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# Characterization of Static/Dynamic Topological Routing For Grid Networks

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## Abstract

*Grid or 2D Mesh structures are becoming one of the most attractive network topologies to study. They can be used in many different fields raging from future broadband networks to multiprocessors structures. In addition, the high requirements of future services and applications demand more flexible and adaptive networks. Topological routing in grid networks is a simple and efficient alternative to traditional routing techniques, e.g. routing tables, and the paper extends this kind of routing providing a "Dynamic" attribute. This new property attempts to improve the overall network performance for future necessities.*

## 1. Introduction

Grid structures have been implemented in many different fields. In telecommunications, they have been proposed on fiber optic backbone structures, wireless networks such as ORBIT [1] or for energy saving on sensor networks [2] (wireless). In computing, they have been proposed on multiprocessor interconnection, for example, Intel is developing the next generation microprocessors "Intel 80 Core", where 80 are cores connected as grid structure [3]. Besides these IT applications, grid structures can be identified as well in other fields such as water distribution, roads or power supply networks. Hence, Grid structures have been and still are an interesting researching field in order to improve the existing networks. This work focuses on communication networks and moreover in routing aspects of Grid structures, specially topological routing.

Topological routing is an alternative to traditional routing methods, based on tables. It allows for very fast restoration, and is particularly well suited for large-scale communication where table updates can be time consuming and introduces significant overheads [4].

Topological routing is defined as: *At a given address scheme, from any node any packet can be routed given only knowledge of the addresses of the current and the destination node, no routing tables are involved.*

This method has been implemented on Grid networks [4], dynamic routing has been theoretical introduced in [5] for traffic load in these topologies and the following natural step is to simulate its performance and also introduce new concepts of dynamic routing.

Dynamic routing, basically, consists on making routing decisions based on real time network status information. This decision can be made based on node congestion, link capacity, link reliability [6], battery lifetime (in case of wireless sensors) [2] or many others. Most of these adaptive techniques are implemented on pre-calculated path protocols, the paths are calculated periodically. One of the main properties of topological routing is the avoidance of path calculations, hence, the dynamic concept has to be applied in a different way. Furthermore, the nodes only have local information available, neighbors information, and the dynamic routing protocol has to be defined in such a way that it can perform just using this information but at the same time improve the performance of the global network. This work will treat the performance of the algorithms considering nodes congestion and delay of the transmissions as conditioning factors for the dynamic decisions.

The main goal is to analyze the methodology and scenarios where it is beneficial to implement a dynamic routing algorithm instead of the static. The existing topological routing algorithm is very simple, it requires a small amount of resources and time to be performed. In case that there is no problems or failures in transmissions between pairs of nodes, the packets will always follow the same path. Due to this simplicity, any modification to check the status information and to make routing decisions will add complexity implying an increment on the performing time (delay).

The rest of the paper is as follows: Section 2 introduces the concepts related to the topic of the paper. Section 3 presents the case study and the simulation concepts. Section 4 the results are represented and discussed and finally Section 5 exposes the conclusions.

## 2. Preliminary

### 2.1. Grid

Let $dim_x$ and $dim_y$ be positive integers. They define a regular grid *S* with node set *N* and line set *L* as follows. Every node in *N* is associated with a pair of coordinates (X, Y) such that $0 \leq X \leq dim_x$ and $0 \leq Y \leq dim_y$, and every coordinate pair is associated with a node. There are exactly ($dim_x$ +1)($dim_y$ +1) nodes in *S*. If a node *u* is associated to a coordinate pair ($X_u$, $Y_u$), we write u = ($X_u$, $Y_u$) to ease notation. The lines are given as follows: Two nodes ($X_u$, $Y_u$) and ($X_v$, $Y_v$) are connected by a line if $\mid X_u$-$X_v \mid + \mid Y_u$-$Y_v\mid$ = 1.

