



GREEN ROUTING ALGORITHM FOR DATA NETWORKS

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Abstract: The explosive development of Information and Communication Technology (ICT) has significantly increased both energy demands and carbon dioxide emission. This leads to the energy crisis and global warming problems worse. The escalating energy costs and the environmental concerns have already created an urgent need for more energy-efficient "GREEN" computational methods. Energy efficient coding may involve improving computational efficiency so that data is processed as quickly as possible and the processor can go into a lower power "idle" state. In this paper we, modified the existing routing algorithm to minimize the energy loss by minimizing the computational time in selecting the routes between source and destination in a data network. This work shows that the proposed algorithm takes less computational time than the expected proximity algorithm (EP) and maximum proximity (MP) algorithm. The performance is studied computationally on various networks under static traffic model.

Keywords: Green Computing, Global Warming, Routing Algorithm, Congestion

1. INTRODUCTION

The reduction of energy consumption has become a key issue for industries, because of economical, environmental and marketing reasons. If this concern has a strong influence on electronics designers, the information and communication technology sector, and more specifically the networking field, is also concerned. For instance, data-centers and networking infrastructure involve high-performance and high-availability machines. They therefore rely on powerful devices, which require energy-consuming [6] air conditioning to sustain their operation, and which are organized in a redundant architecture. As these architectures are often designed to endure peak load and degraded conditions, they are under-utilized in normal operation, leaving a large room for energy savings. In recent years, valuable efforts have indeed been dedicated to reducing unnecessary energy expenditure, which is usually nicknamed as a greening of the networking technologies and protocols.

As energy-related studies in data networks are very specific and would require a dedicated study. In data networks, energy saving often requires to reduce network performance or redundancy.

Considering this compromise between the energy consumption is a real challenge. However, although the green networking network performance and energy savings, determining efficient strategies to limit the network field is still in its infancy, a number of interesting works have already been carried out, which are overviewed in this paper.

Consciousness of environmental problems tied to Green- House Gases (GHG) increased during the recent years. All around the world, various studies started highlighting the devastating effects of massive GHG emissions and their consequences on the climate change. According to a report published by the European Union, a decrease in emission volume of 15%–30% is required before year 2020 to keep the global temperature increase below 2°C. GHG effects are not limited to the environment, though. In particular, [5] projected that a 1/3 reduction of the GHG emissions may generate an economical benefit higher than the investment required to reach this goal. Political powers are also seeking to build a momentum around a greener industry, both in the perspective of enforcing a sustainable long-term development, and as a possible economic upturn factor on a shorter perspective.



GHG reduction objectives involve many industry branches, including the Information and Communication Technology sector, especially considering the penetration of these technologies in everyday life. Indeed, the volume of CO₂ emissions produced by the ICT sector alone has been estimated to an approximate 2% of the total man-made emissions in [6, 15]. This figure is similar to the one exhibited by the global airline industry, but with higher increase perspectives. Moreover, when considering only developed countries such as the United Kingdom, this figure rises up to 10% [17]. Nevertheless, these studies all agree on the fact that ICT represents an important source of energy consumption and GHG emissions. Even if the incentives are still not clear (e.g., in term of regulations), there seems to be a clear innovation opportunity in making network devices and algorithms aware of the energy they consume, so that they can make efficient and responsible (or “green”) decisions.

Problem of finding energy efficient routing algorithms has been a modern research area in the field of data networks. There are two types of Routing Algorithms namely Static routing and Nondeterministic routing (Dynamic). In static routing the selection of routes and the assignment of flows on the links are decided before the routing tables are downloaded into the network's switches, and remain unchanged in time. In contrast, the nondeterministic (dynamic) routing algorithm requires changing routing decisions continuously according to the changes in the traffic and congestion conditions in the network. Earlier models of Static and Dynamic routing, algorithm consider the shortest path routing [1,8] algorithm to minimize the expected delay; however computational time and energy gain due to efficient coding are not addressed.

