



Scratch Recognition With In Wireless Sensor Networks

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ABSTRACT: We suggest an algorithm that allows (i) each node to detect when the connectivity to a particularly chosen node has been lost, and (ii) one or more nodes (that are connected to the special node after the cut) to notice the incidence of the cut. The algorithm is dispersed and asynchronous: every node wants to converse with only those nodes that are within its message range. The algorithm is based on the iterative calculation of a fictitious “electrical potential” of the nodes. The meeting rate of the underlying iterative scheme is self-governing of the size and arrangement of the network. We demonstrate the effectiveness of the proposed algorithm through simulations and a real hardware implementation. In this paper, employ a sensible restricted random mobility model, we try to fill this gap. Specifically, we suppose that a network of unit area with n nodes is evenly divided into cells with an area of n each of which is

further evenly divided into squares with an area of $n^{-2\beta}$ ($0 \leq \alpha \leq \beta \leq \frac{1}{2}$). All nodes can only move inside the cell which they are at first dispersed in, and at the start of each time slot, every node moves from its current square to a uniformly chosen point in a time after time chosen adjacent square. By proposing a new multi hop relay scheme, we there smooth trade-offs between throughput and delay by scheming nodes' mobility. We also consider a network of area $n^{-\gamma}$ ($0 \leq \gamma \leq 1$) and find that system size does not affect the results obtain before.

I. INTRODUCTION

In this article we propose a distributed algorithm to detect cuts, named the *Distributed Cut Detection* (DCD) algorithm. The algorithm allows each node to detect DOS events and a subset of nodes to detect CCOS events. The algorithm we propose is distributed and asynchronous: it involves only local communication between neighboring nodes, and is robust to temporary communication failure between node pairs. A key component of the DCD algorithm is a distributed iterative computational step through which the nodes compute their (fictitious) electrical potentials. The convergence rate of the computation is independent of the size and structure of the network. The DOS detection part of the algorithm is applicable to arbitrary networks; a node only needs to communicate a scalar variable to its neighbors. The CCOS detection part of the algorithm is limited to networks that are deployed in 2D Euclidean spaces, and nodes need to know their own positions. The position information need not be highly accurate. The proposed algorithm is an extension of our previous work [5], which partially examined the DOS detection problem.

Notice that all the aforementioned research on the capacity of mobile ad hoc networks assumes global mobility, i.e., nodes can move around the whole network. However, this might not always be the case because in many situations nodes only move within a limited region. For example, in a wireless network covering a big city, each network user usually only moves around a small area close to his or her home, including the work place, groceries, restaurants, and so on. As another example, consider a wireless network in a battlefield. Soldiers are not allowed to move around the whole battlefield. Instead, they can only move in their own post areas in the battlefield. In the literature, Mammen and Shah study in the throughput capacity under a restricted mobility model, where each node is allowed to move along a randomly chosen great circle on the unit sphere with a uniform stationary distribution along the great circle. They show that a constant per-node throughput can be achieved with a delay. In this paper, we investigate the throughput capacity under a more practical restricted random mobility model, and attempt to provide a smooth trade-off between throughput

International Journal of Innovative Research in Computer and Communication Engineering

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Vol. 2, Issue 11, November 2014

and delay to fill the big gap existing in the literature. Moreover, we notice that in the literature the capacity of wireless networks is usually studied either in a dense network or in an extended network. In this study, we also explore the impact of network size on the capacity and delay in the network. In particular, we consider a network of area n , where $0 \leq \gamma \leq 1$, and show that network size does not change the capacity and delay bounds in the network.

II. DISTRIBUTED CUT DETECTION

2.1 Definitions and Problem Formulation

The problem we seek to address is twofold. First, we want to enable every node to detect if it is disconnected from the source (i.e., if a DOS event has occurred). Second, we want to enable nodes that lie close to the cuts but are still connected to the source (i.e., those that experience CCOS events) to detect CCOS events and alert the source node. There is an algorithm-independent limit to how accurately cuts can be detected by nodes still connected to the source, which are related to holes. Figure 1 provides a motivating example. This is discussed in detail in the Supplementary Material, including formal definitions of “hole” etc. We therefore focus on developing methods to distinguish small holes from large holes/cuts. We allow

