Predicting Needs in Future Decentralized Networks through Analysis of Barrage Relay Networks

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***Abstract*—Improved routing algorithms are needed for the rapid proliferation of inexpensive, wireless network devices. In certain scenarios, decentralized wireless networks are either necessary or preferred over centralized ones. The barrage relay network (BRN) is an emerging ad hoc, decentralized wireless network designed to address issues of network reliability and routing overhead. In BRNs, the routing of unicast transmissions is controlled by the cooperative formation of controlled-barrage regions (CBRs), based on a simple set of rules. In this paper, we simulate CBR formation to study the routing reliability and node utilization, with the goal of predicting BRN utility in future scenarios. We have three specific aims which have not been addressed in other BRN studies: 1) we study the impact of channel effects on BRN routing, 2) we study the impact of node density significantly above the theoretical minimum density required to guarantee a fully connected network, and 3) we employ large ensembles of random networks to account for the wide variability that ad hoc networks may encounter. We find that CBRs tend to grow spatially as network density increases, leading to significant network utilization. Furthermore, we find with the most realistic fading model employed, a random channel model, requires the most network resources in high density networks. Then, we investigate a trade-off in network resources and reliability. Understanding these effects will lead to the design of more efficient and robust routing algorithms for high density decentralized networks for use in disaster relief, military, vehicle-to-vehicle and wireless sensor network applications.**

I. Introduction

With the rapid proliferation of inexpensive, networked wireless devices, the spatial density of transmitters is anticipated to rise sharply, complicating routing and crowding RF channels. New or improved routing algorithms will be needed to handle this rise, addressing both centralized and decentralized wireless networks. While centralized wireless networks are typically more efficient in terms of data throughput, decentralized wireless networks are either necessary or preferred in certain scenarios and use cases. For example, centralized networking may be impractical or unsustainable in regions with limited or damaged infrastructure, such as those encountered in disaster response [1], [2], resource extraction or military scenarios [3]–[5]. Alternatively, decentralized networks may be used to enhance privacy and/or security or aid in rapid deployment of private communications, sensor networks [6], [7] or vehicle-to-vehicle communications [8].

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The Barrage Relay Network (BRN) [9] is an emerging technology that uses cooperative broadcasting and link-layer routing for robust, low-latency communication on decentralized, ad hoc wireless networks. BRNs employ multihop routing with nodes acting as relays so that other nodes can perform unicast and broadcast communications on the network. Nodes make independent routing decisions based on locally received and decoded routing packets to reduce the overhead of the network and mitigate the impact from unreliable links. Nodes are not required to know their relative location or even know the identity of nodes they are sending to and receiving packets from. The BRN unicast routing protocol operates by establishing a *controlled barrage region* (CBR). A node participates in a CBR as a relay or a buffer node based on the number of hops between the source, destination and node. More specifically, the relay nodes will aid in relaying data packets between the source and destination and the buffer nodes will remain quiet during data packet transmission to prevent interference between different communication links. Routing and data packets are cooperatively broadcast by multiple nodes coordinated by time-division multiple access (TDMA). The cooperative broadcast mitigates routing failures and the impact of a single failing link.

Many aspects of BRNs have been studied in the literature. The original works studied BRNs on a connected graph model (CGM) where an edge connecting two nodes implied that those nodes would receive each other's transmissions. Under this framework, the authors defined a protocol which guarantees there is no interference between packets [10] and minimum latency is achieved [9]. This work was expanded in [11], where edges are defined when pairs of nodes are within a fixed transmission radius. The authors of [11] demonstrated that the throughput of BRNs scales identically to networks in the seminal work of Gupta and Kumar [12]. Multiple research efforts have studied the reliability of data transmission in CBRs with varying physical layer and outage models [13]–[15]. In particular, [13] studies the advantages of cooperative broadcasts in BRNs in the presence of link outages. Furthermore, the performance of CBRs in the presence of Rayleigh fading, path loss and interference has been studied in [14], [15]. The authors developed a method using Markov chains to resolve the transport capacity of a CBR in a line network. However, the impact of channel effects and node density on formations of CBRs, or routing in BRNs, has yet to be studied.