Nondeterministic routing techniques such as hot-potato routing, deflection routing [7] and convergence routing [8,10] ensure no packet loss due to congestion inside the network with minimum buffer requirements. Such nondeterministic routing combines, in a dynamic fashion, the on-line routing decision with the instant traffic load inside the network. Convergence routing ensures that packets will reach their destinations without being routed on the same link twice [13, 14]. Thus it ensures a

deterministic bound on the maximum route length in an arbitrary topology network [3].

The rest of this paper is organized as follows. Section II describes the Green strategies. In section III we present the convergence routing operations and a model. The proposed algorithm is given in section IV. Section V shows the performance analysis of the algorithm and section VI gives the conclusion of this paper.

II. GREEN STRATEGIES

Traditionally, networking systems are designed and dimensioned according to principles that are inherently in opposition with green networking objectives: namely, over-provisioning and redundancy. On the one hand, due to the lack of QoS support from the Internet architecture, over-provisioning is a common practice: networks are dimensioned to sustain peak hour traffic, with extra capacity to allow for unexpected events. As a result, during low traffic periods, over-provisioned networks are also over-energy-consuming. Moreover, for resiliency and fault-tolerance, networks are also designed in a redundant manner. Devices are added to the infrastructure with the sole purpose of taking over the duty when another device fails, which further adds to the overall energy consumption [4]. These objectives, radically opposed to the environmental ones, make green networking an interesting, and technically challenging, research field. A major shift is indeed needed in networking research and development to introduce energy-awareness in the network design [9] and algorithm design, without compromising either the quality of service or the network reliability.

There are four classes of solution to reach the green objectives, namely resource consolidation, virtualization, selective connectedness, and proportional computing. These four categories represent four research directions, which may find further detailed applications in device and algorithm design. Resource consolidation regroups all the dimensioning strategies to reduce the global consumption due to devices underutilized at a given time. Given that the traffic level in a given network approximately follows a well-known daily and weekly behavior [2], there is an opportunity to “adapt” the level of active over-provisioning to the current network conditions. In other words, the required level



of performance will still be guaranteed, but using an amount of resources that is dimensioned for current network traffic demand rather than for the peak demand. This can, for example, be achieved by shutting down some lightly loaded routers and rerouting the traffic on a smaller number of active network equipment. Resource consolidation is already a popular approach in other fields, in particular data centers and CPU.

Virtualization regroups a set of mechanisms allowing more than one service to operate on the same piece of hardware, thus improving the hardware utilization. It results in lowered energy consumption, as long as a single machine under high load consumes less than several lightly loaded ones, which is generally the case. Virtualization can be applied to multiple kinds of resources, including network links, storage devices, software resources, etc. A typical example of virtualization consists in sharing servers in data centers, thus reducing hardware costs, improving energy management and reducing energy and cooling costs, ultimately reducing data center carbon footprint. Virtualization solution designed explicitly to reduce network energy consumption has yet to appear [15, 16]. Proportional computing was introduced in [17] and may be applied to a system as a whole, to network protocols, as well as to individual devices and components. Energy-agnostic devices, whose energy consumption is constant, independently of their utilization, represent the worst case: such devices are either on and consume the maximum amount of energy, or off and inoperative. In contrast, fully energy-aware devices exhibit energy consumption proportional to their utilization level.

A. ENERGY EFFICIENT CODING

All of the above measures are intended to permit computers to most energy-efficiently run existing applications, an alternative approach to power saving is energy efficient coding. The principle behind energy efficient coding is to save power by getting software to make less use of the hardware, rather than continuing to run the same code on hardware that uses less power. Of course combining these two approaches can lead to even greater energy savings. For many years, writing small and efficient -- let alone energy conscious -- software has hardly been a priority given continual increases in computer

processor power and storage capacity. However, with some estimates suggesting that energy efficient coding [16] could reduce the energy consumption of data centers by 25 to 30 per cent, it is unlikely to be possible to continue to ignore electricity usage as a factor in good software design. In this paper we restrict our discussion to energy efficient coding.

B. DEFICIENCIES OF EXISTING ALGORITHM

In Expected Proximity and Maximum proximity algorithms [11] the computational time is increased as the density of the network increases. In order to compute the expected or maximum proximity value of a virtual node i to the destination k , one has to find all of the paths from i to k on the directed acyclic graph. Then it computes the products of the factors $(1 - \rho_{ij})$ along the paths. The number of paths between source and destination is increased and the computation of the expected and maximum proximities become very expensive [13].