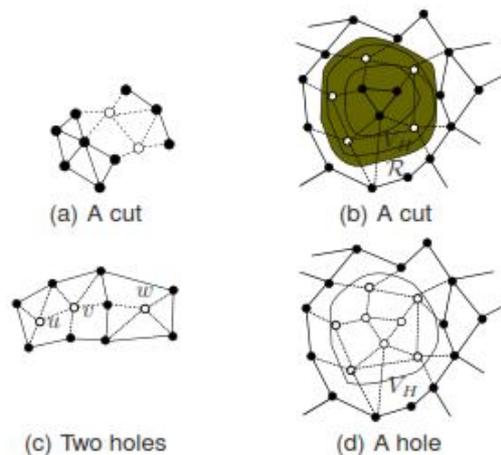


Fig. 1. Examples of cuts and holes. Filled circles represent active nodes and unfilled filled circles represent failed nodes. Solid lines represent edges, and dashed lines represent edges that existed before the failure of the nodes. The hole in (d) is indistinguishable from the cut in (b) to nodes that lie outside the region R .

the possibility that the algorithm may not be able to tell a *large* hole (one whose circumference is larger than γ from a cut, since the examples of Figure 1(b) and (c) show that it may be impossible to distinguish between them. Note that the discussion on hole detection part is limited to networks with nodes deployed in 2D.

2.2 State update law and electrical analogy

The DCD algorithm is based on the following electrical analogy. Imagine the wireless sensor network as an electrical circuit where current is injected at the source node and extracted out of a common *fictitious* node that is connected to every node of the sensor network. Each edge is replaced by a 1Ω resistor. When a cut separates certain nodes from the source node, the potential of each of those nodes becomes 0, since there is no current injection into their component. The potentials are computed by an iterative scheme (described in the sequel) which only requires periodic communication among neighboring nodes. The nodes use the computed potentials to detect if DOS events have occurred (i.e., if they are disconnected from the source node). To detect CCOS events, the algorithm uses the fact that the potentials of the nodes that are connected to the source node also change after the cut. However, a change in a node’s potential is not enough to detect CCOS events, since failure of nodes that do not cause a cut also leads to changes in the potentials of their neighbors. Therefore, CCOS detection proceeds by using probe messages that are initiated by certain nodes that encounter failed neighbors, and are forwarded from one node to another in a way that if a short path exists around a “hole” created by node failures, the message

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 11, November 2014



Fig. 2. A graph describing a sensor network G (left), and the associated fictitious electrical network G_{elec} (right). S Amp current is injected into the electrical network through the “source node” (unfilled circle), and extracted through the “ground” node (filled triangle). The line segments in the electrical network are 1Ω resistors.

2.3 The Distributed Cut Detection (DCD) Algorithm

2.3.1 DOS detection

The approach here is to exploit the fact that if the state is close to 0 then the node is disconnected from the source, otherwise not (this is made precise in Theorem 1 of Section . In order to reduce sensitivity of the algorithm to variations in network size and structure, we use a normalized state. DOS detection part consists of steady-state detection, normalized state computation, and connection/separation detection. Every node

i maintains a binary variable $\widehat{DOS}_i(k)$, $\widehat{DOS}_i(k)$, which is set to 1 if the node believes it is disconnected from the source and 0 otherwise. This variable, which is called the *DOS status*, is initialized to 1 since there is no reason to believe a node is connected to the source initially. A node keeps track of the positive steady states seen in the past using the following method. Each node i computes the *normalized state difference* $\delta x_i(k)$ as follows:

$$\delta x_i(k) = \begin{cases} \frac{x_i(k) - x_i(k-1)}{x_i(k-1)} & \text{if } x_i(k-1) > \epsilon_{zero} \\ \infty & \text{otherwise} \end{cases}$$

where ϵ_{zero} is a small positive number. A node i keeps a Boolean variable PSSR (Positive Steady State Reached) and

updates $PSSR(k) \leftarrow 1$ if $|\delta x_i(\kappa)| < \epsilon_{\Delta x}$ for $\kappa = k - \tau_{guard}, k - \tau_{guard} + 1, \dots, k$ consecutive iterations),

where $\epsilon_{\Delta x}$ is a small positive number and τ_{guard} is a small integer. The initial 0 value of the state is not considered

a steady state, so $PSSR(k) = 0$ for $k = 0, 1, \dots, \tau_{guard}$.

Each node computes a *normalized state* $x_i^{norm}(k)$ as:

$$x_i^{norm}(k) := \begin{cases} \frac{x_i(k)}{\hat{x}_i^{ss}(k)} & \text{if } \hat{x}_i^{ss}(k) > 0 \\ \infty & \text{otherwise} \end{cases}$$

where $\hat{x}_i^{ss}(k)$ is the last steady state seen by i at k , i.e., the last entry of the vector $\hat{X}_i^{ss}(k)$.

If the normalized state of i is less than ϵ_{DOS} , where ϵ_{DOS} is a small positive number, then the node declares a cut has taken place:

$\widehat{DOS}_i \leftarrow 1$. If the normalized state is ∞ , meaning no steady state was seen until k , then $\widehat{DOS}_i(k)$ is set to 0 if the state is positive and 1 otherwise.



