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Self-Organizing Self-Adaptive Network through Differential Elasticity

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I. Introduction

Redundancy has always been an essential ingredient of networks and a contributor to fault-tolerance. Uniformly distributed redundancy helps maximize fault-tolerance to "mechanical" node failure, but does not provide adequate tolerance to malicious attacks. Malicious attacks, by design, are often targeted to affect the most vulnerable or the most critical resources of a system. In sensor networks, because of the large amount of inherent redundancy, the most serious threats are the ones attacking critical paths in the network, thus disrupting the overall function of the network. In this paper we define a set of graph properties that characterize the level of vulnerability of specific links. We use these properties to define a bio-inspired model of self-organization and adaptive reorganization that impart networks with resilience in the face of a variety of scenarios from simple power depletion to targeted malicious attacks. The proposed concepts of differential connectivity and differential elasticity, help us realize the objective of self-organizing nodes in a self-aware dynamic environment.

II. Discussion

For the nodes in a sensor network, coverage and connectivity are two important concerns. To ensure connectivity, when the sensing range is large enough, resilience and fault tolerance require more than simple coverage. This introduces the concept of multiple and redundant connectivity, also known as k-connectivity (a) the vertex connectivity Kv(G) of a connected graph G is the minimum number of vertices whose removal can either disconnect G or reduce it to a 1-vertex graph; (b) the edge connectivity Ke(G) of a connected graph G is the minimum number of edges whose removal can disconnect G. There has been a wide variety of research work focusing on the connectivity based on (a) linear time approximation algorithms; (b) heuristic algorithms for deciding which nodes to wake when some nodes fail and for identifying locations where additional nodes should be placed; (c) optimal deployment using patterns such as the triangular lattice and square grids and connectivity ; (d) conditional connectivity using the quantitative aspects. The approach proposed in this paper takes into account the conditional probability that the failure of a node will indeed lead to the failure of a network.

The approach is motivated by three intuitive concepts (a) the level of a redundancy of a node (Fig. 1); (b) centrality of a node : chipping versus chattering the network (Fig. 2); (c) diameter of a node : the intensity of the flow that goes through it.(Fig. 3) These three concepts help understand various vitalities associated with a node like (a) conditional probability of network getting disconnected when a node fails is inversely proportional to the size of cut ; (b) nodes in a cut that barely chips are less critical than nodes in cuts that chatter the network ; (c) the criticality of a node can be ascertained by the information flow through it. This suggests that, to organize a network, nodes with high information flow should have high redundancy. These concepts only serve as intuitive motivation for the idea presented in the paper and hence, are not quantified or computed.

III. Approach

a) Differential Redundancy

• Differential Connectivity

The idea behind differential connectivity is that given a set of nodes available, instead of placing the nodes so as to ensure a uniform size cut everywhere throughout the network, and thus decreasing the conditional probability of failure of the network if a node fails, we should instead place the nodes so as to decrease the probability proportionally to the size of the flow going through a node.

• Differential Elasticity

We want the elasticity to be in the direction of the flow. In other words the "stretching" of the network must be done primarily in parallel with the direction of the flow rather than transversally to it. This direction of movement of the nodes will be in line with where the highest need is likely to be and will also minimize un-necessary back and forth of the nodes, as the network thins out.