C. PRELIMINARY OPERATIONS

The network topology is assumed to be arbitrary, and all links are bi-directional or full duplex. The network is represented by an undirected simple graph $G=(V,E)$ such that each node in the network corresponds to a vertex, and each full-duplex link is represented by an undirected edge. Let N and M be the number of nodes and links respectively. Each node has its own unique ID, denoted by a capital letter A, B, C, D...etc as in Fig. 1.

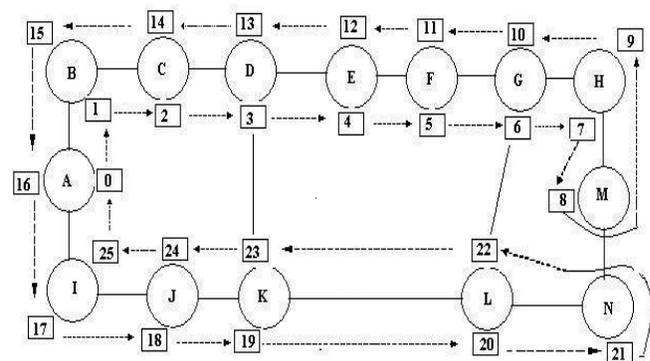


Fig 1: A Network with Virtual Ring

A virtual ring is embedded in a network by a Graph Embedded Ring Algorithm (GER) [12].

III. CONVERGENCE ROUTING OPERATIONS



The default routing operation in convergence routing is simply to follow the virtual ring, which will guarantee that the packet will reach its destination. This is a simple method is but not very efficient. Therefore, the routing mechanism at every intermediate node tries to decrease the distance to the destination – as much as possible by the following two non-default routing methods [10, 11].

- (i) **Short-cut** via a virtual node on the same node that is “closer” to the destination node.
- (ii) **Jump** on a thread link from a virtual node (on one node) to virtual node (on a neighbour node) that is “closer” to the destination.

Example

Suppose that in Fig. 1, a packet arrives at VN₃ and its destination is VN₂₀ (node L), it may shortcut to virtual node VN₁₃ or jump via a thread link to VN₁₉. This kind of switching is possible only if the next ring link, which is reachable by the non-default operations, is available. A link is defined to be available if it is (i) idle (ii) not marked by another packet as its default link. A link is marked by a packet if it is the default route for that packet, in order to avoid congestion and loss.

A. GLOBAL SENSE OF DIRECTION WITH DIRECTED ACYCLIC GRAPH (DAG)

The assignment of virtual address to the nodes according to the virtual ring embedding results in a linear ordering of the nodes. The linear ordering of nodes is used for global sense of direction and all of the routing operations by using a directed acyclic graph (DAG). DAG-based representation enables us to model and to formulate convergence routing precisely.

(i) Forward Node:

Let i, j and k be virtual nodes. Then, j is called a forward node and (i,j) a forward link of i for destination k if and only if the following conditions are true.

- (i) $DIST(j, k) \leq DIST(i, k)$;
- (ii) There exists a physical link (I,J) in the network, such that i is a virtual node of I and j is a virtual node of J. This can be either a ring or thread link.

For example, in Fig. 1, the forward nodes VN₂ for destination VN₁₇ are VN₃, and VN₁₅. The corresponding forward links are (2,3), (2,15).

Let the sets N(i,k) and L(i,k) denote the forward nodes and links of virtual node i for destination k, respectively. A forward path from i to k is a chain of forward links ie. a path of the form (v₁,v₂,...,v_n) where v₁=i, v_n=k, and (v_l,v_{l-1}) ∈ L(v_l,k), where l=1,...,n-1.

Example

A forward path in Fig. 1 is the path (2,15,16,17) or (2,3,14,15,16,17) from VN₂ to VN₁₇.

