TELEPHONE NETWORK BEHAVIOUR IN REPEATED ATTEMPTS ENVIRONMENT A SIMULATION ANALYSIS

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ABSTRACT

DUE TO THE WIDE DIFFUSION OF DDD SERVICE AND SPC SWITCHING, TODAY NATIONAL AND INTERNATIONAL TELEPHONE NETWORKS ARE VERY SENSITIVE TO SITUATIONS ARISING FROM DEPARTURE FROM NORMAL CONDITIONS (OVERLOADS), IN ORDER TO ENSURE MAXIMUM NETWORK CALL CARRYING CAPACITY UNDER THESE CONDITIONS NETWORK MANAGEMENT ACTIONS HAVE TO BE TAKEN. THE PAPER DESCRIBES A MODEL FOR INVESTIGATING THE EFFECTIVENESS OF A RESTRICTIVE NETWORK MANAGEMENT ACTION ACCORDING TO WHICH OVERFLOW TRAFFIC IS PREVENTED FROM ACCESSING NETWORK RESOURCES WHEN PREDETERMINED OCCUPANCY LEVELS ARE REACHED, AS TO THE ASSOCIATED ATTEMPTS PHENOMENON AND QUEUEING AND TIME-OUT MECHANISM IN THE SWITCHING CENTERS.

1 INTRODUCTION

DUE TO THE DIFFUSION OF DDD SERVICE AND SPC SWITCHING, TODAY NATIONAL AND INTERNATIONAL TELEPHONE NETWORKS ARE VERY INTERDEPENDENT SYSTEMS INTO WHICH THE SUBSCRIBERS ARE OFFERED INCREASING POSSIBILITY OF PROMPT ACCESS TO OTHER SUBSCRIBERS. REACTION TO FAILURE TO CONNECT WITH THE CALLED PARTY IS THEN IMMEDIATELY REFLECTED IN THE NETWORK VIA REPEATED ATTEMPTS. THIS PAPER DESCRIBES A MODEL FOR INVESTIGATING THE EFFECTIVENESS OF A RESTRICTIVE NETWORK MANAGEMENT ACTION ACCORDING TO WHICH OVERFLOW TRAFFIC IS PREVENTED FROM ACCESSING NETWORK RESOURCES WHEN PREDETERMINED OCCUPANCY LEVELS ARE REACHED, AS TO THE ASSOCIATED ATTEMPTS PHENOMENON AND QUEUEING AND TIME-OUT MECHANISM IN THE SWITCHING CENTERS.

2 THE NETWORK MODEL

IN THE FOLLOWING THE ESSENTIAL CHARACTERISTICS REGARDING THE NETWORK MODEL ARE DESCRIBED.

- TOPOLOGY
  THE CONSIDERED TELEPHONE NETWORK MAY BE REPRESENTED AS A DIRECTED GRAPH WHERE NODES STAND FOR SWITCHING CENTERS AND ORIENTED ARCS FOR ONE-WAY TRUNK GROUPS. ALTHOUGH THE SIMULATION PROGRAM, /17/, ENABLES A WIDE RANGE OF COMBINATIONS AMONG STRUCTURAL AND OPERATIONAL CHARACTERS OF THE INVESTIGATED NETWORKS, FULL MESH NETWORK WILL BE CONSIDERED IN THE FOLLOWING.

- ROUTING
  BESIDES DIRECT, ALTERNATE ROUTES INVOLVING ONLY ONE TRANSIT CENTER ARE ALLOWED, ALTERNATE ROUTING OCCURS ON A SYMMETRICAL BASIS IN A NETWORK WITH N CENTERS THE FIRST TRANSIT CENTER FOR A CALL ORIGINATING IN I AND DIRECTED TO J, IS SELECTED AS J+1 IF J IS LESS THAN N, OTHERWISE IT IS TAKEN AS 1, SUBSEQUENT TRANSIT CENTERS ARE HUNTED ACCORDING TO INCREASING LABEL VALUE (LABEL 1 FOLLOWS LABEL 2).

- TRAFFIC PROCESS

THIS PAPER BASE ON CONTROLS WHICH HAVE ALREADY BEEN CONSIDERED BY GRANJEAN, /6/, AND MEAN, /17/.

