Fig. 4 to 5, which can be practically implemented without re-arranging the terminations or inter-stage links which previously existed.

(B) If $N = M - 1$, increase $N$ by unity. This is illustrated by the transition from Fig. 5 to 6, which in practice involves paralleling additional switches on the first and last stages of each node and multiplying the appropriate new terminations. Again this can be practically implemented without disturbing the terminations which existed in Fig. 5.

This growth procedure can be continued without theoretical limit and avoids the frequently encountered problem referred to in the introduction of either only having a limited range of sizes for a switching system or having to perform complicated and expensive rearrangements of links and terminations to achieve growth. This extension process has been proved in practice using plug and socket techniques and eliminates the problem of having to leave empty spaces in racks to allow for growth.

The nodal switchblock arrangement can apply equally to each plane of a multi-plane switchblock, which is the form of implementation usually envisaged. The planes do not have to be identical although for the purposes of this paper only the cases where they are identical will be considered.

3. EXAMPLES OF ELEMENTAL SWITCH ARRANGEMENTS

3.1 2 STAGE: SINGLE PLANE Fig. 7; MULTIPLANE Fig. 8.
The simplest form of node is a two stage switch. The "fixed" capacity part of the switch is a set of wire links. This form of switch has the advantage that the N-multiple on the first and last stages can be implemented by a single multiple consisting of an interconnection between the corresponding centre links of N identical two stage switches. One such two stage switch, whether single or multiplane comprises the standard building block for any size of switchblock.

3.2 2-STAGE MULTIPLANE WITH 3RD INTERPLANE OVERFLOW STAGE. FIG. 9

This is similar to Fig. 8 except that the overflow switch provides interconnection between planes.

Normally routes would consist of one or more groups of like numbered inlets/outlets across the planes. The 3rd stage thus provides additional availability between routes which would otherwise be confined to terminations in the same plane. The third stage can be varied to suit the required congestion by splitting it into several switches which interconnect some of the planes or in the opposite sense by increasing the size of the switch and number of links connected to it. In any case the congestion is minimised by using the third stage as a last choice path, i.e. as an overflow stage.

An example of a 5-plane module of this type which has been manufactured is shown in Fig. 10. This can be configured into any number of planes in multiples of five, an example being 15 planes as shown in Fig. 11, which forms a useful analogue interface to 30/32 channel PCM systems.

3.3 3-STAGE SINGLE PLANE - FIG. 12

The centre stage remains fixed for each node throughout the growth process for all values of N and M. In the multiplane case one or more interplane switches can be provided, as a last choice in the path search.
4. TRAFFIC CHARACTERISTICS

For the envisaged applications of this form of switching network, it is necessary to determine the point-to-point blocking in one plane. This is the first step towards determining the congestion between routes connected across the planes for which the inlet and outlet blocking probability must be taken into consideration as well as the internal blocking of the switch. This single plane loss is inevitably high for the high occupancies envisaged. The switch which would usually be preceded by other switching stages, is likely to carry "smooth" traffic, i.e. with mean/variance < 1 and the binomial distribution should be applicable.

Consider first the application of Lee's linear graph method (1) applied to Fig. 8, using the symbols shown for switch dimensions and link load. For one plane the point-to-point loss probability is given by:

$$ B_1 = 1 - (1-\alpha)^p (1-\alpha_1) $$

Since the $p$ planes are independent, the blocking across $p$ planes between routes of $p$ circuits on opposite sides of the switch will be:

$$ B_p = [1 - (1-\alpha)^p (1-\alpha_1)]^p $$

Note that in accordance with Fig. 3, the traffic per centre link $Q_c = QN \frac{1}{M}$.

Where $\alpha$ is the average occupancy of the external connections to the nodal switchblock. However, the inlet and outlet loading to one node will be $\alpha_1 = \alpha$, since it is independent of both $N$ & $M$; the multiple $M$ has no effect because when one inlet of $M$ nodes is occupied, the parallel inlets of the other $M-1$ nodes are clearly not available.

Thus, $B_p = 1 - (1-\alpha)^p (1-\alpha_1)^p$  

Normally $N = M$, except in intermediate growth stages ($N = M-1$).

Since interference may occur between two $p$-plane blocking calculations, it is necessary to introduce an additional factor $\Pi$ to correct them. Hence:

$$ B_p = \left[1 - (1-\alpha)^p (1-\alpha_1)^p \right]^p $$.  

The two stage network can obviously be treated by a number of well known approximate methods as enumerated by K. Kümmerle (2) and others. As an example the Jacobaeus (3) method for and binomial distributions on the outlets and links leads to:

$$ B_p = \left[QN \frac{1}{M} \left(\frac{\alpha_1}{N} + \frac{\alpha}{M} \right) \right]^p $$

Normally $N = M$, except in intermediate growth stages ($N = M-1$).

It should be noted that any small error in the single plane point-to-point loss $B_1$ causes a considerable error in the route-to-route loss $B_p = (B_1)^p$, where $p$ is typically of the order of 30. At the high loadings (e.g. about 0.7) for route switching, formula I with its assumptions of statistical and functional independence between stages is probably very pessimistic. Formula II was found to be nearer expectations and simulations but should still be regarded with caution.

It is hoped in the future to present a more extensive traffic analysis of the networks shown including those employing overflow techniques in Figs. 9 and 10.