(ii). Directed Acyclic Graph (DAG)

Directed Acyclic Graph (DAG) is a linear ordering of the virtual nodes in a network for a specific source to destination. Directed Acyclic Graph is used in many applications to indicate precedence among events. If a graph G = (V, E) contain an edge (u,v), then u appears before v in the ordering. The linear ordering of nodes is used for global sense of direction. The assignment of virtual address to the nodes according to the virtual ring embedding results in a linear ordering of the nodes. All the routing operations can be based on the directed acyclic graph.

Directed Acyclic Graph based representation enables us to model the convergence routing precisely.

The directed acyclic graph for the source virtual node i, and the destination virtual node k is represented by DAG_i^k. It is the union of all the forward paths from virtual node i to the virtual node k. The example given demonstrates the convergence routing operation on a directed acyclic graph.

Suppose that node G wants to send a packet to node N as in Fig. 1. Then, DIST(G,N)=DIST(6,21) and therefore, the packet will enter the virtual ring via VN₆ for destination VN₂₁. The resulting DAG is shown in Fig. 2. The different kinds of links are shown in Fig. 2.

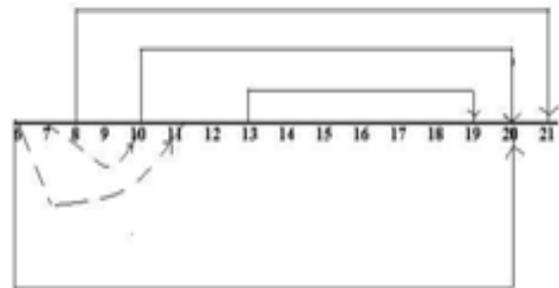


Fig 2: DAG FOR VN₆ TO VN₂₁



B. CONVERGENCE ROUTING MODEL

In this section a new analytical model for the behavior of convergence routing at a node (switch) has been introduced. This model will enable us to determine the routing probabilities at each node for a given destination. At each node, the routing probabilities are computed according to an ordering of the forward links of this node for the destination. Precisely, let $|N(i,k)|=n_i^k$ be the number of forward nodes from node i to destination k . These nodes are ordered in its routing table according to their “closeness” to destination k . Note that such an ordering provides a priority assignment over the forward links, such that if node $j \in N(i,k)$ is in the y^{th} position, then the priority of the link (i,j) for destination k by $\pi_{i,j}^k$.

(i). COMPUTING ROUTING PROBABILITIES:

Given a priority assignment and utilization values on the links, the computation method for the routing probabilities is discussed here. Note that convergence routing algorithm will switch a packet designated for k to the link (i,j) with priority y if all of the links with higher priority are busy and this link is available. Precisely, the probability $P_{i,j}^k$ that edge (i,j) is selected for destination k with priority y , is

$$P_{ij}^k = (1 - \rho_{ij}) \prod_{x:\pi_{ix}^k > y} \rho_{ix} + \left(\prod_{x=1}^{n_i^k} \rho_{ix} \right) \frac{1 - \rho_{ij}}{\sum_{x=1}^{n_i^k} (1 - \rho_{ix})}$$

The first part of the equation captures the case where all of the highest priority links are busy for that destination. The second part considers the case where all of the forward links are busy and link (i,j) becomes the first empty one.

According to the probability law, the sum of routing probabilities for a destination at an intermediate node/switch must add up to unity (ie. $\sum_{ij} P_{ij}^k = 1$ at node i for destination k).

C. MINIMUM PROXIMITY

The proximity value of the source virtual node i to the destination virtual node k is the sum of the utilization values of the links along the path. The

minimum of such a proximity value is called minimum proximity value (MiP). The proposed algorithm defines a new notion of distance with the following properties:

- (i) Minimum number of hops to destination.
- (ii) Link with minimum utilization value.
- (iii) There may be several forward links leading to destination. The forward node with the smallest minimum proximity value should be chosen.

