A LOAD-BALANCED TOPOLOGY MAINTENANCE WITH PARTIAL RECONSTRUCTION OF CONNECTED DOMINATING SETS

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Abstract: Node failure in a connected dominating set (CDS) is an event of non-negligible probability. For applications where fault tolerance is critical, a traditional dominating-set based routing may not be a desirable form of clustering. For a typical localized algorithm to construct CDS, it has the time complexity of $O(\Delta^3)$, where Δ is the maximum degree of an input graph. In this paper we inspect the problem of load balancing in a dominating-set based routing. The motivation of load balancing is to prolong the network lifetime, while minimize the partitions of the network due to node failure, where they cause interruptions in communication among nodes. The idea is that by finding alternative nodes within a restricted range and locally reconstructing a CDS to include them, instead of totally reconstructing a new CDS. The number of nodes which should be awaken during partial reconstruction is less than $2(\Delta\text{-}1)\times\rho$, where ρ is the number of nodes from CDS and the number of neighbour of the faulty node.

1 INTRODUCTION

A connected dominating set (CDS) can create a virtual network backbone for packet routing and protocol. In a dominating set based routing, messages can be routed from the source to a neighbour in the dominating set, along the CDS to the dominating set members closest to the destination node, and then finally to the destination (Blum, 2004).

A set of dominating nodes is to awake to maintain network connectivity, while other nodes can be put to sleep. A dominating node handles higher traffic load and thus consumes more energy. Without preparing load balancing strategy, a dominating node can become a faulty node due to shortage of its battery. Node failure in a CDS is an event of non-negligible probability. To overcome this, we propose a partial reconstruction of CDS. A CDS construction is a time-consuming work and causes heavy traffic to overall network. The idea is that by finding alternative nodes within a restricted range and locally reconstructing a CDS to include them, instead of totally reconstructing a new CDS. Figure 1 shows an illustrative example to give an insight how to partial reconstruction will be applied.

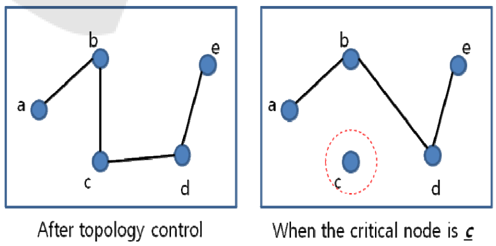

Figure 1: An example of partial topology reconstruction in the case of node failure.

In Section 2, we review the related work in CDS construction. The proposed partial topology reconstruction algorithm will be explained in more detail in Section 3. Section 4 presents some experimental results.

2 REALTAED WORKS

Guha and Kuller (Guha, 1998) proposed two centralized CDS construction algorithms. However, for sensor networks and ad-hoc networks, distributed CDS construction is more effective due to the lack of a centralized administration. Various distributed approaches that seek to balance the competing

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requirements of complexity, running time, stability, and overhead have been proposed. Notice that finding a minimum-sized dominating set is NP-hard.

Wu et al's work (Wu, 2002) proposes a completely localized algorithm to construct CDS in general graphs. A node having two unconnected neighbours is chosen as a dominating node. They also present two pruning rules to minimize the number of dominating nodes.

In a weakly CDS (WCDS), the vertex set is partitioned into a set of cluster-heads and cluster members, such that each cluster member is within radio range of at least one cluster-head. Chen et al (Chen, 2002) propose approximation algorithms for computing a small WCDS. Blum et el (Blum, 2004) gives performance comparison for distributed CDS construction algorithms in lately proposed methods. A CARCODS (Cho, 2005) tries to minimize reconstruction of CDS by delaying neighbour set advertisement message broadcast in proportion to residual energy, mobility and the number of neighbour nodes.

3 A PARTIAL TOPOLOGY RECONSTRUCTION

3.1 CDS Maintenance Algorithm

An ad-hoc network can be modeled as a graph *G* = (*V*, *E*), where *V* is the set of vertices (nodes) and *E* the set of edges (links) which represents the available communication. If a node *v* is a physical neighbor of a node *u,* then there exists an edge (*u, v*). That means *v* is within the communication range *R* of a *u* and thus receives its messages.

$$E = \{(u,v) \in V^2 \mid d(u,v) \le R\} \qquad (1)$$

$d(u,v)$ is the Euclidean distance between nodes *u* and *v*. We define the neighbor set N (*u*) of a node *u* as:

$$N(u) = \{v \in V \mid v \ne u \bigcap (u,v) \in E\} \qquad (2)$$

Then, we will explain our proposed algorithm in a stepwise execution style by taking an illustrative example as shown in Figure 2. Let n_c be the faulty node. In Figure 2, there are four dominating nodes {2, 5, 7, 9}. Assume that the current battery level of the node 5 is under a given threshold. Notice that without loss of generality we assume that an initial CDS construction is built. Thus our proposed method is applied after initial CDS construction.