There is a high number of possible combinations to form an optimal path in terms of logical distance. The optimal routing path area is defined as the rectangle formed by the source and destination. Let $N_s = (X_s, Y_s)$ and $N_d = (X_d, Y_d)$ be any source and destination nodes with their respective coordinates, and let be $N_c = (X_c, Y_c)$ any intermediate node involved in the path between $N_s$ and $N_d$. Then $Nc$ belongs to any optimal path as long as Formula (1) is fulfilled [7]:

$$\begin{array}{c} X_s \leq X_c \leq X_d \ or \ X_d \leq X_c \leq X_s \\ \& \\ Y_s \leq Y_c \leq Y_d \ or \ Y_d \leq X_c \leq Y_s \end{array} \tag{1}$$

### 2.2. Static and Dynamic Topological Routing

Topological routing is an alternative method for packet transmissions between network elements. This method has been studied for many regular topologies. It is specially beneficial in this kind of structures due to the simple mathematical properties that can be used to implement efficient and low consuming resources routing algorithms. Basically, it consists on codifying in the routing algorithm the network structure using these mathematical properties to rapidly make routing decision with small amount of information, usually just current and destination nodes addresses. These decisions are taken at every node involved in the path until the destination is reached. For this study the way the algorithm is configured is in such a way that packets are forwarded along the $X$ axis as long as possible.

Routing can be static or dynamic. Traditionally, static routing involves, when there are no failures, that the same path between the same pair of nodes is followed by the transmissions. On the other hand, dynamic routing presents the possibility of varying the path based on real time information of the network such as traffic congestion [8]. Normally, the routing decisions are based on the status of the complete potential paths, but in the case of topological routing this is not possible. The decision has to be taken based on local information since the elements do not receive information from further away than their neighbors. This is the real challenge of the study, to discover if it is possible to route dynamically without the whole path status information and still have benefits. It is important to mention that the optimal path area condition is kept, Formula (1), packets can not be routed outside that area.

## 3. Case Study

This work is focused on the simulation and experimentation of topological routing algorithms for grid networks, static and dynamic. Transmissions between pairs of nodes are simulated using both solutions and some output performance parameters are compared. The dynamic routing method should be based on real time information, in this case the node congestion is the parameter selected to be implemented. The packets will be routed through the least loaded of the options.

The goal is to illustrate how the dynamic approach affects the traffic balancing, delay on packets or queue sizes by conditioning the routing decisions to the commented congestion of the neighbor nodes. Congestion is simply defined in this case as the number of packets waiting to be routed at the nodes queues. The modeling of the behavior of the nodes can be complex due to the inclusion of many aspects that are involved in transmissions. The purpose of this simulation is to illustrate how the dynamic method performs using status information at each node to make the routing decisions. Therefore, as long the same characteristics are kept for all the methods tested, the node's model can be highly simplified due to the independence between the routing method and the queuing or transmission systems. The nodes consist on a basic FIFO queuing system, only one packet is routed at a time per node. This queueing system is by far the simplest and it is used, for example, by Cisco on high speed interfaces [9]. The simplicity of this system allows to easily extrapolate the results for other queueing models. This kind of queueing system will clearly illustrate the effect of the routing options not only over each individual packet but also over the global transmission.

The first step is to study the traffic distribution and behavior for the static topological routing. It is important to determine the characteristics of the traffic to document and experiment on this topic. The first parameter to study is the traffic limitation, in this case packets that can be transmitted by the nodes and their effect. A priori, the traffic load of the network has influence on transmissions, and therefore, the highly and lowly loaded network situations must be defined.

There is a point when the network becomes saturated and cannot handle all the packets transmitted, in this case when the queues of the nodes are full, any incoming packet is dropped. On the other hand, if the packets are transmitted *"slowly enough"* the network is capable of handling $100\%$ of the information (packets). In this study, the delay time considered only covers execution of routing algorithms and the packet size is constant. The formulas exposed are based on the influence of this parameter as minimum bounds. In real networks other factors will add delay when routing packets, affecting both static and dynamic routing. When a network is saturated, unavoidably, some packets cannot reach their destination. When any queue is full, the incoming packets are dropped. This packet loss requires retransmissions, affecting the delay and efficiency/performance of the global network. It is expected from a dynamic routing method to be able to reduce the packet losses by redistributing the traffic.

