

Localized algorithms for detection of critical nodes and links for connectivity in ad hoc and sensor networks

Tutorial
Medhoc 2004

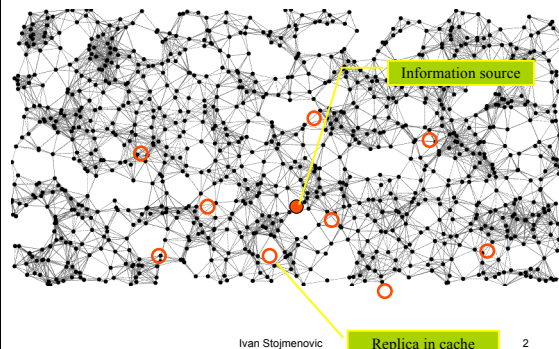
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Data replication (motivation)



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Replica in cache

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Cooperative caching

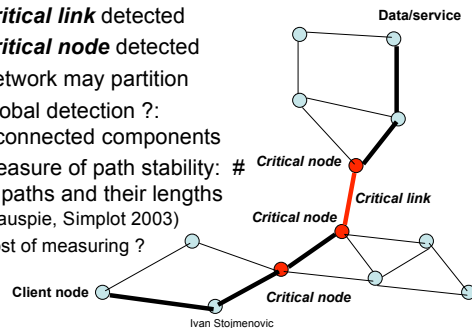
- A Cooperative Cache Based Data Access framework Guohong Cao, Liangzhong Yin, and Chita Das, IEEE Computer, February 2004.
- data from server is replicated on some nodes
- Methods:
 - *caching data paths toward replicated copy* by current node, or
 - *making another copy of data at the node*, plus
 - *some hybrid method* based on some criteria.

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When to replicate data/service ?

- **Critical link** detected
- **Critical node** detected
- Network may partition
- Global detection ?:
biconnected components
- Measure of path stability: # of paths and their lengths (Hauspie, Simplot 2003)
- Cost of measuring ?



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Why localized algorithm ?

- Localized algorithm obviously may fail to estimate criticality since long alternative routes are impossible to detect locally
- Long service path may be critical →
- **Localized detection** may suffice, even if not accurate

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Critical node detection

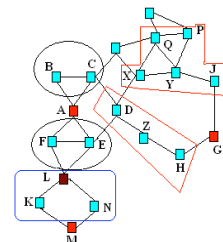
- **C critical node** iff subgraph of k -hop neighbors (without C) is disconnected

Topologically or positionally critical nodes

A is 1-hop critical

G is topologically 3-hop critical and positionally 2-critical

M is 1-hop critical



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Critical links - common k -hop neighbors

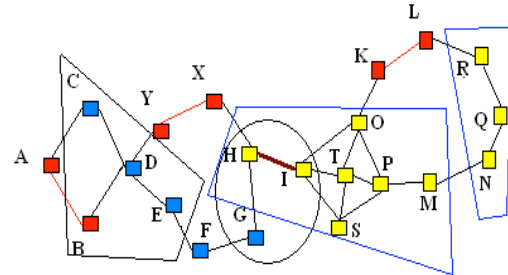
- **Topological:** AB is a critical link if the sets of k -hop neighbors of A and B (assuming that the link AB does not exist) are disjoint.
- **Positional:** AB is a critical link if the sets of k -hop neighbors of A and B are disjoint, and there are no two nodes, one from each set, which are neighbors.

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Examples

critical links HI , AB , XY and KL



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Critical links – loop lengths

- A link UV is k -loop_critical if the hop distance between U and V in the given graph, with only edge UV being eliminated, is $>k$.
- Implementations:
 - A link UV is (k_U, k_V) -loop_top_critical if the sets of k_U -hop neighbors of U and k_V -hop neighbors of V are disjoint.
 - A link UV is (k_U, k_V) -loop_pos_critical if the sets of k_U -hop neighbors of U and k_V -hop neighbors of V are disjoint, and there are no two nodes, one from each of these sets, that are neighbors.

