Minimizing Communication Interference for Stable Position-Based Routing in Mobile Ad Hoc Networks

Abedalmotaleb Zadin\textsuperscript{a}, Thomas Fevens\textsuperscript{a,}\textsuperscript{*}

\textsuperscript{a}Department of Computer Science and Software Engineering, Concordia University, Montréal, Québec, Canada

Abstract

For efficient communication in a mobile ad hoc network (MANET) dealing with interference while performing multihop routing is of great importance. By establishing an interference-aware route we can potentially reduce the interference effects in the overall wireless communication, resulting in improved network performance. Typically, mobile devices, represented by nodes in a MANET, are used to broadcast in limited shared media. Therefore, using both routing and scheduling mechanisms for wireless transmissions reduces both redundancy and communication interferences. We study communication interference problems in the context of maintaining stable connection routes between mobile devices in MANETs. In this paper, we extend our previous position-based stable routing protocol (namely, the Greedy based Backup Routing Protocol with Conservative Neighborhood Range) to maintain connection stability while minimizing the number of corrupted packets in the presence of more general communication interference. Simulation results demonstrate the effectiveness of the new protocols.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Mobile Ad Hoc Networks; Path Stability; Interference

1. Introduction

Mobile ad hoc networks (MANETs) are a type of wireless network where mobile devices are themselves responsible for communication with each other without the presence of a centralized infrastructure. MANET networks are formed through interconnected devices communicating wirelessly within a relatively limited and shared area. Mobile devices in MANETs can typically move in any direction and therefore the shared media between the mobile devices may frequently change. In MANETs, all nodes that have messages (packets) to exchange must transmit their packets concurrently if there is no interference that can affect their communication. In other words, to achieve high network efficiency in MANETs, parallel transmissions on more than one link must be considered by routing and scheduling protocols. Interference in MANETs is a result of concurrent transmissions taking place in the neighborhood (asynchronous) and is also associated with collisions (which produce corrupted data) arising from nodes outside the range of each other transmitting to a common receiver at the same time (synchronous). However, in MANETs, when con-

\textsuperscript{*} Corresponding author. Tel.: +1-514-848-2424x3038; fax: +1-514-848-2830.
E-mail address: fevens@cse.concordia.ca

1877-0509 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Conference Program Chairs
doi:10.1016/j.procs.2015.05.015
sidering interference, the route from the source to the destination in a specific path may not be the optimal choice. That is, to minimize communication interference, the selected path may not be the shortest path or may increase the number of hops in the routing path. In previous work\(^1\), as discussed later in the Subsection 3.3, we studied the idea of using a Conservative Neighborhood Range (CNR) which eliminate the need to establish backup paths while maintaining stability, a routing protocol we called Greedy-based Backup Routing Protocol with Conservative Neighborhood Range (GBR-CNR). Without the requirement of backup paths to maintain stability, we expect it can be modified to reduce the interference better than the previously studied protocols where backup path mechanisms or multi-paths are used to maintain path stability. In the context of this paper, we introduce an approach based on GBR-CNR\(^1\), a version of the original Greedy-based Backup Routing Protocol (GBR)\(^2\), to establish the interference-aware stable paths.

The rest of this paper is organized as follows. In Section 2, we review specifically related work including giving a brief description of different approaches to studying the interference in MANETs. We provide details of related stable routing protocols in Section 3. In Section 4, we propose our developments to improve a network throughput by minimizing communication interference in MANETs. Experimental results are given in Section 5. Finally, concluding remarks are made in Section 6.

2. Related Works to Minimize Interference in MANETs

Interference limits the throughput of communication in MANETs by corrupting some of the packets that are exchanged among the mobile devices. Therefore, it is of critical importance to study the interference that affect the receivers in the MANETs environment. Pyun et al.\(^3\) proposed a distributed topology control scheme in MANETs where the transmission power of each node was adaptively adjusted based on both the number of its neighbor nodes and the amount of interference that the node generated for its neighbors. De Rango et al.\(^4\) considered a protocol that introduced the concept of interference in the choice of optimum routes in order to improve wireless system performance. Two distinct metrics were proposed: the first one was based on global interference perceived by nodes involved in the communication. The second one was based on the interference perceived only on the links belonging to the route from the source to the destination. The proposed metrics were not based on the minimum hop number, such as in the AODV protocol, but on the global interference perceived by nodes (the first metric), and on the interference affecting the link involved in the transmission (the second metric).