STEP 1: Check the Coverage of a Faulty Node. Node 5 is n_c and it informs its neighbor dominating nodes {2, 7}. Since $N(5)$ were covered with {2, 7}, there are no more nodes to be covered by them (Figure 2 (b)).

$$\begin{aligned} &N(5) - N(2) \bigcap N(5) - N(7) \bigcap N(5) - \bigcup_{(5,j)\in Ed} j \\ &= \{2,3,4,7,8\} - \{3,4\} - \{8\} - \{2,7\} = \Phi \end{aligned} \qquad (3)$$

Where, E_d is the set of edges which belong to the CDS.

STEP 2: Find an Alternative Node to maintain the Connectivity among the Existing Dominating Nodes. For the one-hop neighbor dominating nodes {2, 7} for n_c, search process begins to see whether there is an alternative node or not to find a possible routing path to connect them. There is no alternative path.

$$N(2) \bigcap N(7) = \{1,3,4\} \bigcap \{8,9\} = \Phi \qquad (4)$$

Then by extending to the 2-hop neighbors of n_c, search process continues to find an alternative node. The set of neighbor nodes of node 2 represent the 2-hop neighbors of n_c. Notice that one of them can be connected to the dominating node 9 (Figure. 2 (c)).

$$\bigcup_{(2,j)\in E} N(j) \bigcap N(7) = \{2,4,6,9\} \bigcap \{8,9\} = \{9\} \qquad (5)$$

We can do perform the search process for the set of neighbor nodes of node 7, instead of node 2,

$$N(2) \bigcap \bigcup_{(7,k)\in E} N(k) = \{1,3,4\} \bigcap \{4,7,8,9,10,11\} = \{4\} \qquad (6)$$

If the process fails for the above cases, search process continues for the set of neighbor nodes of $N(2)$ and $N(7)$.

$$\bigcup_{(2,j)\in E} N(j) \bigcap \bigcup_{(7,k)\in E} N(k) \qquad (7)$$

STEP 3: Select the Alternative Node. If there is more than one node to choose, the priority of node *i* can be calculated by the following equation.

$$P_i = \alpha \times EL_i + \beta \times ND_i \qquad (8)$$

where, EL_i and ND_i is the current energy level and the node degree of node *i*, respectively. In addition, both α and β indicates the weighting factors.

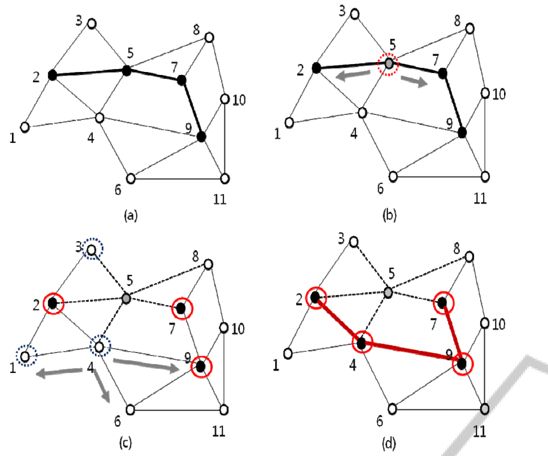

Figure 2: An example of partial reconstruction of CDS.

3.2 Duration of Partial Reconstruction

The duration of a partial reconstruction of CDS (abbreviated as PRCDS) is shorter than that of a CDS construction. With a shorter duration of PRCDS the possibility of maintaining a connected dominating set becomes higher.

As shown in Figure 3 (a), in a CDS construction none-CDS nodes have regular intervals of both sleep mode and wake-up mode. However, in the case of PRCDS, they have shorter period of sleep mode. In PRCDS, the number of nodes which should be awaken during reconstruction is less than 2(Δ-1)×ρ, where ρ is the number of dominating nodes and the number of neighbors of the faulty node. In most cases, an alternative node was found by just searching 2-hop neighbors of the faulty node.

Our simulation results show that execution time of PRCDS is faster than that of CDS by 40%. For a typical localized algorithm to construct CDS, it has the time complexity of $O(\Delta^3)$, where Δ is the maximum degree of an input graph.

4 EXPERIMENTAL RESULTS AND ANALYSIS

For the purpose of simulation QualNet Exata 4.0 (http://www.scalable-networks.com) is modified to incorporate with the proposed algorithms. The performance evaluation is based on the comparison of three different metrics: node mobility, packet receive ratio, and energy consumption. These metrics are also evaluated for SDAA (Wu, 2002) and CARCODS (Cho, 2005) for comparison purposes.

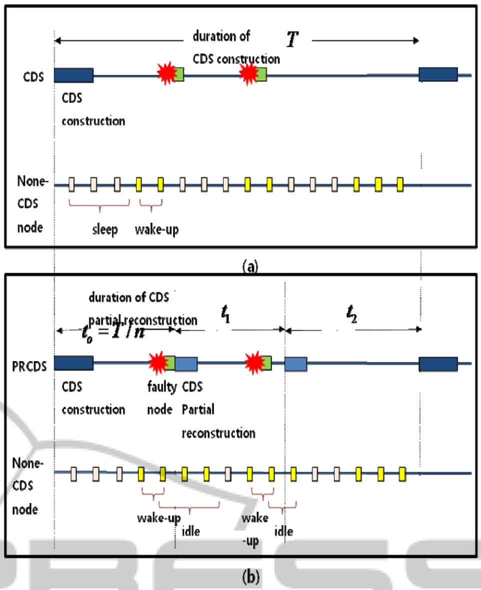

Figure 3: Duration of CDS construction: (a) CDS full construction (b) PRCDS.