### 3.1. Notation

The following notation are used along the document and are explained in the paragraph below:

- Generation time, $T_G$: Average packet generation or transmission time at the nodes.
- Routing time, $T_R$: Time required to run the routing algorithm to make a routing decision.
- Grid dimension, $GD$: Number of rows or columns.
- Increment of the routing time, $IT_R$: Overhead introduced by the dynamic routing method due to extra routing tasks. It is a percentage of the $T_R$.
- Reduction or Increment of Generation time, $RT_G$ and $IT_G$: Values used in the simulations to express the percentage of reduction or increment of $T_G$ when $T_G = GD * T_R$ (Saturation point).
- Queue size, $Q_s$: Max.number of packets at a node.
- Saturation point, $S_p$: Instant when packets start being dropped due to full queues.

### 3.2. Simulation set-up

A simulator has been implemented for purpose of this study. The language used is PHP combined with Mysql due to large amount of information required to be kept in order to perform and analyze the simulations. The simulation consists in two tasks:

**Packet generation or transmission**: The packet generation can be defined as random since the destinations of the packets are chosen regardless the source node. Each node generates traffic and has its own generation rate, being able to modify it giving different ratios to different nodes. The packet generation rate follows a Poisson distribution. Two cases are considered: homogeneous generation rate, all the nodes equally generate packets, and heterogeneous generation rate, some nodes generate significantly more packets than others on a given time. The generation procedure finalizes by saving on a database all the packets generated, keeping information such as source, destination or generation instant. This packet database allows to compare the algorithms under exactly the same conditions, the same packets are transmitted at the same simulation instants. It is important to mention for the validity of the results that the method used to generate random variables is *Mersenne Twister*. This method has been extensively used for similar purposes of random variable generation.

**Routing Procedure**: The routing procedure is based on the previously mentioned FIFO queues and the packet database. The sources transmit the packets accordingly to the instants and destinations established on the database. In the middle nodes, the incoming packets are introduced in the queues and wait to be transmitted. Once a packet is the first in the queue, the algorithm is performed based on its destination address. The time it takes to execute the algorithm depends on the hardware used, and even though it could be measured using a regular computer, it was preferred to make an analysis performing a sweep of $T_R$ and $IT_R$ for a more general documentation. The procedure is the same at every node involved in the path for every packet until the destination is reached. The criteria to decide which option to choose is the number of elements in the queues of the potential next hops, the packet will be forwarded to the less loaded node.

## 4. Experiments

In this Section, the four experiments performed and their results and interpretation are presented. The information provided by these first four experiments about dynamic topological routing for grid networks already give some important characteristics to be considered when implementing similar routing techniques. The simulations consist on 4-regular Grids of different sizes and transmissions between pairs of nodes are performed in order to define and document the benefits of dynamic routing. The same scenario is simulated several times in order to verify the stability of the results. The input and output parameters used are:

-**Input parameters**: Grid dimension, $GD$, generation time, $T_G$, routing time, $T_R$, queue size, $Q_s$, and increment of the routing time, $IT_R$

-**Output parameters**: Number of packets, dropped packets rate and average and maximum delay per hop.

The goal is to relate these input parameters to the effect of the static and dynamic routing by analyzing the output results. The work can be divided in a number of experiments introduced and explained below.

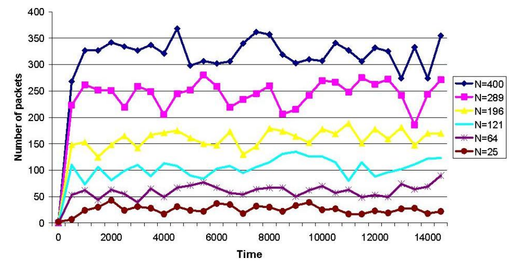
### 4.1. Static Saturation Point Calculation