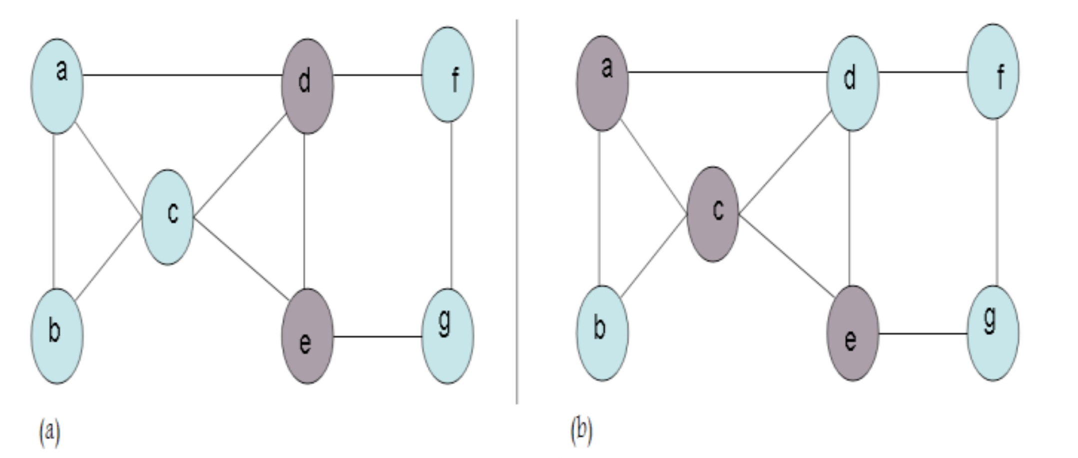

Figure 1. a) cut size 2

b) cut size 3

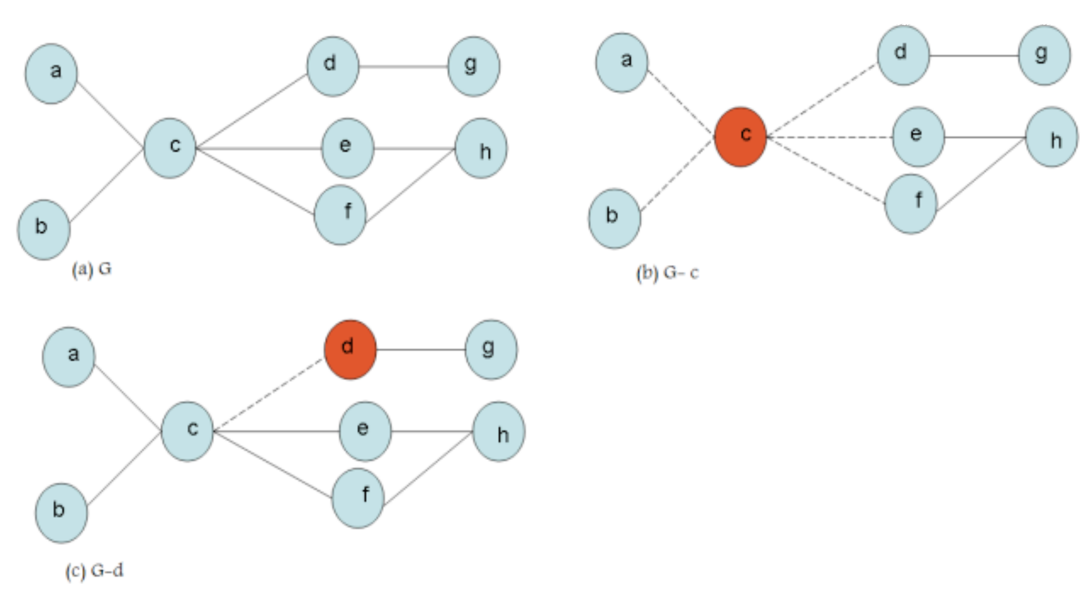

Figure 2. (a) Connected Graph G, (b) G after failure of c, (c) G after failure of d.