Role of multiple antennas to void such strong interference was studied by Huang et al.\(^5\). The study focused on canceling strongest of interference by using receivers which zero-forcing beamformed. This method zero-forcing beamforming interference management method is widely used many Media Access Control (MAC) protocols which effectively created an interference-free area around each receiving node through carrier sensing. This interference free area is usually called a guard zone. Optimizing this guard zone area can results in significant transmission capacity increase when a single-antenna in MANETs are used. Such a guard zone which can help with interference cancelation and hence would allow nearby transmitters to continue transmitting. For example a network with Poisson distributed transmitters and independent Rayleigh fading channels, the transmission capacity is derived, which gives the maximum number of successful transmissions per unit area. Mathematical analysis from stochastic geometry are applied to obtain the asymptotic transmission capacity scaling and to characterize the impact of inaccurate Channel State Information (CSI). The effective interference model resulting from perfect interference cancelation is illustrated in Figure 1a. Also, as illustrated in Figure 1b, CSI estimation errors result in additional interference with respect to the case of perfect CSI.

Also, in previous work, Gu and Zhu\(^6\) presented the Interference Aware Cross Layer Routing protocol (IA-CLR), an interference aware routing protocol based on a node’s sending and receiving capacities. IA-CLR builds the routes with the minimum bottleneck link interference by using the new routing metric that can comprehensively reflect the real network condition. Also, Zhou et al.\(^7\) tackled the challenges of localized link scheduling posed by complex physical interference constraints. By integrating the partition and shifting strategies into the pick-and-compare scheme, they presented a class of localized scheduling algorithms with provable throughput guarantees subject to physical interference constraints. The basic pick-and-compare scheme works as follows: at every time slot, it generates a feasible schedule that has a constant probability of achieving the optimal capacity region. If the weight of this new solution is greater than the current solution, it replaces the current one.
Fig. 1: Effective interference model for a typical receiver canceling the two strongest interferers.

3. Routing Environments and Models in MANETs

Routing in a MANET depends on many factors including network topology, the type of information available during routing and specific underlying network characteristics that could serve as a heuristic to find a path efficiently and with less communication interference. However, to define how connections between communicating nodes are established in MANETs, in this paper, we first define our network model of a MANET and discuss how routes are determined in this model.

3.1. Network Model of MANETs

MANETs can be modeled using a graph $G = (V, E)$ where $V$ represents the set of nodes/vertices, and $E$ represents the set of links/edges. Each edge represents a link between two nodes currently within the transmission range that, for this work, we assume to be the same for all nodes. The resulting graph is termed a Unit Disk Graph (UDG). We denote the set of neighbors of a node $v_i$ by $N(v_i)$. A path of length $n$ between a source node $S$ and a destination node $D$ is denoted by $(S = v_0, v_1, v_2, \ldots, v_n = D)$ where $v_i \in V$ and $v_i \in N(v_{i-1})$. A path which is used as the first choice while transmitting from the source to the destination is called a primary path. Each node in the MANET has a unique identifier and its geographic position is known. In the real world context, we assume that the location of the nodes in a MANET are tracked using a Global Positioning System (GPS) and/or Location Services (LS). We assume the nodes are arranged in a two dimensional 2D Euclidean space such that $G$ is a geometric graph. We also assume that all nodes broadcast their positions to their neighbors using HELLO messages at regular intervals (also called beacon messages).

3.2. Position-based Routing Model

There are two main categories of routing on ad hoc networks, namely, Topology-based routing and Position-based routing. Topology-based routing protocols use link information available from the network to determine a route between the nodes. Position-based routing uses the positions of nodes to determine routes. In position-based routing each network node is informed about its position, its neighbors’ positions, and the position of the destination. Since it is not necessary to maintain explicit routes, position-based routing scales well even when the network is highly dynamic. This is a major advantage in mobile ad hoc networks where the topology may change frequently.