SUCH CONTROLS PREVENT OVERFLOW TRAFFIC FROM ACCESSING NETWORK RESOURCES - RHUB LINES IN TRUNK GROUPS OR COMMON DEVICES IN SWITCHING CENTERS- WHEN PREDETERMINED OCCUPANCY LEVELS ARE REACHED, AS A FURTHER STEP TOWARD A CLOSER MODELING OF THE NETWORK BEHAVIOUR, THE REPRODUCTION OF FAST REFUSALS IS PURSUED HERE THROUGH A SIMULATIVE APPROACH.

SUCH A CLOSER MODELING ENABLES TO VERIFY THE EFFECTIVENESS OF ALREADY INVESTIGATED NETWORK MANAGEMENT ACTIONS IN A MORE REALISTIC ENVIRONMENT, TO GET DEEPER INSIGHT INTO THE MECHANISM OF FEEDBACK REACTIONS AFFECTING THE NETWORK PERFORMANCE AND TO COMMENT ON SOME RECENTLY PROPOSED, COMPREHENSIVE NETWORK PERFORMANCE METRICS.
THE PROCESS OF REPEATED ATTEMPTS ORIGINATING FROM CALLS THAT FAIL TO COMPLETE IS SUPERIMPOSED TO THE FORMER ONE.

DETAILS ABOUT THE RETRIAL PROCESS ARE FOUND IN SECTION 4.

- SWITCHING MACHINES

THE SWITCHING MACHINES ARE ASSUMED TO INTRODUCE BOTH DELAY AND LOSS IN THE NETWORK.
THE SWITCHING MACHINE MODEL CONSISTS OF A POOL OF COMMON DEVICES, FULLY ACCESSIBLE VIA A QUEUE WITH A LIMITED NUMBER OF WAITING PLACES. MOVED WAITING IN THE QUEUE IS UPPER BOUNDED THROUGH A TIME-OUT MECHANISM.

EACH COMMON DEVICE IS HELD SEIZED FOR A TIME RESULTING FROM TWO COMPONENTS: A CONSTANT SERVICE TIME AND A WAITING TIME FOR A COMMON DEVICE IN THE DOWNSTREAM SWITCHING CENTER ALONG THE CONNECTION PATH.

THE SERVICING DISCIPLINE IN THE QUEUE IS FCFS (FIRST COME FIRST SERVED), NEITHER LOSS INDUCED BY THE SWITCHING NETWORK NOR OTHER DELAYS DUE TO CONTROL OF THE SWITCHING CENTER ARE TAKEN INTO ACCOUNT.

- THROUGH-CONNECTION MODE

CONNECTON BETWEEN CALLING AND CALLED PARTIES IS SET UP ON A STEP-BY-STEP BASIS. THE INFORMATION DIALLY BY THE CALLING PARTY IS PROCESSED IN A COMMON DEVICE AND, IF THE CALLED PARTY IS NOT YET REACHED, THE ADDRESS INFORMATION IS PASSED ON TO A SUBSEQUENT SWITCHING CENTER.

TO THIS END A WAITING PLACE IN THE DOWNSTREAM CENTER IS SEIZED AS A RECORD OF A PENDING REQUEST FOR A COMMON DEVICE THERE. THE COMMON DEVICE IN AN UPSTREAM SWITCHING CENTER IS HELD SEIZED UNTIL EITHER A COMMON DEVICE IN THE SUBSEQUENT CENTER BECOMES AVAILABLE OR TIME-OUT OCCURS (AT THIS EPOCH ALSO THE WAITING PLACE BECOMES FREE AGAIN). CALLED PARTY ADDRESS INFORMATION IS TRANSFERRED TO SUBSEQUENT SWITCHING CENTERS VIA SPEECH TRUNK LINES.

TRANSMISSION RESOURCES INCLUDED IN CONNECTING PATHS DURING THROUGH-CONNECTION STAGE ARE HELD RESERVED UNTIL EITHER THE CALLED PARTY IS REACHED OR CONNECTION IS CLEARED DUE TO LACK OF TRANSMISSION AND/OR SWITCHING RESOURCES.