The Minimum Proximity algorithm is defined as the convergence routing algorithm that assigns the priorities of the forward links of the source virtual node i by sorting the nodes in $N(i,k)$ in ascending order of their minimum proximity values to the destination virtual node k . Using this new definition the minimum proximity value can be calculated very efficiently using given below equation.

$$MiP_i^k = \min_{j \in N(i, k)} \sum_j MiP_j^k \rho_{ij}$$

IV. PROPOSED ALGORITHM

- Step – 1 : Input – The given network in matrix form and number of nodes.
- Step – 2 : Find the forward nodes for each virtual node.
- Step – 3 : Compute the distance between each node in hops.
- Step – 4 : Find the number of forward nodes or links for a source to the same destination.
- Step – 5 : Assign initial utilization value for each link in the network.
- Step – 6 : Assign initial load / traffic to each link in the network.
- Step – 7 : Compute the minimum proximity (mip) value.
- Step – 8 : Assign priority to each link.
- Step – 9 : Set up the routing table at each node.
- Step – 10 : Compute the routing probability for each link.
- Step – 11 : Compute the flow on each link using the equation.



$$f_{ij}^k = \begin{cases} 0, & \text{if } (i, j) \text{ is a shortcut link} \\ t_{ik} P_{ij}^k + \sum_{u \in U_i} f_{ui}^k P_{ij}^k + \sum_{u \in w_j} \sum_{w' \in U_w} f_{u'w'}^k P_{ij}^k & \text{other wise} \end{cases}$$

Step – 12 : Find the congestion on each link.

Step – 13 : Find the maximum value of the congestion.

Step – 14 : Compute the new utilization value using the equation

$$\rho_{ij} = \frac{\sum f_{ij}^k}{Z}$$

Step – 15 : Maximum number of iterations performed or convergence, terminate the process otherwise go to step7.

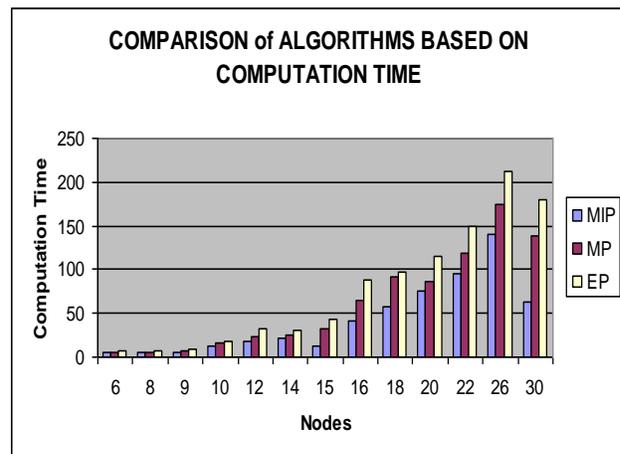
Step – 16 : Display the computational time .

NODE	COMPUTATION TIME ms		
	MIP	MP	EP
6	5	6	7
8	5	6	8
9	6	7	9
10	13	16	18
12	18	24	32
14	21	26	31
15	13	32	44
16	41	65	89
18	57	92	98
20	76	87	116
22	96	118	149
26	141	174	212
30	63	139	179

V. PERFORMANCE ANALYSIS OF THE ALGORITHM

In the proposed Minimum Proximity algorithm the computational time is reduced because it will not recompute the proximity value every time along the path. The minimum proximity value can be computed recursively. The computation time may vary depending on the number of nodes in the network. From the computational of the algorithm it was observed that the computational savings obtained on the basis of number of iterations is invariably greater than the obtained based on time. The number of iterations is an algorithm dependent one where as the time is independent of algorithm. For any given network, the Minimum Proximity Algorithm has always been superior to the Expected Proximity and Maximum Proximity Algorithms on the basis of computation time. The performance measure considered in this work is to minimize the computational time which in turn reduces the energy needed for of the routing algorithm. The performance improvements are shown experimentally on various network topologies.

Table 1: Comparison of Minimum Proximity (MIP), Maximum Proximity (MP) and Expected Proximity (EP) Algorithms on the basis of Computation time



Graph 1: Comparison of Minimum Proximity (MIP), Maximum Proximity (MP) and Expected Proximity (EP) Algorithms on the basis of Computation time

VI.CONCLUSION

In this paper the implementation of the proposed Minimum Proximity algorithm to minimize the computation time is discussed. The preliminary operations needed to implement the algorithm and the step by step procedures are also discussed. The performance of the proposed algorithm is compared with the existing algorithms. The proposed algorithm always performs better in computation time which in turn reduces energy.



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BIOGRAPHY



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