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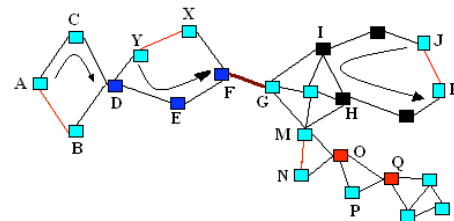
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Examples of critical links by loop length

FG (all k), AB (2- t , 1- p), XY (3- t , 2- p), JK (4- t , 3- p)

$k=1$ all links topologically critical (e.g. MN is 1- t)

Worse detection accuracy than by the first definition



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Critical links by critical nodes

- A link AB is declared critical if both endpoints are critical nodes
- Nodes may merely exchange their decisions about criticality, or use $(k+1)$ -hop info
- Worse accuracy than with the first definition

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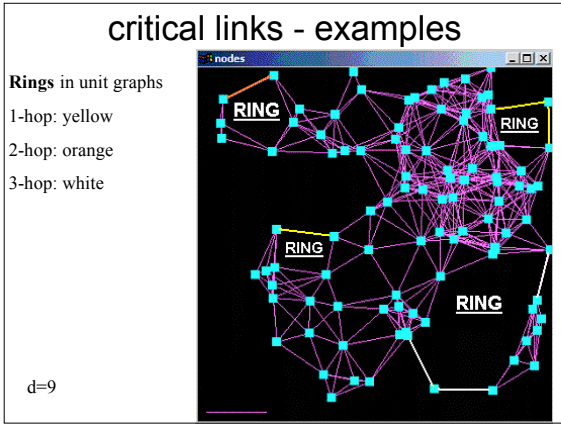
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Generating random unit graphs

- Normally, n nodes are generated at random inside a region (square), all edges are sorted, then R is selected as $dn/2$ -th edge in the list, (d = desired average # of neighbors), Dijkstra's shortest path is used to test connectivity
- Generating sparse connected graph ($d < 5$) is slow

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Detection ratios for critical nodes

degree	1-hop	2-hop	3-hop
15	50	71	83
10	71	85	98
7	65	82	90
6	62	79	86
5	49	76	85
4	51	80	92
3	56	70	86

probability that detected node is indeed critical,
500 connected nodes, positional criterion

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- ### Accuracy of local tests
- Number of critical nodes decreases with increased density
 - **over half of locally estimated critical nodes and links were indeed globally critical even for k=1**
 - **the accuracy increases to over 70% for k=2 and over 80% for k=3**
 - The overhead created by using local criterion in data or service replication is reasonable (twice more actions for k=1, under 50% more actions for k=2)
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Detection ratio for critical links

degree	1-hop	2-hop	3-hop
15	31	50	71
10	51	73	90
7	44	68	85
6	49	73	85
5	46	72	81
4	48	79	93
3	49	67	87

500 nodes, topological criterion, common k-hop neighb.

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- ### Future work
- Service replication.** Critical link/node on a particular client/server path is not always alarming (alternative routes may already exist). The removal of considered critical node or link should also disconnect the client from server, before resorting to service replication. (Ph.D. thesis by Hauspie)
- localized algorithms for deciding, at each node, whether or not graph is **k-connected** (Jorgic, Nayak, Stojmenovic):
 - A graph is considered **k-connected** if it is still connected after removing any **k-1** nodes.
 - algorithm 1: each nodes makes a decision by verifying whether or not itself and each of its **p-hop** neighbors has $\geq k$ neighbors
 - Algorithm 2: + if the subgraph of **p-hop** neighbours of a given node (including node itself) is **k-connected**.
 - Algorithm 3: If the local graph contains at least one critical node then the graph is declared as 2-unconnected. If the node itself and one other node in the local neighborhood is critical, graph is declared 3-connected. This definition is being generalized.
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- ### Open problems
- Find detection ratio bounds analytically, and its dependence on n and d
 - Application in sensor networks for reporting critical spots and improving coverage
 - assign, in localized manner, transmission radii to each node so that the network is **k-connected** with high probability.
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