LESSE COMPLEXITY IN THE SWITCHING CENTERS AND FOR A DIFFERENT SCHEDULING ALGORITHM OF THE PENDING REQUESTS FOR COMMON DEVICES.

FIG. 1 SHOWS A 4-NODE NETWORK OF THE KIND CONSIDERED HERE.

A DESCRIPTION OF THE HANDLING OF AN ALTERNATE ROUTED CALL WILL HELP IN CLARIFYING THE HOLDING SEQUENCE OF NETWORK RESOURCES DURING THE CALL SET UP STAGE.

- UPON CALL ARRIVAL AT THE SYSTEM A WP (WAITING PLACE) IN THE ORIGIN CENTER IS SEIZED AND QUEUING FOR A FREE CD (COMMON DEVICE) BEGINS. A CALL MAY BE REJECTED IN THE ORIGIN CENTER EITHER BECAUSE NO FREE WAITING PLACE IS AVAILABLE OR BECAUSE THE MAXIMUM ALLOWED TIME IN QUEUE EXPIRES, I.E., TIME-OUT OCCURS. BEFORE A COMMON DEVICE BECOMES FREE.

- AFTER A CD IS SEIZED AND THE WP RELEASED IT IS HELD FOR A CONSTANT OPERATING TIME (UP TO THE REQUESTED DESTINATION AND AN AVAILABLE WAITING PLACE IN THE DESTINATION CENTER ARE SEARCHED FOR. BOTH OF THEM HAVE TO BE SIMULTANEOUSLY SEIZABLE OTHERWISE THE CALL MAY NOT BE DIRET ROUTED. ACCORDING TO THE ASSUMPTION OF ALTERNATE ROUTED CALL this SEARCH ENDS UNSUCCESSFULLY.

- THE SEARCH IS REPEATED OVER AN ALTERNATE ROUTE (THE SEARCH IS ONLY TRIGGERED BY UNAVAILABILITY OF A LINE AND NOT BY THE UNAVAILABILITY OF A WAITING PLACE).

ARRIVAL AT THE SYSTEM

TIME-OUT

TIME-OUT

TIME-OUT

TIME-OUT

START CHARGING

DEPARTURE FROM THE SYSTEM

FIG. 1 TIMING DIAGRAM OF THE NETWORK RESOURCES HOLDING TIMES

AGAIN ACCORDING TO THE ASSUMPTION, A CONNECTION TOWARD A TRANSIT CENTER (PERHAPS AFTER SOME HUNTING) ENDS SUCCESSFULLY, A LINE TOWARD THIS CENTER IS RESERVED AND A WP THERE SEIZED, ANYWAY THE CD IN THE ORIGIN CENTER IS NOT RELEASED UNTIL A CD IN THE TRANSIT CENTER BECOMES AVAILABLE (BEFORE TIME-OUT FOR THE WP THERE OCCURS), AT THIS TIME BOTH THE WP AND THE CD IN THE TRANSIT CENTER ARE RELEASED AND THE LINE IMMEDIATELY HELD RESERVED.

- A CONNECTION TOWARD THE DESTINATION CENTER IS ATTEMPTED AND THE COURSE OF UPDATES MIGHT SEALS ITSELF: A LINE TOWARD THE DESTINATION IS RESERVED, A WP IN THE DESTINATION CENTER

FIG. 2 THE NETWORK MODEL

THIS MODEL CLOSELY RESEMBLES THE MODEL CONSIDERED BY FRANKS AND RISHEL, /4/, BUT FOR A

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Seized, the Cd in the destination center found free and the Cd in the transit center together with the Wp in the destination center released.

- After the operating time for the Cd in the destination center has elapsed, the called party is reached. If the called party is not busy, the connection path is still held for a time corresponding to the reaction of the calling party to the busy tone. If the called party is not busy two cases are possible: either it answers or it does not. Accordingly, the ineffective holding time of the connection path may be different. If the call attempt ends with a conversation, an effective loading of the connection path follows the ineffective one.

A timing diagram of holding times for all devices involved in a successful alternate route call is depicted in Fig. 2.

