Ad Hoc Networks 15 (2014) 67–77

Contents lists available at SciVerse ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Distributed node placement algorithm utilizing controllable mobility in mobile ad hoc networks ☆

Hee-Tae Roh, Jang-Won Lee *

Department of Electrical and Electronic Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 31 October 2012
Received in revised form 19 March 2013
Accepted 24 June 2013
Available online 5 July 2013

Keywords:
Node placement
Controllable mobility
Mobile ad hoc network (MANET)
Game theory

ABSTRACT

In this paper, we study a node placement problem in mobile ad hoc networks with controllable mobility. Especially, we consider mission-critical networks in which nodes have their own specific mission whose degree of satisfaction depends on their locations. In addition to accomplish their mission, nodes want to maintain a good communication quality with their neighbor nodes that also depends on their locations. In general, the best location of a node for its mission is not coincident with that for its communication quality, and thus it is important to control the mobility of a node to find its appropriate location jointly considering both its mission and communication quality. Hence, in this paper, we study a joint mission and communication aware node placement problem. We formulate the problem as a potential game and develop a distributed algorithm that converges to the Nash equilibrium. In addition, we also show that if some minor conditions are satisfied, our algorithm provides a global optimal solution that minimizes the weighted sum of costs for mission and communication.

1. Introduction

In conventional communication networks, such as cellular networks and wireless LANs, nodes within the network are interested in only providing a good communication quality to other nodes or getting serviced with a good communication quality. However, in many emerging networks, such as sensor networks, military networks, vehicular networks, and networked robots, nodes in the network have their own specific mission that should be accomplished with high degree of satisfaction. We call those networks *mission-critical networks*. In mission-critical networks, nodes in the network are interested in not only their communication quality but also the satisfaction for their mission. Hence, controlling both communication quality and satisfaction for the mission of each node is very important to improve the overall performance of mission-critical networks.

In general, the communication quality between two nodes depends on the channel condition of the link between them, which in turn strongly depends on the distance between them. As the distance between two nodes increases, the channel condition of the link between them gets worse, and thus the error rates increase and the achievable data rates decrease. Hence, if we control the mobility of two nodes to make the distance between them be as small as possible, we can significantly improve the communication quality between them. We call this kind of mobility control, which controls the location of a node in the network to improve the communication performance, *communication-aware mobility control*. If a node maintains a link with only one neighbor node, then the optimal solution for communication-aware mobility control would be trivial. We only have to move the node as close to its neighbor node as possible. However, if a node maintains multiple links with its multiple neighbor nodes

☆ The earlier version of this paper was presented at WiOpt 2012 [1]. This work was conducted when H.-T. Roh was a Ph.D. student in the Dept. of EEE, Yonsei University.

* Corresponding author. Tel.: +82 2 2123 5869; fax: +82 2 312 4584.
E-mail addresses: heetae-roh@yonsei.ac.kr (H.-T. Roh), jangwon@yonsei.ac.kr (J.-W. Lee).

1570-8705/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.adhoc.2013.06.010

together, then the optimal solution for communication-aware mobility control might not be trivially obtained.

In many cases in mission-critical networks, the mission of nodes is location-specific. For example, consider a surveillance network for a specific area with networked robots each of whose mission is to lookout its own sub-area. In this case, each robot may have the best spot for keeping watch on its sub-area, and as it further deviates from that spot, the degree of satisfaction for its mission might get more degraded. Hence, in this case, if we control the mobility of a node to place it to the best spot for its mission as possible, we can improve the degree of satisfaction for its mission. We call this kind of mobility control, which controls the location of a node in the network according to its mission, *mission-aware mobility control*. Hence, in contrary to conventional mobile networks, in which communication-aware mobility control is important, in mission-critical networks, we should consider not only communication-aware mobility control but also mission-aware mobility control. Since those two mobility controls have a different objective with each other, they may result in different best locations for a node. Hence, in mission-critical networks, it is important to control the mobility of a node jointly considering its mission and communication quality to improve the overall performance, which makes a mobility control problem much difficult to study.

In this paper, we study a problem that controls the locations of nodes in the mission-critical ad hoc network with jointly considering their mission and communication quality. We define two cost functions for each node that represent its degree of dissatisfaction for its mission and communication quality, respectively. We then define the overall cost function for a node as the weighted sum of its costs for mission and communication and try to minimize the sum of overall costs of all nodes in the network. This problem can be solved by using either an optimization-theoretic approach or a game-theoretic approach. However, since we consider mobile ad hoc networks where there is no centralized controller, we should develop a distributed algorithm with which each node controls its own location with its local information. Hence, in this paper, we will use a game-theoretic approach that is, in general, a more appropriate framework to develop a distributed algorithm when there is no central controller. We will show that our game possesses an exact potential function, and thus our game is a potential game. We provide a distributed algorithm that converges to the Nash equilibrium by using theories of the potential game. Even though the theories of the potential game allow each player (each node) to determine its strategy (its location) in a distributed way, in general, it is required that only one player updates its strategy at each iteration for the convergence. Hence, it requires some degree of coordination among players through a centralized manner. However, in this paper, we will show that in our case, multiple nodes can update their locations simultaneously at each iteration, if they are not neighbor nodes of each other. By using this property of our game, we will develop a protocol with which each node can decide whether it can update its location or not at each iteration in a distributed way. In addition, we will also show that if some minor conditions are satisfied, our algorithm converges to the global optimal solution that minimizes the sum of cost functions of all nodes in the network.

This paper is organized as follows. We present related work in Section 2. In Section 3, we introduce our system model and problem. We provide our distributed node placement algorithm in Section 4 and numerical results in Section 5. Finally, we conclude in Section 6.

2. Related work

Recently, mobility control or node placement problems are extensively studied in mobile sensor and ad hoc networks. In [2–5], problems for relay node placement for minimizing power consumption or maximizing network lifetime are studied with modeling transmission power consumption as a function of the distance between two nodes. In [6–8], problems that place the minimum number of relay nodes while satisfying the constraints on node connectivity or traffic demands are studied.

In [9], a mobility control problem in ad hoc networks is studied to maximize the throughput based on the IEEE 802.11 throughput analysis in [10] without considering the variation of the link capacity according the distance change between two end nodes. In [11–13], problems that place relay nodes considering the throughput of the network are studied. In [11], considering the probabilistic model for the positions of nodes, an algorithm for the relay node placement that maximizes the throughput of the network is proposed. In [12], joint relay node placement and assignment problem is studied. Once the relay node assignment is determined, the problem in [12] is reduced to the problem to find the optimal position of a single relay node while other nodes that communicate with the relay node are assumed to be fixed. In [13], a cascaded network in which relay nodes form a single chained communication flow is considered and a gradient-based algorithm is proposed to control the position of relay nodes to maximize the minimum throughput among those of all the links in the chain. In our earlier works [14–16], we study communication-aware node placement problems. In [14] and its extended version [15], we study a node placement problem of a single relay node with controllable mobility considering multiple nodes with uncontrollable mobiles. We then extend them to a linear network in which multiple nodes with controllable mobility are aligned as a chained topology in a line in [16].

The work that we consider in this paper is clearly different from those in [11–16] in several critical aspects. First, we consider a network with multiple nodes with controllable mobility in a mesh topology in a two-dimensional space. In fact, the extension from a single node with controllable mobility [11,12,14,15] or from the chained topology [13,16] to multiple nodes with controllable mobility in a mesh topology is not straightforward. Second, instead of trying to maximize the minimum performance of nodes as in [13–16], in this paper we try to maximize the sum of performances of nodes, which requires a different approach. Third, while only communication-aware node placement