We investigate the reliability and node utilization of CBRs with three specific aims. First, we study the impact of channel effects and cooperative broadcasting on routing in BRNs. We are the first to show that for high density networks, cooperative broadcasting alone can act as a failure mechanism in BRN routing, even in the absence of fading. Moreover, we find that channels effects significantly increase the node utilization compared to the CGM, and this is partly necessary to ensure reliability. Second, we study the impact of node density and observe resource allocation and reliability in BRNs. We show the current BRN designs may not achieve high throughput for future applications with expected node densities as high as 1 million devices per square kilometer [16]. Third, because of the limited information shared between nodes and unpredictability of BRNs, we provide significant statistics on ensembles of geometric random networks.

The remainder of the paper is organized as follows. In Section II, we explain our network and channel models as well as provide a summary of the BRN routing protocol. Then in Section III, we provide details and results of the BRN simulations. In Section IV, we analyze our results and identify the impacts of node density and channel effects on BRN routing. Finally, in Section V, we provide concluding remarks and identify promising future research directions.

Notation Convention: We use $|\cdot|$ to represent the cardinality of a set or the length of a vector. Also $[n] := \{1, 2, \dots, n\}$.

II. Network and Channel Models

Our wireless network model consists of n nodes, labeled as $\{1, \dots, n\}$, with a uniform random distribution on a square of side length L. Following the BRN algorithm, in time slot t, a set of nodes $\mathcal{X}_t$ cooperatively broadcast a routing packet, with only one unique packet broadcast in each time slot to avoid inter-packet interference.[1] We define $d_{j,k}$ as the physical distance between the two nodes j and k, and assume all nodes are in far-field distance from one another. While we do not enforce a minimum distance between nodes, it can be shown the nodes are in far-field with probability near 1. We consider the following three channel models.

A. Connected Graph Model (CGM)

A node $k \in [n] \setminus \mathcal{X}_t$ successfully receives the packet in slot t if there exists a transmitting node $j \in \mathcal{X}_t$ such that $d_{j,k} \leq d_0$ where d_0 is the transmission radius. The effects of node cooperative broadcasts and fading are not considered. This model is equivalent to the network model of the original BRN works [9], [10].

B. Random Channel Model (RCM)

This model, derived from [17], defines the conditions of a successful message reception from multiple, uncorrelated transmitters. It accounts for effects from cooperative broadcasts including the possibility of constructive and deconstructive interference. A receiving node $k \in [n] \setminus \mathcal{X}_t$ perceives the combined incoming transmissions as a single flat fading channel. The packet, $\boldsymbol{x}^{(t)}$, in time slot t consists of a series of complex symbols with a symbol variance of 1. Then, at node k, the received message is

$$\boldsymbol{y}_k^{(t)} = \boldsymbol{x}^{(t)} \sqrt{P} \sum_{j \in \mathcal{X}_t} g_{j,k}^{(t)} \sqrt{d_{j,k}^{-\alpha}} \; + \; \boldsymbol{z}_k^{(t)} \tag{1}$$

where P is the transmit power of each transmitting node in $\mathcal{X}_t$, $g_{j,k}^{(t)}$ is the complex fading gain between nodes j and k at time t, $d_{j,k}$ is the distance between nodes j and k, α is the path loss constant and $\boldsymbol{z}_k^{(t)}$ is the noise at the receiver of node k at time slot t. The phases of the individual channels are unknown at the nodes and the phases of the multiple transmissions are not aligned. Node k learns the combined channel via a pilot and the equivalent complex channel gain is

$$G_k^{(t)} = \sum_{j \in \mathcal{X}_t} g_{j,k}^{(t)} \sqrt{d_{j,k}^{-\alpha}}. \tag{2}$$