THE NETWORK MANAGEMENT ACTION

The following conclusions drawn in works investigating network performance under overload conditions are generally agreed upon:

- The major gain obtainable through alternate routing in full mesh symmetrical networks is already achieved with overflow routes through one transit center. In fact, further gains pursued allowing for more than one transit center contribute only marginally, /6/, /18/, and /17/.

- Occupancy thresholds introduced for limiting overflow traffic are an effective means to implement selective cancellation of alternate routing, i.e., to prevent undesirable seizure of network resources by peaked traffic, /6/ and /17/.

- A similar mechanism for accessing queues in switching centers is also effective, /17/.

- Once a new network equilibrium induced by variation of some traffic parameters has been reached, an opposite variation of greater intensity is needed to re-establish the former equilibrium. In other words, the network displays a certain hysteresis, /17/.

The network management action considered in this paper reflects the acceptance of these conclusions. It consists in denying alternate routing to overflow traffic when specified occupancy thresholds on trunk groups are reached. A sophistication of this rule so as to account for hysteresis in the trunk group occupancy has also been implemented: each trunk carrying overflow traffic is at any instant in one of two mutually exclusive and possibly overlapping classes, the first identified by a number of busy lines ranging between \( u \) and \( x \), and the second by a number of busy lines between \( y \) and \( L \) (\( x \) greater or equal to \( y \), with \( L \) equal to the trunk capacity). Transitions from a class to another are represented in Fig. 3.

As it has been evidenced by Uranjean for networks without retrials, /6/, such a means proves effective: in that it increases the call carrying capacity of the network at moderate, with critical overloads with respect to that of a strict direct routed one. Moreover it limits the negative effect of strict, simple alternate routing at heavy overloads, forcing the network behavior to that of a direct routed one.

Another factor influencing network response is represented by time-out in the access queue to common devices.

THE CONTROL FEATURES REPRODUCED IN THE MODEL DO ACT IN THE LINE OF

![Overflow Traffic Inhibited](image)

![Overflow Traffic Allowed](image)

### Fig. 3 I Occupancy Classes and Hysteresis on Trunk Groups Carrying Overflow Traffic

The above stated principles, in contrast to other network management actions that prove effective but require a certain amount of information exchange between switching centers and monitoring of the attempts outcome on a per destination basis, /13/, the investigated action requires only local, non-selective intervention on access to trunks.

4 SUBSCRIBER BEHAVIOUR PROFILE

Measurement campaigns undertaken both in the past, /9/, /10/, /20/, and recently, /13/, /14/,

<table>
<thead>
<tr>
<th>Calling Party</th>
<th>Reattempt Probabilities</th>
<th>Network</th>
<th>Called Party Status Probabilities</th>
<th>Calling Party Average Time of Listening to Tones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NO</td>
<td>REJECTION</td>
<td>ANSWER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ANSWER</td>
<td>.75</td>
<td>8.5 s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>REJECTION</td>
<td>.59</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>ANSWER</td>
<td>.05</td>
<td>.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO</td>
<td>REJECTION</td>
<td>NO ANSWER</td>
</tr>
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<td></td>
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<td>.14</td>
<td>38 s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO</td>
<td>REJECTION</td>
<td>BUSY</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ANSWER</td>
<td>.17</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO</td>
<td>REJECTION</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ANSWER</td>
<td>.45</td>
<td>4.5 s.</td>
</tr>
</tbody>
</table>

### Fig. 4 I Call Disposition
1/6/, agree in evidencing a remarkable attitude of the subscribers to repeating attempts when a call does not complete, and a relatively short reaction time till a next attempt, results of measurements relate in some cases to retrials delayed by several minutes, whereas in other cases, as for example in 1/3, to retrials delayed at most one minute. Out of the events that may lead to reattempting, the three major ones are considered in the model namely: blocking in some parts of the system, called party does not answer and called party busy. These events account for about 95% of all causes of retrails, 1/3, Fig. 4 shows the modeled call disposition together with the probabilities of the considered outcomes, and the related average reaction times (the distribution of such times is assumed negative exponential). The values reported in the figure relate to fast retrails, i.e., retrails that are attempted within 60 seconds since preceding unsuccessful attempt.