Determine the saturation point, $S_p$, of the network based on the dimension $GD$, routing time $T_R$ and packet generation time $T_G$. The main goal is to find a relation between the parameters and the $S_P$ of the network. The experiment consists on simulating 15000 time units for each case to determine the network status. The number of packets in the network are counted at intervals of 500 time units. The network does not saturate if the number of packets in the network remains constant after the initial transition time. The dimension of the network given values are $GD = [5, 15]$, the $T_R$ range varies from 10 to 50 time units and $T_G$ given to each node is the same and varying from 1000 to 50 time units (values chosen to illustrate the transition between saturation and no saturation state). If the number of packets diverges, then the network is saturated and unavoidably some packets must be dropped to maintain the stability of the system. After many runs, the conclusion achieved is the following:

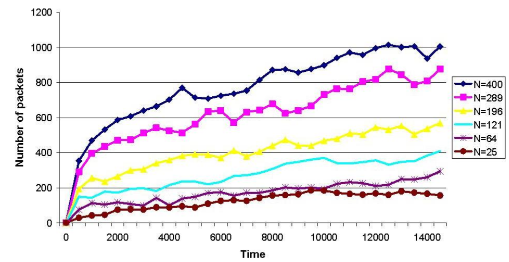
Equation (2) represents the condition when a network is saturated as a function of $GD$, $T_G$ and $T_R$, in time units per packet routed/generated.

$$T_R * GD \geq T_G \qquad (2)$$

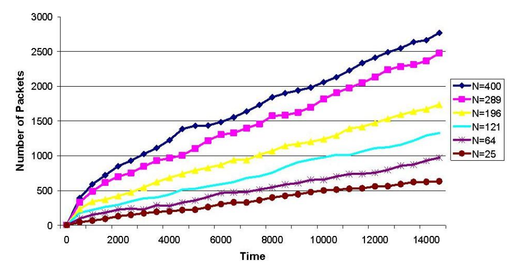
Fig. 1 illustrates the transition point between the two states being $T_R = 20$ and $T_R * GD = T_G$. The graph represents the dimension of the grid $GD = [5, 20]$, $T_R$ is modified to $T_R \pm 25\%$ and remaining $T_G$ constant to illustrate the transition. The influence of $T_R$ can be clearly identified; in Fig. 1(a) the number of packets remains constant in time for each of the cases, different $GD$. In Fig. 1(b), where $T_R$ corresponds to the $S_p$, the number of packet is slowly increasing, and therefore, at some point the network with finite queues will not be able to handle 100% of the transmissions, some packets will be dropped. Finally, in Fig. 1(c) the number of packets in the network rapidly increases.




(a) $T_R = 15$




(b) $T_R = 20$




(c) $T_R = 25$

**Figure 1.** $T_R$ **vs** $T_G$

### 4.2. Dynamic Routing For No Saturation

Determine the effect of using dynamic routing when the network is not saturated and nodes transmitting at the same speed. For this experiment, the increment of $T_G$ over the $S_p$ ($IT_G$) is varied from 0 to 2000% and the extra time consumed ($IT_R$) varies from 0 to 50 %. The parameters used for the comparison of the static and dynamic solutions are average and maximum delay time by hop. The values are expressed in “delay time by hop” and not by transmitted packet as it is normally expressed. The path distance in both cases is always optimal, being the delay parameters always equivalent.

Firstly, the same $T_R$ is given to both options ($IT_R = 0$), with the consequence of improving the average delay per hop and maximum delay when routing dynamically. Obviously, the extra dynamic routing tasks will always have an overhead, hence $IT_R$ should be higher in a real network. When the routing time for the dynamic algorithm is increased by just $IT_R = 10\%$, in the most of the cases the average delay per hop is longer and only when the $T_G \approx S_p$ the maximum delay is improved beyond this 10% but nothing significant to be taken into account. It is not worthy to use dynamic routing under these conditions if it implies an increment of the routing time ($IT_R > 0$). As an orientation value, when the dynamic algorithm is executed on a regular PC the increment on the routing time ($IT_R$) is around 25%. Therefore, the conclusion is that in this scenario dynamic routing should not be considered. Equation (2) can be considered the first of the conditions to apply dynamic routing.

### 4.3. Dynamic Routing For Saturation

Determine the effect of using dynamic routing when the network is saturated. The two main parameters to focus on are the number of dropped packets due to full queues and delay. This experiment can be divided in four sub-experiments, dropped packets and delay analysis for static and dynamic routing.