Position-based routing uses one or a combination of two types of geometric based routings that are Greedy and Face based routing. However, in this study we use Hybrid-based Routing, combining the benefits of both Greedy and Face routing. Face based routing helps obtain alternate node(s) when greedy based routing fails to find closer node(s) leading to the destination. Face algorithms use the right-hand rule in order to recover from failure. The greedy algorithm can be used once a node closer to the destination is found to continue discovering the path. This
routing technique is called Greedy Face Greedy (GFG)\textsuperscript{11}. There is a similar hybrid based routing algorithm called Greedy Perimeter Stateless Routing (GPSR)\textsuperscript{12}.

### 3.3. Conservative Neighborhood Range Model

In previous work\textsuperscript{1}, we proposed an approach for position-based stable routing for MANETs, which we review here. Since nodes are in constant movement with different speeds and directions, a node positioned within the transmission range of another neighboring node at a certain time might be out of the range at another time. In Greedy-based Backup Routing Protocol (GBR)\textsuperscript{2}, GPSR is used to construct the primary path such that each node considers the closest node to the destination within its transmission range as its next hop. To maintain local link stability, GBR locally constructs backup paths. Due to the greedy manner of GPSR, a node may move out of transmission range before the next HELLO beacon will broadcast, resulting in no further received transmissions.

As we introduced previously\textsuperscript{1}, we modified GBR by introducing a Conservative Neighborhood Range (CNR) which takes into account the possibility of nodes that could go out of range during the interval and subsequently avoided including them in the path leading to a significant reduction in the packets losses as well as increasing the reliability of communication. The CNR in Figure 2 is defined by the conservative neighborhood transmission range $R_c$ which depends on the velocity of the node, the interval between the HELLO message broadcasts, and the actual transmission range value. $R_c$ is given by $R_c = R - (v_{max} t)$ where $R$ is the actual transmission range, $v_{max}$ the maximum node velocity, and $t$ is the time interval between HELLO message broadcasts. If the next hop neighbor $v_{i+1}$ is chosen within this conservative neighborhood range from $v_i$, then $v_{i+1}$ will not go out of transmission range of $v_i$ during this interval, and no links in the primary path will break before the next HELLO beacon will broadcast. There will be no need to back up the primary path. This is called a Greedy-based Backup Routing Protocol with next-hop neighbors chosen from the CNR (GBR-CNR).

### 3.4. Interference Ratio Models

As there is no centralized station that manages the traffic, mobile device scheduling should determine which device should transmit at which times, what modulation and coding schemes to use, and at which transmission power levels a communication should take place at.

**Measurement of Interference:** The Signal-to-Interference-plus-Noise Ratio ($SINR$) is commonly used in wireless communications in order to measure the quality of wireless connections\textsuperscript{13}. If we consider a particular receiver located at position $d$, its corresponding $SINR$ is given by: $SINR(d) = P / (I + N)$, where $P$ is the sender transmission power, $I$ is the interference resulted by the active transmission power of the neighborhood devices surrounding the receiver, and $N$ is a noise term. In this paper, in order to improve $SINR$, we focus on minimizing the interference $I$ that affects the receiver by choosing the next hop node either with fewer neighbors or with the least usage in previously constructed paths. Indeed, interference takes place when a sender $S$ communication is scheduled at a specific time slot during which one or more neighbors of the sender’s receiver $R$ are also scheduled, which causes the corruption of packets that are received by $R$. The interference $I$ is defined as:

$$I = \sum_{i \in \tau} P_i h_i l(|| d_i ||)$$

where the summation for $I$ is taken over the set of all interfering transmitters $\tau$, $P_i$ is the transmitting power, $h_i$ is the random variable that characterizes the cumulative effect of shadowing and fading, and $l$ is the path loss function.
assumed to depend only on the distance \( \| d_i \| \) from the origin of the interferer situated at position \( d_i \) in space. Often \( l \) is modeled as a power law, \( l(\| d_i \|) = k_0 \| d_i \|^{-\alpha} \), or in environments where absorption is dominant, as an exponential law, \( l(\| d_i \|) = k_0 \exp(-\gamma \| d_i \|) \). In a large system, the unknowns are \( \tau \), \( h_i \), and \( d_i \), and perhaps \( P_i \), but it is the locations of the interfering nodes that most influences the SINR levels, and hence, the performance of the network.