**FIG. 5** DISTRIBUTION OF TIME TO NEXT RETRIAL

The fast retrial process accounts only for a segment of the whole retrial process, since hours or even days may elapse between failure and a retrial. It is however fast retrails that are liable to decisively affecting the system response within the time span that is of interest here, i.e., of the order of one hour or so.

For the time elapsed between two successive attempts a distribution derived from that reported in 1/3 has been adopted; its shape is given in Fig. 5, owing to the short reaction time before reattempting an unsuccessful call, the probability that an attempt following a former one failed due to called party busy will itself also fail for the same reason should not be considered independent of the reattempt order, nevertheless this independency will be assumed in the following both due to lack of sufficient information about such conditional probabilities and to the minor impact that these causes of reattempting have on the total fast retrial process.

**5 NETWORK PERFORMANCE METRICS**

Two metrics have been proposed, 1/11, 1/12, for characterizing the performance of a network in repeated attempt environments: the efficiency ratio, R, and the average number of attempts per call intent, b. They are defined in the following way:

**CHARGED CALLS**

\[ R = \frac{\text{INTENTS} \times \text{REATTEN PS}}{\text{INTENTS}} \]

**UNCHARGED CALLS**

\[ R = \frac{\text{INTENTS} \times \text{REATTEN PS}}{\text{INTENTS}} \]

The metric R has a comprehensive meaning, in that it informs about the effort in terms of attempts submitted to the system necessary to produce a certain amount of charged calls. The efficiency ratio takes into account both the system performance and the subscriber's behavior and is thus simultaneously systems- and subscriber-oriented.

The metric R has a selfexploratory meaning, from R and a third figure may be derived, namely:

**CHARGED CALLS**

\[ b = \frac{\text{INTENTS} \times \text{REATTEN PS}}{\text{INTENTS}} \]

This has formally a meaning analogous to the complement of the 'grade of service' in the lost=call-cleared model, but in practice ranges in a quite different interval of values due to the not negligible share of call intents that results in abandonments.

All of the above metrics are produced in the simulation on a point-to-point basis, page 6 several others are produced in order to monitor significant network behavior aspects, they include:

- Charged and uncharged traffic on each trunk group;
- Charged node-to-node traffic;
- Mean route length for effective calls;
- Percentage of calls failed due to various reasons (called party busy or no answer, blocking in the speech network, time-out or shortage of waiting places in the switching centers) depending on the attempt order;
- Distribution of waiting time throughout all switching centers (meaningful for symmetrical engineered networks).

**6 SIMULATION CAMPAIGN**

A simulation campaign is under way to evaluate the impact of widespread overload and hysteresis levels of the management action on the network behavior. Due to the manifold of parameters involved in the model and to the corresponding complexity in discriminating among the relative impact, a certain number of them is being held fixed. These are: network size, engineering of switching and transmission equipment, subscriber persistence and called party status probabilities.

The main results of the simulation campaign will be given at the presentation of the paper at the Congress.

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7 CONCLUSION

A TOOL FOR INVESTIGATING THE EFFECTIVENESS OF A NETWORK MANAGEMENT ACTION CONSISTING IN PREVENTING OVERFLOW TRAFFIC FROM ACCESSING NETWORK TRANSMISSION RESOURCES WHEN PREDETERMINED OCCUPANCY LEVELS ARE REACHED ON TRUNK GROUPS HAS BEEN DESCRIBED, FEATURING NON-TRANSPARENCY OF SWITCHING CENTERS AND REPEATED ATTEMPTS. ON THE BASIS OF THE RESULTS OBTAINED, THE ACTION APPEARS EFFECTIVE EITHER AT MODERATE AND AT HEAVY OVERLOAD CONDITIONS.

ALTHOUGH OTHER MEANS FOR HOLDING THE NETWORK CALL CARRYING CAPACITY NEAR TO MAXIMUM HAVE BEEN ENVISAGED AND SUCCESSFULLY TESTED, THE INVESTIGATION ONE SEEMS TO HAVE SOME MERITS OF ITS OWN.

ACKNOWLEDGEMENTS

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