5. TRUNKING OF A ROUTE SWITCH

5.1 AS PART OF A LOCAL EXCHANGE

Fig. 14 shows the role of a Route Switch (typically containing elements of the type shown in Fig. 11) in a Local Exchange. Interconnection between one or more concentrators and the Route Switch is typically via four 30 circuit routes for each concentrator, with an occupancy of 0.7 per junctor.

Access switches, typically of the type shown in Fig. 15 provide connection to incoming routes which are assumed to be point traffic sources. However, outgoing routes, unless small, can be connected direct to the Route Switch, and it is also possible (although not shown) to connect large outgoing routes direct from the concentrators.

In this application all routes are connected with an equal number of connections on each side of the Route Switch, e.g. a 30 circuit route would have 15 circuits connected, one per plane to the inlets and 15 to corresponding outlets.

This provides accessibility between all routes including that required for own-exchange calls in the concentrators.

5.2 AS PART OF A TRUNK EXCHANGE

Fig. 16 shows an arrangement of the standard modules which suits a trunk exchange consisting mainly of bothway routes. In a similar manner to the incoming routes of a local exchange, all routes, after passing through the Access Switches, are split equally between each side of the Route Switch.
5. SIMULATION

A number of computer simulations have been carried out for both local and trunk exchange applications, both for point-to-point and point-to-point network configurations. These simulations incorporate the nodal implementation shown in Fig. 11. As an example, we show the results of a limited simulation of a point-to-point network. The parameters M and N are varied to produce a range of network sizes, which is shown over the range 480 to 23520 terminations. The latter does not represent an upper limit. This arrangement has a relatively high crosspoint count owing to its function for point-to-point applications with unrestricted accessibility. As a result of the constant loss feature for all sizes, they all closely approximate the performance shown in Fig. 18, which has been obtained by computer simulation, i.e. a point-to-point loss of about 0.005 at 0.75 average loading per termination.

7. CROSSPOINT COUNT

7.1 POINT-TO-POINT NETWORK

Table I shows the number of crosspoints over a range of sizes required by the arrangement shown in Fig. 16, using the 15-plane nodal implementation shown in Fig. 11. The parameters M and N are varied to produce a range of network sizes, which is shown over the range 480 to 23520 terminations. The latter does not represent an upper limit. This arrangement has a relatively high crosspoint count owing to its function for point-to-point applications with unrestricted accessibility. As a result of the constant loss feature for all sizes, they all closely approximate the performance shown in Fig. 18, which has been obtained by computer simulation, i.e. a point-to-point loss of about 0.005 at 0.75 average loading per termination.

| TOTAL NO. OF TERMINATIONS | M | N | ACCESS CROSS- | ROUTE CROSS- | CROSPOINTS PER TERMINATION |
|---------------------------|---|---|SWITCH | POINTS | SWITCH | POINTS |
| 480                       | 1 |   | 11520 | 3600 | 31.5 |
| 960                       | 2 | 1 | 23040 | 14400 | 39 |
| 1920                      | 2 | 2 | 46080 | 24000 | 36.5 |
| 2880                      | 3 | 2 | 69120 | 34000 | 42.75 |
| 4320                      | 3 | 3 | 103680 | 75600 | 41.5 |
| 5760                      | 4 | 3 | 138240 | 134400 | 47.3 |
| 7680                      | 4 | 4 | 184320 | 172800 | 46.5 |
| 9600                      | 5 | 4 | 230400 | 270000 | 52.1 |
| 12000                     | 5 | 5 | 288000 | 330000 | 51.5 |
| 14400                     | 6 | 5 | 345600 | 475200 | 57 |
| 17280                     | 6 | 6 | 414720 | 561600 | 56.5 |
| 20160                     | 7 | 6 | 483840 | 764400 | 61.9 |
| 23520                     | 7 | 7 | 564480 | 882000 | 61.5 |
7.2 POINT-TO-POINT NETWORK

For applications requiring point-to-point networks as shown in Fig. 17, but for simplicity omitting any bothway terminations, the crosspoint requirements are as shown in Table II over the range 960 (M=1, N=1) to 47,040 (M=7, N=7) total terminations, incoming plus outgoing. This assumes a nodal implementation of the type shown in Fig. 11 but with 30 instead of 15 planes. We expect internal switching blocking values for 60 circuit routes to be of the same order as shown in Fig. 18, but this has yet to be corroborated by simulation.

### TABLE II

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8. CONCLUSION

It has been shown that nodal switchblocks can have important applications in various types of space switching networks to ease problems of adequate size range and extendability. Incidentally, the methods described in this paper were investigated quite independently of the nodal switchblock envisaged by A.E. Joel (4), which bears some similarity but has also some fundamental differences.

It is apparent that nodal techniques offer great potential in enabling a few standard items of switching equipment to suit a wide variety of functions with important consequences in reducing development and production costs. However, it is also apparent that these and allied techniques have not, as yet, been fully investigated or exploited; for instance, the extent of the applicability of nodal techniques to digital switching systems such as Time-Space-Time or Space-Time-Space configurations is worthy of further investigation.

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REFERENCES

(b) AEU 25 (1971) pp. 466-471.
(4) A.E. Joel, Jr., 'Nodal Switching Networks'. 7th ITC Stockholm, pp. 312/1-6.