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The role of congestion in probabilistic broadcasting for ubiquitous wireless multi-hop networks through mediation analysis

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ABSTRACT

Broadcast schemes play an important role in the performance of mobile ad hoc networks, which are a clear example of ubiquitous wireless multi-hop networks where nodes collaborate in a distributed way. They are widely used as a dissemination mechanism and as a part of the discovery phase of routing protocols. The simple flooding algorithm is the usual mechanism employed in mobile ad hoc networks, but its inefficiency has been demonstrated in congested scenarios due to the high number of collisions and contentions. However, these problems can be partially alleviated by using a probabilistic broadcast approach in which every node forwards the incoming packets according to a certain forwarding probability. In this paper, we use a simple probabilistic broadcast protocol to evaluate the effects of congestion on the performance of broadcasting in ad hoc networks through a mediation analysis. We hypothesize that the congestion mediates in the relationship between the forwarding probability (independent variable) and the output metric (dependent variable). We consider several output metrics according to the application of the broadcasting protocol such as reachability, broadcasting delay, packet delivery fraction and end to end delay. The simulation results show the existence of the mediating effects and how such effects may be counterbalanced depending on the target use of the probabilistic broadcast scheme.

1. Introduction

Broadcasting protocols are generally used in ubiquitous wireless multi-hop networks such as Mobile Wireless Ad Hoc Networks (MANETs) and Vehicular Ad Hoc Networks (VANETs) [1,2] in two ways, as a stand-alone dissemination technique and as a part of the discovery process of routing protocols [3,4]. In the former case, the same information has to be transmitted to every node in the network as quick as possible. This is the case of disaster/emergency scenarios, which are typical applications of MANETs [5–7]. In the latter, nodes need to collect neighbour information in order to find a communication path between a source node and a destination node (unicast) or several destination nodes (multicast). In particular,

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many routing protocols designed for MANETs and VANETs rely on broadcasting as the mechanism to find an available route between two nodes [2]. As a consequence, an efficient broadcast mechanism is of paramount importance for establishing secure mobile ubiquitous communications among wireless electronic devices such as smartphones, laptops, tablets, etc.

In general, nodes use a simple broadcasting approach, namely flooding, in which every node retransmits once a given incoming packet. The simplest form of flooding has been demonstrated to be inefficient in terms of bandwidth and power consumption, causing the well-known Broadcast Storm Problem [8]. Alternative techniques to simple flooding can be found in [9]. A basic classification of broadcasting protocols divides them into two main categories, deterministic and probabilistic protocols. In deterministic protocols, a subset of nodes are selected as forwarders. Connected Dominating Sets (CDS) and Minimum Spanning Trees (MST) are some examples of deterministic broadcasting protocols [10]. However, such optimal solutions are NP-problems and may require global information, which is costly in terms of information exchange. Although there are distributed versions of CDS and MST [10], deterministic approaches may present some problems in mobile conditions since the algorithm used to select the forwarders has to be rerun continuously due to the topological changes. On the other hand, in probabilistic protocols, all nodes in the network have the opportunity of forwarding an incoming broadcast packet [11]. On receiving a new packet, a node forwards the received packet with probability p and it does not forward the packet with probability $1 - p$. Although the simplicity of the probabilistic approach, it is not easy task to find the optimum forwarding probability which guarantees a high reachability in the network. Yet, probabilistic broadcast exhibits several advantages such as a good balance of power consumption among nodes and robustness against mobility and malicious nodes. The probabilistic broadcast schemes require an adequate selection and adaptation of the probability value depending on the specific conditions of the target scenario. Many heuristics have been proposed in the literature [11–14], which determine the forwarding probability based on parameters such as the position of nodes [12], the density of nodes [11] and the speed of nodes [13], among other parameters [14]. The main problem is that there are many interrelated variables that may cause undesirable effects when modifying the value of probability.

In this paper we focus on simple probabilistic broadcast scheme since the forwarding probability value allows us to easily tune the performance of probabilistic broadcast. In particular, we hypothesize that congestion is the key variable mediating the effects of the forwarding probability on the performance of a given output metric. To accomplish this goal we propose the use of a mediation analysis [15], which is a widely used technique in statistics to evaluate the effects of a mediator variable in the relationship between a dependent variable and an independent variable. This work is an extension of our previous work [16], considering delay-based output metrics and the implications of the obtained results for designing broadcasting and routing protocols based on probability.

The rest of this paper continues as follows: Section 2 includes a related work which is divided into two parts, the first one introduce probabilistic broadcasting in ad hoc networks, and the second one presents the role of broadcasting in the congestion of ad hoc networks. Section 3 describes the proposed mediation analyses. Section 4 details the simulation results of the mediation analyses. Section 5 contains the discussion of the results presented in Section 4 and some future works. Finally, the conclusions of this paper are included in Section 6.

2. Related work

2.1. Probabilistic broadcasting in ad hoc networks

Probabilistic broadcasting has been an active research field in ubiquitous wireless multi-hop networks such as MANETs and VANETs for the last decade [4,11–14,17]. The main objective of probabilistic broadcasting is to find a forwarding probability value which guarantees that every node in the network receives a given broadcasting packet sent by a source node. The simplest solution may be simulating different forwarding probabilities until achieving the desired reachability, applying a try-and-error approach. However, it is not an efficient solution in extremely changeable environments such as MANETs and VANETs, where it is very difficult to find the same topology in two different moments.

Percolation theory and the phase transition phenomenon presented in random networks [18,19] seem to be a possible solution to find the desired optimal forwarding probability. A complex network like an ad hoc network exhibits the phase transition phenomenon, when the connectivity of the network changes abruptly, from a non-connected network to a connected network (giant component), by slightly varying a network parameter like the density (number of nodes) or the node's transmission range. In the probabilistic broadcasting case, the idea is to check out if varying the forwarding probability value, we are able to observe such abrupt connectivity change beyond certain critical probability. In Sasson et al. [18], the authors study the phase transition phenomenon in ad hoc networks and indicate some important differences between real-world MANETs and mathematical graphs such as random networks:

(1) the real-world MANETs are not infinite so border effect may impact the system's behaviour,
(2) nodes can leave and join the networks constantly modifying the network's density and consequently affecting the phase transition phenomenon and
(3) collisions and contention also impact on the critical probability. The simulation results in [18] show that in real-world MANETs the phase transition is linear with the density of nodes for low network's densities so the network's connectivity does not change abruptly.