The fading gain between different transmitter-receiver pairs are independent and follow a complex normal distribution with zero mean and power of 1,

$$g_{j,k}^{(t)} \sim \mathcal{CN}(0, 1). \tag{3}$$

Therefore,

$$G_k^{(t)} \sim \mathcal{CN}\left(0, \sum_{j \in \mathcal{X}_t} d_{j,k}^{-\alpha}\right) , \tag{4}$$

as the sum of complex normal distributions equates to a complex normal distribution with summed variance. We define the power of the noise to be N and the received signal-to-noise ratio (SNR) is

$$\gamma_k^{(t)} = \frac{P}{N} \cdot \left| G_k^{(t)} \right|^2 , \tag{5}$$

which follows the Rayleigh fading model. Given a minimum SNR, β, for successful reception, based on Rayleigh fading, the probability of successful communication is

$$p_k^{(t)} = \mathbb{P}\left[\gamma_k^{(t)} \geq \beta\right] = \exp\left(-\frac{\beta}{\frac{P}{N} \cdot \sum_{j \in \mathcal{X}_t} d_{j,k}^{-\alpha}}\right). \tag{6}$$

C. Deterministic Channel Model (DCM)

The DCM is a hybrid model, similar to the RCM, such that the effects of cooperative broadcasts are considered but random fading is not.[2] The received power is deterministic and is equal to the sum of the individual powers from the transmitters, accounting for path loss. The received signal-to-noise ratio (SNR) at node $k \in [n] \setminus \mathcal{X}_t$ in time slot t is

$$\gamma_k^{(t)} = \frac{P}{N} \cdot \sum_{j \in \mathcal{X}_t} d_{j,k}^{-\alpha}. \tag{7}$$

Successful communication occurs if $\gamma_k^{(t)} \geq \beta$. Equivalently, by using (6), successful communication occurs if $p_k^{(t)} \geq \exp(-1)$.

[1] Within each time slot, effects of varying transmission delays and imperfect TDMA synchronicity among $\mathcal{X}_t$ are assumed to act like multipath effects and are implicity mitigated with an appropriate scheme such as OFDM.

[2] In the DCM, the channel experienced at a receiving node is equivalent to a selective fading channel that has been corrected using OFDM such that the channel gain is equal to the expected gain of a wide-band channel.

D. Barrage Relay Network Routing

We provide a brief overview of routing, or formation of CBRs, in BRNs and refer readers to [9], [10] for more details. The goal of routing in BRNs is to define a CBR, consisting of relay and buffer nodes. Nodes determine their status solely based on locally successfully received packets. TDMA is employed by defining time slots in which particular packets are transmitted. In general, nodes re-transmit packets in the time slot just following the time slot that the packets were successfully received.

To begin routing, a source node transmits a Request-To-Send (RTS) packet that is re-transmitted in subsequent time slots by nodes that successfully receive it. After the RTS reaches the destination node, a Clear-To-Send (CTS) packet is propagated from the destination node similar to the RTS packet. The RTS and CTS packets contain incremental counter such that nodes can learn there distance in hops, h_{RTS} and h_{CTS}, from the source and destination node, respectively. A node will determine itself as a relay node in the CBR if

$$h_{\mathrm{RTS}} + h_{\mathrm{CTS}} \leq h_{\mathrm{SD}} + w \ , \tag{8}$$

where h_{SD} is the minimum hops between the source and destination and w is a non-negative integer parameter called the *excess width*. Otherwise, if $h_{\mathrm{RTS}} + h_{\mathrm{CTS}} > h_{\mathrm{SD}} + w$, a node is a buffer. Similarly, a node is a buffer if it receives the RTS packet and a non-relayed Buffer (BUF) packet, but not the CTS packet or does not receive the RTS packet, but receives a CTS packet.

We study two metrics of CBRs in BRNs which are reliability and node utilization, which are defined as follows.

Definition 1: Reliability is the probability that a CBR will form, computed as the number of successfully formed CBRs divided by the total number of trials on random networks.