International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 11, November 2014

2.3.2 CCOS detection:

The algorithm for detecting CCOS events relies on finding a short path around a hole, if it exists, and is partially inspired by the jamming detection algorithm proposed in [6]. The method utilizes node states to assign the task of hole-detection to the most appropriate nodes. When a node detects a large change in its local state as well as a failure of one or more of its neighbors, and both of these events occur within a (predetermined) small time interval, the node initiates a PROBE message. The pseudocode for the algorithm that decides when to initiate probe is included in Section of the Supplementary Material. Each PROBE message p contains the following information: (i) a unique probe ID, (ii) probe centroid C (see Algorithm PROBE INITIATION in the Supplementary Material), (iii) destination node, (iv) path traversed (in chronological order), and (v) the angle traversed by the probe around the centroid. The probe is forwarded in a manner such that if the probe is triggered by the creation of a small hole or cut (with circumference less than $\frac{1}{2}$ the probe traverses a path around the hole in a counterclockwise (CCW) direction and reaches the node that initiated the probe. In that case, the net angle traversed by the probe is $\pm 360^\circ$. On the other hand, if the probe was initiated by the occurrence of a boundary cut, even if the probe eventually reaches its node of initiation, the net angle traversed by the probe is 0. Nodes forward a probe only if the distance traveled by the probe (the number of hops) is smaller than a threshold value. Therefor if a probe is initiated due to a large internal cut/hole then it will be absorbed by a node (i.e., not forwarded because it exceeded the distance threshold constraint) and the absorbing node declares that a CCOS event has taken place. Details on when the source node is alerted about the occurrence of a cut in the network is included in the Supplementary Material. Max The information required to compute and update the probe variables necessitates the following assumption for CCOS detection:

Assumption 1: i) The sensor network is a two-dimensional geometric graph, with $P_i \in \mathbb{R}^2$ denoting the location of the i -th node in a common Cartesian reference frame; ii) Each node knows its own location as well as the locations of its neighbors.

The location information needed by the nodes need not be precise, since it is only used to compute destinations of probe messages. The assumption of the network being 2D is needed to be able to define CW or CCW direction unambiguously, which is used in forwarding probes. At the beginning of an iteration, every node starts with a list of probes to process. The list of probes is the union of the probes it received from its neighbors and the probe it decided to initiate, if any. The manner in which the information in each of the probes in its list is updated by a node is described in Section of the Supplementary Material.

III. A MULTIHOP RELAY SCHEME

Before we move on with our main results, we first present a new multihop relay scheme for the transmissions between source-destination pairs. S-I. Each square in the network becomes active in every c ($c \geq 1$) time slots. According to the mobility model, in each time slot every node moves a distance of $\Theta(n^{-\beta})$ at a speed of $\Theta(n^{-\beta})$. So the length of a time slot is set to be The value of c will be determined later.

S-II. A node in an active square can transmit its packet to another node only if they are in the same square or in two adjacent squares. Specifically, each time slot is further divided into three subslots A, B, and C, of the same length. For a square with N nodes, each subslot is further divided into N minislots of the same length. In subslot A, if $N \geq 2$, every node acting as source transmits one-by-one in a minislot its packet to another randomly chosen node in the same square, which acts as a relay. This relay node can also be a destination node. In subslot B, if this active square is an interior square, nothing happens. Otherwise, if this active square is on the boundary of a cell, every node in this square acting as a relay transmits one-by-one in a minislot its packet to another randomly chosen node in the adjacent square in the adjacent cell, which also acts as a relay. This relay node can also be a destination node. In subslot C, if $N \geq 2$, every node acting as a relay transmits one-by-one in a minislot its packet to the destination node if it is in the same square. Otherwise, nothing happens. In other words, after receiving a packet from a source node in the same cell, a relay node carries this packet and moves around until it goes to the boundary of the cell, where this relay node forwards the packet to another node in an adjacent cell. Thus, a packet is transmitted at least once and at most twice in each of the cells it goes through

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 11, November 2014

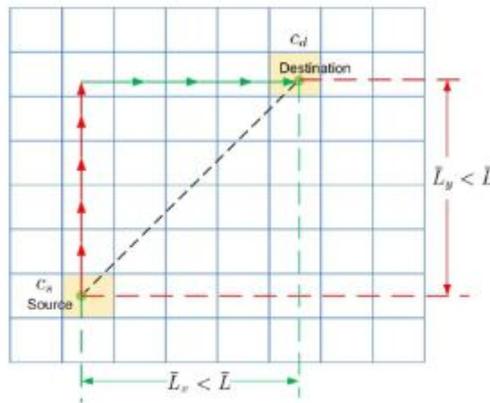
3.1 Throughput Capacity and Mobility

We first derive an upper bound on the throughput capacity for all the schemes satisfying assumptions (A1) and (A2).