**Interference Mathematical Model:** The majority of previous studies have focused on reducing interference primarily on the sending node and have been proposed for topology based routing. This approach relied on probabilistic models to model the node neighborhood, etc., to decrease interference. In order to reduce the interference some researchers have proposed defining a restricted area in which no nodes should be used as a next hop. Wang et al.\(^{14}\) based their choice of neighbors for routing on a critical transmission radius for energy efficiency combined with dynamic transmission ranges to define their Restricted Neighborhood Area. In this work, we define our restricted area by Equation 2.

\[
\text{Area} = \frac{R^2}{2} \left( \frac{\pi}{180} \times \theta - \sin \theta \right)
\]

where \( R \) and \( \theta \) are illustrated in Figure 3.

In Figure 3, node \( A \) is the sender and node \( D \) is the destination. Node \( A \) will pick the node \( B \) that is closest to the destination as its next-hop node since node \( B \) is within the restricted area. Also, \( R \) is the transmission range, \( a \) is the coordinate of the sender, and \( \theta = 2\alpha \). The restricted area \( \alpha \) is calculated as \( \alpha = \frac{\pi}{2} \) as used by Wang et al.\(^{14,15}\). This allows us to calculate the coordinates of the following points \( b, c, d \) and \( e \) defining the restricted area as shown in Figure 3. Now only nodes within this area will be considered by our algorithm as next hop candidates. That is, if the sender node location is \((x, y)\) we confined the nodes that would have been considering \((u, v)\) should have been \( x - \frac{R\sqrt{3}}{2} \leq u \leq x + \frac{R\sqrt{3}}{2} \) and \( y + \frac{R}{2} \leq v \leq y + R \) respectively. However, the node chosen should fulfill two conditions: first, it should be closest to the destination; and, second, either \( i) \) it is not being used in a path, or \( ii) \) it has the fewest number of neighbors. This was a greedy based selection. If the node is already in use we pick the second closest node which satisfies the conditions, and so on.

4. Minimizing Interference Schemes

Our study focuses on minimizing interference to maintain communication stability by decreasing the number of packets corrupted in Position-based routing protocol. Furthering previous work\(^{1,2,16,17,18}\), we propose to improve network efficiency (in terms of network throughput) and overall communication interference using ideas such as choosing the hereafter hop either to be a node with few neighbors or a node utilized in few paths instead of simply using the closed node with the destination. Also, we assume that all nodes were uniformly and randomly distributed in a 2D space. Each node has a single channel Time Division Duplex (TDD) and the same transmission range. For simplicity, we assume the interference range is equal to the considered transmission range of the nodes.

4.1. Minimizing Interference Using the Node with Fewer Neighbors.

In order to develop a more interference-efficient variation of GBR-CNR, we consider the number of neighbors in the receiving node. The algorithm is GBR-CNR with less neighbors (GBR-CNR-LN), so in the Figure 4a node \( A \) will prefer, as a next hop, \( B_2 \) instead of \( B_1 \) because the number of neighbors of \( B_2 \) are fewer than the neighbors of \( B_1 \). Fewer neighbors translates into a lower probability of corrupted packets, hence, an increase in network throughput.
4.2. Minimizing Interference Using the Node that is Less Used.

Exploring another variant of the aforementioned approach to achieve more interference-efficient routing using GBR-CNR, we consider the number of communications the receiving node is already participating in. The algorithm is GBR-CNR with the less used (GBR-CNR-LU) nodes chosen as next hops. For example, in Figure 4b we assume that there are two paths and node $B_1$ is chosen as the next hop for node $A_1$. So far, when our protocol will establish the second path, node $A_2$ will prefer, for the next hop, node $B_2$ instead of $B_1$ since node $B_1$ participates in more communications than node $B_2$ even though node $B_1$ is closer to the destination $D_2$ than node $B_2$. Thus, a node that participates in fewer communication paths is less susceptible to message corruption.