In this study, retransmissions are not implemented, but it can be assumed that less packet lost in a given time and lower delays will benefit the performance of the network. In the future, it might be interesting to document the influence of the retransmissions.

There are four main factors considered for this analysis: $GD$, $Q_s$, $T_G$ and $IT_R$. The size of the packets remain constant and it is assumed that as long as both routing methods are compared using the same fixed packet size it will not have effect on the results. A sweep of these four parameters is performed to collect enough data about their influence over the performance of the network. The sweeping values are:

- Grid Dimension ($GD$): 5, 7 and 10.
- Queue size ($Q_s$): The values chosen are a function of the grid dimension, $GD$, and they correspond to $GD$, $2*GD$, $3*GD$ and $4*GD$.
- Generation time ($T_G$): The values used start from the $S_p$, Equation (2), and they are decreased by 10% down to 60%, $RT_G = [0, 40]$
- Increment of the routing time ($IT_R$): It is increased from 0 to 50% by a step of 10%. It represents the time it takes to check the memory registers where the information about the neighbors is kept and extra routing tasks.

*1) Dropped packets analysis for static routing:* The goal is to define under which conditions the dynamic solution is a feasible to be used. The percentage of dropped packets is the first characteristic to look at. Table 1 illustrates these percentages related to $Q_s$ and $T_G$, for the static solution. The values in each of the cells represent the min and max percentage of dropped packets of the complete set of simulations. $T_G$ is represented in percentages, meaning 100% the saturation point, $S_p$, and then it is reduced down to 60%, and $Q_s$ is presented as a function of the grid dimension,$G_D$. It is important to understand that when $T_G$ is expressed in time units per packet, if it decreases, the transmission speed of the node increases.

| $T_G$ \ $Q_s$ | $G_D$ | $2*G_D$ | $3*G_D$ | $4*G_D$ |
|---|---|---|---|---|
| 60% | 40,5-42,7 | 34,8-40,9 | 31,9-37,7 | 27,5-34,7 |
| 70% | 29-31 | 24,7-28,7 | 20,4-24,5 | 17-23,8 |
| 80% | 19,7-22,3 | 11,4-17,2 | 11,2-17,2 | 4-10,6 |
| 90% | 10,2-16,1 | 8,7-12,4 | 4-10,6 | 1,9-6,4 |
| 100% | 7,3-10,8 | 2,2-4,3 | 1,2-3,1 | 0,8-2,4 |

**Table 1 . Min-max % of dropped packets for static routing**

The number of dropped packets is directly related $Q_s$ and $T_G$ when their values are given as a function $GD$, see Table 1. The variation of the dropped packets can be considered approximately constant, the largest difference between the maximum and minimum values of each set of simulations under the same conditions is around 7%. Therefore, the results present the stability of the model required to make a comparison with the dynamic option.

*2) Dropped packets analysis for dynamic routing:* The following step is to define the limitations of usage of the dynamic solution. Table 2 presents the edge values as a function of $GD$, $T_G$ and $Q_s$. The edge represent the maximum increment on the routing time, $IT_R$, allowed for each case and still have less dropped packets. The edge values expressed have an accuracy of 10% due to the step of the sweep. The real result corresponds to range of values of $IT_R = [IT_R, IT_R + 9.9]$, i. e. a value of 20 could go from 20% to 29.9%. When the expressed value is 50, it corresponds to $\geq 50\%$ since 50% is the maximum given value for $IT_R$. Later in the study, the average and maximum delays are taken into consideration as well. The values of each cell correspond in order to $GD = 5, 7, 10$.