Recall that a transmission is considered to be successful if the Protocol Model is satisfied. Suppose that T_i^t transmit and T_j^t

, respectively, at the same time t. Then, we have R_i^t and R_j^t , respectively

$$\begin{aligned} |R_i^t - R_j^t| &\geq |T_i^t - R_j^t| - |T_i^t - R_i^t| \\ &\geq (1 + \Delta)|T_j^t - R_j^t| - |T_i^t - R_i^t|. \end{aligned}$$



The cells a packet may go through.

3.2 Average Packet Delay and Mobility

We ignore the transmission time of the packets, since the transmissions are carried out at a much smaller time scale than the nodes' mobility. We also ignore the queuing delay as in [31]. In this study, we mainly focus on the delay caused by nodes' random mobility. We define three kinds of cells. A cell in which the source node of a packet is located is called a Source Cell. A cell which

the destination node of a packet lies in is called a Destination Cell. The other cells which a packet goes through are

called Relay Cells., we have proved that when $0 < \beta < \frac{1}{2}$, a square has at least two nodes with probability 1. Thus, a source node can always find a relay node. Denote the time needed for the relay node in source cell to first hit a

boundary square by T square instead of a torus with size n S . Note that a cell is a $n^{\beta-\alpha} \times n^{\beta-\alpha}$. Thus, due to which

approaches to 1 as $n \rightarrow +\infty$. So, a packet can be relayed between cells successfully with high probability. Let T_R

denote the time spent in each relay cell, and $E[T_R]$ the expectation. Notice that Lemma 4 gives the expected

$\sqrt{n} \times \sqrt{n}$ first hitting time when n nodes are uniformly distributed in squares, while in a relay cell, a node needs to hit a boundary from the opposite boundary. Since [23] shows that the travel time increases as the distance, the expected boundary hitting time in a relay cell is lower bounded by the expected first hitting time defined before, i.e.,

$$E[T_R] = \Omega(n^{2\beta-2\alpha} \log n).$$



International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 11, November 2014

3.3 Trade-Offs among Capacity, Delay, and Mobility

Recall that two parameters α and β together define mobility pattern, and β also defines a lower bound on the transmission range. In Theorem 1, we observe that in order to obtain higher throughput, we need to increase β while decreasing α , which means that we need to allow nodes move in a larger area while have a smaller transmission range. However, by doing this, the delay will also increase as the throughput increases, as we can find in Theorem As a result, obviously, there are trade-offs among capacity, delay, and mobility.

Then, the exponential order of the upper bound on the expected average packet delay is This work was partially supported by the US National Science Foundation under grants CNS-0916391, CNS0716450, CNS-0721744, and CNS-1147813/1147851, and the China 111 Project under grant B08038. The work of J. Li was also partially supported by Grand-in-Aid for Scientific Research from the Japan Society for Promotion of Science and Technology (JSPS), the Okawa Foundation for Information and Telecommunications. The work of X. Huang was also partially supported by the National Natural Science Foundation of China under grant 60903192 and the National High Technology Research and Development Program of China (863 Program) under grant 2011AA010503. An earlier version of this paper was presented at INFOCOM 2010 [19].

IV. CONCLUSION

Mobile ad hoc networks have been proved to be able to provide nondiminishing per-node throughput even when the number of nodes in the network goes to infinity. However, the price to pay is that the end-to-end delay in the network is very high, on the order of $\Theta(n)$ with possible logarithmic factors. Thus, we can only have either very low throughput, $1/\Theta(\sqrt{n})$, and short delay $\Theta(\sqrt{n})$, in static ad hoc networks, or much higher throughput, $\Theta(n)$, and much longer delay, $\Theta(n)$, in mobile ad hoc networks. There is a big gap between the two extremes, which gives rise to an interesting question: how can we fill the gap? This question is surely a valid question. In some scenarios, we do not need high throughput, but have a strict requirement on delay. For example, in a tactical network, we may only exchange limited and encrypted information once in a while to reduce the chance of being eavesdropped. But the information we deliver is expected to be received in time. In other cases, we expect high throughput, but can tolerate a reasonable length of delay. A delay tolerant network (DTN) or a social network can be such an example. Aiming at addressing the above question, in this paper, we propose a new multihop relaying scheme, and investigate the throughput, delay, and mobility in wireless ad hoc networks. Instead of global mobility, we consider a more practical restricted random mobility model, and find that we can provide smooth trade-offs between throughput and delay in mobile ad hoc networks by controlling nodes' mobility pattern (α, β) . In addition, currently we only consider network delay when analyzing the trade-offs between throughput and delay. We will take queuing delay into consideration in our future work.

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Vol. 2, Issue 11, November 2014

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