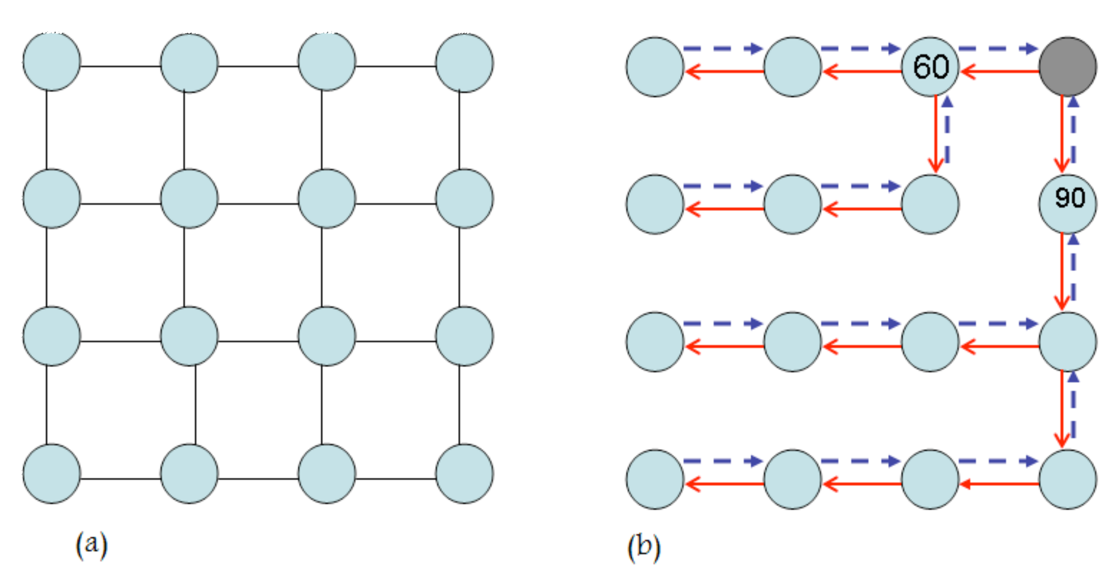

Figure 3. Flow through the network

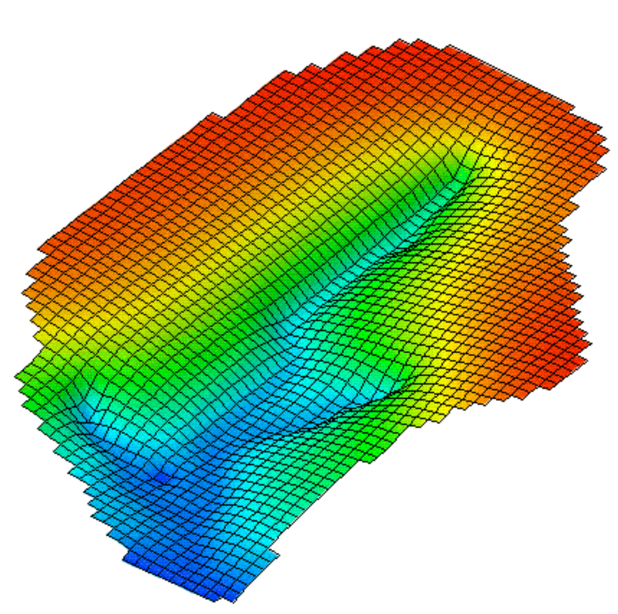

Figure 4.Topography created by the network

b) Adaptive Organization

• Autonomous Organization

We propose a three-step process:

1. A sufficient number of nodes (e.g. 1.5*N) are deployed by spreading them using a uniform random distribution to ensure full coverage and connectivity.

2. This initial set of nodes collaborates to establish a reasonable flow pattern and identify the amount of flow traversing each of the nodes.

3. The remaining nodes are deployed in such a way that areas with high flow will attract a relatively large number of nodes, resulting in larger cuts whereas areas of small flow would attract fewer nodes resulting in smaller cuts. One way to visualize this process is to see the nodes with their flow as points in 3D space where their positions on the plane represent their x and y coordinates and their flow represent their elevation (the elevation is in fact inversely proportional to the flow). Figure 4 shows the topography generated by a network flowing towards the bottom of the area.

Two types of force come into play :

Gravity : The forces used to organize the node are calculated based on local information about gravity forces.

Inertia : Using the gravity alone, nodes stop only when they reach local minima. Because the flow grows rather uniformly from the boundaries of the area towards the sink node, there is a risk that all the nodes will end up flocking towards the lowest elevation point, i.e., the sink node. We add an inertia force to ensure a more distributed spreading of the nodes.

IV. Status and Future Work

Additional refinements and work under may include:

1. Refinement of the parameters used for the elasticity force and for the simulated annealing so as to optimize the triggers used for reorganization. We want to make sure that the network reorganizes soon enough to avoid a loss of functionality, but also that it does not re-organize prematurely and then undo work done later.

2.Assessment of the reorganization. In particular, we will compute the distribution of the ratio size(cut)/flow for every node over time. Ideally we want to see that the variance remains relatively stable over time.

V. References

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