Analyzing Table 2, it can be clearly identified when the dynamic option is beneficial and under which conditions. Three properties can be defined:

- For the same $GD$, the maximum $IT_R$ allowed and still have benefits in terms of dropped packets increases with the increment of $RT_G$.
- For the same $GD$, the maximum $IT_R$ allowed and still have benefits in terms of dropped packets

| $T_G$ / $Q_s$ | $G_D$ | $2*G_D$ | $3*G_D$ | $4*G_D$ |
|---|---|---|---|---|
| 60% | 10/20/0 | 10/20/10 | 0/10/20 | 10/20/30 |
| 70% | 30/20/10 | 20/20/30 | 10/20/40 | 20/40/50 |
| 80% | 30/30/20 | 40/30/50 | 40/40/50 | 40/50/50 |
| 90% | 40/40/40 | 50/50/50 | 50/50/50 | 50/50/50 |
| 100% | 50/40/40 | 50/50/50 | 50/50/50 | 50/50/50 |

**Table 2 . Allowed overhead (%) in dynamic routing for dropped packets for** $GD = 5/7/10$

increases with the increment of $Q_s$.

- For the same $RT_G$ and $Q_s$, $IT_R$ is not proportionally related to $GD$.

At least in the range analyzed, there will always be fewer dropped packets when Formula (3) is fulfilled:

$$\begin{array}{c} T_G \geq S_p * 0,8 \ and \ Q_s \geq 2 * GD \\ or \\ T_G \geq S_p * 0,9 \ and \ Q_s \geq GD \end{array} \quad (3)$$

This statement is based on the overhead practically obtained of 25% of increment on the routing time. The increment of this overhead will decrease the benefit range and vice versa. There are some other cases that are beneficial (considering the real overhead 25%) as well but not in the complete range values. From this point, the analysis range can be reduced to test the effect on the delay of the dynamic option. This chosen range is $T_G \geq S_p * 0,8$ and $Q_s \geq 2 * GD$.

*3) Delay analysis for static and dynamic routing:* The values of the maximum and average delay can be compared, and only the relevant final results are expressed to avoid repetition. The interesting aspect to look at is the time a packet is waiting in the queue of a node to be transmitted, reason why these values are expressed in "delay time by hop". Tables 3 and 4 represent when the dynamic solution performs better in term of average delay of packet per hop.

The expressed values correspond to the previous selection of $Q_s$ and $RT_G$ from 0 % to 20%. The represented values are the maximum $IT_R$ allowed and still reduce the delay as in the dropped packets analysis. It is not possible to give complete analysis on the real delay since in this study the retransmissions are not implemented. But if the dynamic option introduces a lower delay and there are less dropped packets, it can be affirmed that the dynamic solution is always better.

The pattern of the results indicates that the higher $Q_s$ and $GD$, the wider will be the improvement range. In the case of maximum delay, the improvement is more clear, being possible to transmit faster and still have lower peak delays. This result seems completely reasonable since what the dynamic routing does is to spread out the traffic though the network balancing it as much as possible. The same first two rules stated for

| $T_G$ / $Q_s$ | $2*GD$ | $3*GD$ | $4*GD$ |
|---|---|---|---|
| 80% | 0/10/10 | 10/10/10 | 10/10/20 |
| 90% | 10/10/10 | 20/20/30 | 20/30/30 |
| 100% | 20/20/30 | 30/40/40 | 40/40/40 |

**Table 3 . Allowed overhead (%) in dynamic routing for avg. delay for** $GD = 5/7/10$

| $T_G$ / $Q_s$ | $2*GD$ | $3*GD$ | $4*GD$ |
|---|---|---|---|
| 80% | 0/0/20 | 0/10/30 | 0/30/50 |
| 90% | 10/20/40 | 20/40/50 | 40/50/50 |
| 100% | 20/40/50 | 40/50/50 | 50/50/50 |

**Table 4 . Allowed overhead (%) in dynamic routing for max. delay for** $GD = 5/7/10$

Table 2 can be applied to Tables 3 and 4 but in this case it can be affirmed that for the same $RT_G$ and $Q_s$, $IT_R$ is proportionally related to $GD$.

The following two examples briefly illustrate the application of the results exposed in this experiment:

1) *In a network of* $GD = 10$*,* $Q_s = 30$ *and* $IR_T = 25$*, when dynamic routing might be a better option?*

$T_G$ can be reduced 30% of $S_p$ value and still drop less packets, 20% and improve the max delay and 10% and improve the avg. delay. Therefore, to be sure of the benefit of the dynamic option without analyzing the retransmissions and still perform better the $T_G$ conditions must be 90%-100% of $S_p$.