5. Performance Evaluation

This section presents simulation results comparing the algorithms GBR, GBR-CNR, GBR-CNR-LN, and GBR-CNR-LU. First, we discuss the simulation setup and then give the simulation results.

5.1. Simulation Setup

For all the algorithms, we constructed the primary path as described in Subsection 3.3. In addition for GBR, back-up paths were also determined. The simulation environment was modeled using network parameters that were a network area of $2500m \times 2500m$; 400 nodes; a maximum transmission range of $R = 250m$. Each simulation took 600 seconds with enough packets for the simulation time. There were 20 pairs of Constant Bit Rate (CBR) data flows in the network layer and non-identical source and destination flows were randomly selected. Each flow did not change its source and destination throughout the simulations. The direction that a node could move was given randomly at the beginning of the simulation. When a node reached the boundary at angle $\phi$, we reflected the node off the boundary using the formula $\phi + \pi/2 + C$ as in Pazand and McDonald. For each different node density, 28 randomly distributed connected graphs were used as a starting network topology for each run of the simulation for all algorithms using MATLAB. This was done to get average performance results for better analysis. The velocity was chosen to be the same for all nodes at $V = 10m/s$, and the HELLO beacon interval, $t$, was set to two seconds. At the end of the two second interval, if a path was determined to fail within the next two seconds interval (from the path’s PET value), then at the beginning of the next HELLO interval, a new path was determined between the source and the destination.
5.2. Simulation Results

Our simulation results are presented in Figure 5. As was noted previously, the number of packets sent and delivered for the original GBR is much smaller (see Figure 5a) than for the CNR based versions due to the paths breaking and having to be re-established using back-up path or requiring complete recalculation before the end of the HELLO beacon interval. Correspondingly, the percentage of lost packets is highest for GBR, as shown in Figure 5c. Of all the algorithms, the percentage of lost packets is the smallest for GBR-CNR-LU which seeks to use less utilized nodes as next hop nodes, with about 3.5% fewer packets lost as compared to GBR-CNR.

Note that the total number of packets delivered by the algorithms during the total simulation time will the sum of the number non-corrupted and corrupted packets. As seen in Figure 5d, GBR also has the highest percentage of corrupted packets and GBR-CNR-LU has the smallest percentage, with about 3.9% fewer packets corrupted lost as compared to GBR-CNR.

The final metric we consider, being mindful that over-utilization of certain nodes in MANETs such as Sensor networks can lead to node failure, is the maximum number of different paths a node may be a member of. In Figure 5b, we can again see that the original GBR algorithm may tax certain nodes by up to 5 times more than the corresponding maximally used nodes in the CNR versions. Again, GBR-CNR-LU has the smallest maximum usage of nodes, with such nodes being used in 37.9% fewer paths as compared to GBR-CNR.

Fig. 5: Performance of protocols: (a) The total number of delivered packets, averaged over all 40 simulations; (b) Maximum number of times a node is included in distinct connections; (c) The percentage of packets lost during transmission; and (d) the percentage of delivered packets that are corrupted by communication interference.
6. Conclusions

We have proposed new two approaches to improving the performance of the algorithm of GBR-CNR in terms of reducing the communication interference in MANETs. The approaches are based on different strategies, namely the selection of next hop nodes that have the fewest neighbors, or the selection of nodes that have participated the least in previously constructed paths within the restricted area. We have validated our approaches through several simulations that have shown our proposed algorithms significantly improved the performance of the packets delivery assuring higher network stability.

We have shown that using GBR-CNR-LU in particular outperforms all the other versions of the algorithm. Nevertheless, this improvement is established with a cost that which is the increase of the number of hops between a source and a destination when constructing the path. By comparing GBR with the other protocols in terms of the interference, GBR-CNR worked better that is because the GBR has the additional set of determining backup paths which increase number of nodes that participating in the overall communication in MANETs.

References

16. A. Zadin, T. Fevens, Maintaining path stability with node failure in mobile ad hoc networks, Procedia Computer Science 19 (0) (2013) 1068–1073, the 4th International Conference on Ambient Systems, Networks and Technologies (ANT), the 3rd International Conference on Sustainable Energy Information Technology (SEIT).