Nodes begin to move again after specified pause time. In our experiments we varied it between 0 and 600 seconds. The network between the pause times 0 to 150 have a high mobility, whereas the network beyond 450 have a low mobility.

As the node mobility becomes high, the packet receive ratio decreases due to network instability. However, PRCDS tries to maintains network connectivity by establishing partial reconstrction of CDS. In the case of high mobility PRCDS is remarkable better than the two methods as shown in Figure 4.

There is no clear distinction for power consumption with respect to node mobility in Figure 5. We can say that a frequently partial reconstruction of CDS is not a energy-consuming work. In addition, with PRCDS an average remaining battery level of nodes is higher and the standard deviation from its mean is smaller than the other methods as shown in Figure 6.

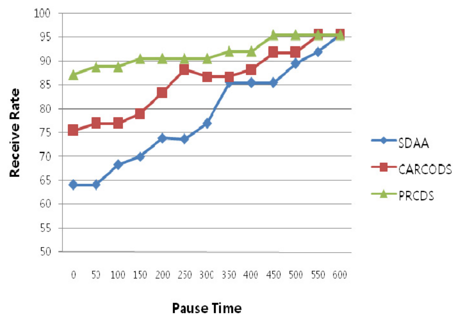

Figure 4: Packet receive rate versus node mobility.

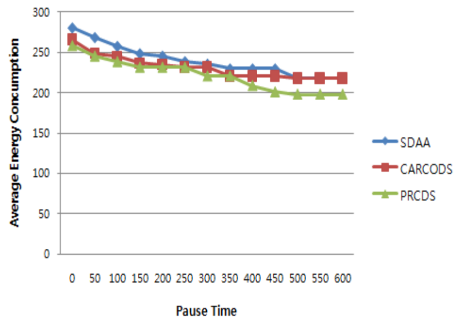

Figure 5: Power consumption versus node mobility.

5 CONCLUSIONS

We propose a partial reconstruction of CDS when applying dominating set based routing in wireless ad-hoc networks. Since a dominating node in a CDS is a gateway node, a failure happened in such a node causes a serious problem on network-wide connectivity. PRCDS searches a restricted area within 2-hop distance of a faulty node to find an alternative node.

Our proposed algorithm shows a remarkable performance in the case of high mobility. It guarantees more stable network connectivity by frequently reconstruction of CDS. In addition, it does not consume more energy but balance average energy consumption per node compared to the CDS construction methods.

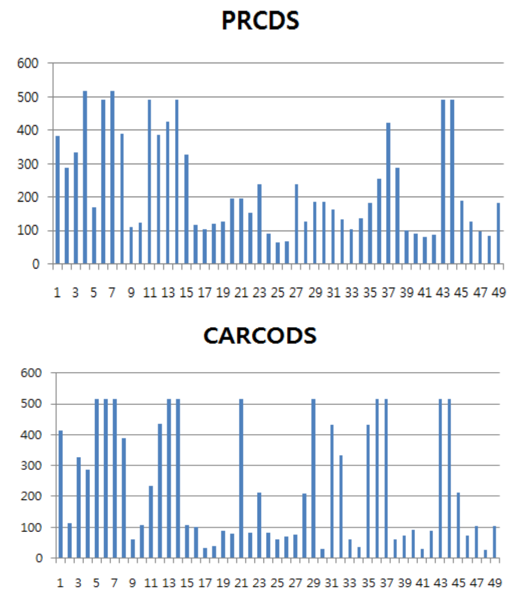

Figure 6: The comparison results of remaining battery level of nodes.

REFERENCES

S. Guha and S. Khuller, Approximation algorithms for connected dominating sets, *Algorithmica*, 20(4), pp.374-387, 1998.

J. Wu, F. Dai, M, Gao, and I. Stojmenovic. “On Calculating Power-Aware Connected Dominating Sets for Efficient Routing in Ad Hoc Wireless Networks,” *Journal of Communications and Networks,* Vol.4, No.1, March, 2002.

Y. Chen, and A. Liestman, “Approximating minimum size weakly-connected dominating sets for clustering mobile ad hoc networks, in Proc. *ACM MobiHoc*, June, 2002.

J. Blum, M. Ding, A. Thaeler, and X. Cheng, Connected dominating set in sensor networks and MANETs, *Handbook of Combinatorial Optimization*, Kluwer Academic Pub., pp329-369, 2004.

H-S., Cho, and S-J., Yoo, “Power, mobility and wireless channel condition aware connected dominating set construction algorithm in the wireless ad-hoc network,” *Domestic Journal*, Vol.30, No.5B, May, 2005.

http://www.scalable-networks.com