2) *In a network of* $GD = 7$*,* $Q_s = 21$*, and it is required to improve the static routing solution for* $RT_G = 20$ *(*$T_G$ *is 80% of the value of* $S_p$*). What is the limitation of the time overhead introduced by the dynamic mechanism at the time of routing the packets?*

By taking look to Table 2, to guarantee the benefit, the dynamic mechanism implemented should not exceed in 20% the static solution execution time. It would be real challenge to reduce it more than the 25% obtained at the experimentation.

It is important to keep in mind that the benefits in terms of delay are probably higher since only the delay of the packets that complete the transmission is considered. If the delay of dropped packets and their retransmission is included, it can be assumed that less dropped packets, this real delay should be lower.

## 4.4. $T_G$ Variation Simulation

This experiment consists on giving different packet generation times (different transmission speed) to each of the nodes. This case is probably closer to the reality since nodes have different amounts of information to transmit and, sometimes, in order to satisfy QoS levels they must transmit faster.

The $T_G$ value of each node is randomly given. The possible ranges for the values in the three cases are $T_G = [S_p, F{*}S_p]$ (always no saturated situations) being $F = 2, 4, 6$, the same procedure was performed for $GD = 5, 7, 10, 13, 15$. Due to the random assignment of $T_G$ it is not possible to guarantee that the results represent the performance of a network of these characteristics. The values obtained are an orientation of how this type of distribution might perform and the difference over the homogeneous traffic cases. The final conclusions are:

- The total time that takes to transmit X packets is similar in both cases. The different is insignificant, less than $\pm 1\%$ but the time always increases as the overhead increases under the same conditions (same $T_G$ and same transmissions generated).
- The maximum delay per hop is in most of the cases lower when routing dynamically with up to an overhead of 40%.
- The average delay is never improved when routing dynamically with an overhead higher than 20%.

The use of dynamic routing for similar scenarios will not improve the average delay but it might be helpful when some of the transmissions experience unacceptable long delays. Other than this possible application, the general conclusion is that dynamic routing is beneficial just when the network is saturated.

It is assumed that for saturated conditions, the dynamic solution will be beneficial under certain conditions. In any case, this kind of traffic distribution should be studied more carefully and it should be applied to real scenarios where more performance parameters are known. For this reason, the experimental analysis concludes at this point and the continuation is proposed as further work in Section 5.

## 5. Conclusion and Further Work

The first step towards the characterization of static and dynamic topological routing in grid networks has returned some interesting conclusions. The first and most important achieved result in this work is that dynamic topological routing is beneficial under highly loaded networks. More accurately, in near saturation situations, to route dynamically improves the packet losses and the delay on the transmission. Saturation conditions are not common, they eventually occur in specific moments of high demand or links/nodes failures. Therefore, saturation and no saturation conditions will take place over the same network and the impression is that the dynamic solution could give a small push to the network performance when saturated. In this case, the solution could be to switch from static to dynamic, requiring less retransmission and reducing delays, so the network can recover faster from this problematic state and work again supporting 100% of the demands. This statement is just theoretical, the methodology and consequences of how and when to apply the switching static/dynamic method should be studied and practically proved.

In practice, it has been proved that it is possible to introduce an overhead on the routing method and still have improvement on the global network performance. The modification from static to dynamic algorithms is possible to be implemented on regular computers with no problems or any difficulties. Thus, it is assumed that at least in networking hardware, this simplicity can be kept if not improved.

The promising achieved results by the performed experiments support the continuation of the work on this topic. But be able to apply this method in real networks, specific scenarios should be described and analyzed. Some of the possible future experiments are:

Due to the regularity of the grid topology and of the traffic generated, weight can be given to the queues. Neighbor nodes can make routing decisions not only based on the pure number of elements of queue but also based on a weight. Multilevel grids, sensors or multiprocessors interconnection networks, where the function, transmission and processing characteristics of each of elements are well-known, might be an interesting topic to continue with.

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