Definition 2: The *node utilization*, U, is the total number of relay and buffer nodes in a successfully formed CBR.

III. Simulation Details and Results

We compute the reliability and node utilization of the CGM, RCM and DCM between a source-destination node pair with fixed distances. The simulations are based on a discrete event simulation, in which any node may transmit or receive within any time slot, following the algorithm described in [9], [10], employing one of the three channel models discussed above to determine if pairs of nodes can connect. The models are considered to be simulating the same situation by equating the cut-off distance, d_0, in the CGM to the cut-off transmission distance of a single node in the DCM, which is given by

$$d_0 = \left(\beta \frac{N}{P}\right)^{-1/\alpha} \ . \tag{9}$$

Similarly, this corresponds to a probability of $\exp(-1)$ of a single-node transmission being received in the RCM.

The networks are all generated on a square with side length $L = 30d_0$ and the source and destination nodes chosen to lie on the diagonal, centered on the center on the square.

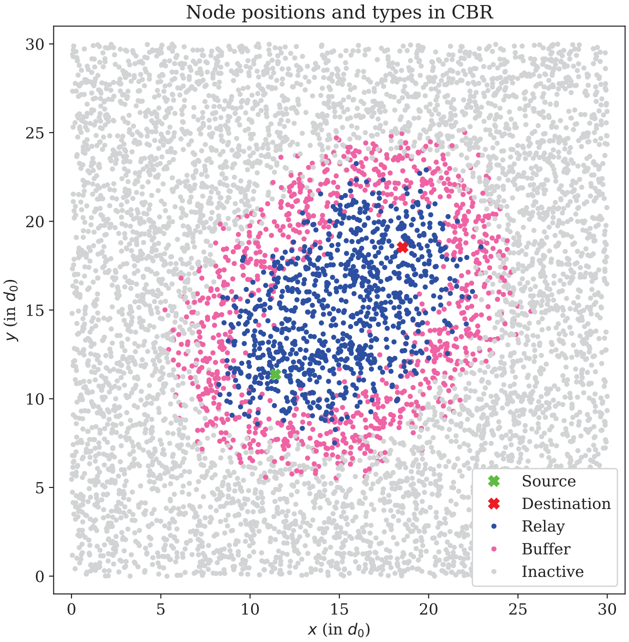

Fig. 1. CBR created on a random network with $w = 3$ and $\rho = 8/(d_0)^2$. Connectivity model is the RCM.

To test the impact of the source-destination distance, we choose to simulate distances of $D \in \{3d_0, 10d_0\}$. For each node density of $\rho \in \{1, 2, 3, 4, 6, 8, 10\}$ nodes / ${d_0}^2$, we generate an ensemble of 4000 random networks, with nodes uniformly distributed, representing the nodes that would be active within the network at the specified locations when the CBR is established. We employ the same ensembles of random networks for the CGM, RCM and DCM models, each with excess width $w \in \{0, 1, 2, 3, 4\}$. Fig. 1 illustrates a CBR established for one such network, with $D = 10d_0$, $L = 30d_0$, $\rho = 8$ nodes / ${d_0}^2$ (7200 total nodes) and $w = 3$. The domain size L was chosen to keep a further buffer of unutilized nodes around the CBR, to minimize the probability that additional nodes would have been included in the CBR if the domain were larger. To measure this, we ensured that the number of utilized nodes for was less than half the total number of nodes in the domain for 97.5% of simulations, and less than two-thirds of the total number for 100% of simulations.

In Fig. 2 we show the reliability of the different models by displaying the fraction of CBRs formed successfully on the ensemble of random networks as a function of node density, indexed by w. At a density of 1 node per ${d_0}^2$, the network is sufficiently disconnected, so the probability of forming a CBR is small. For a density of two or higher for these domains, the network is sufficiently connected, and the CGM is able to form a CBR with probability near one. For the CGM, the excess width, w, does not impact the formation of a CBR, only the number of nodes found in the CBR. However, for the RCM and

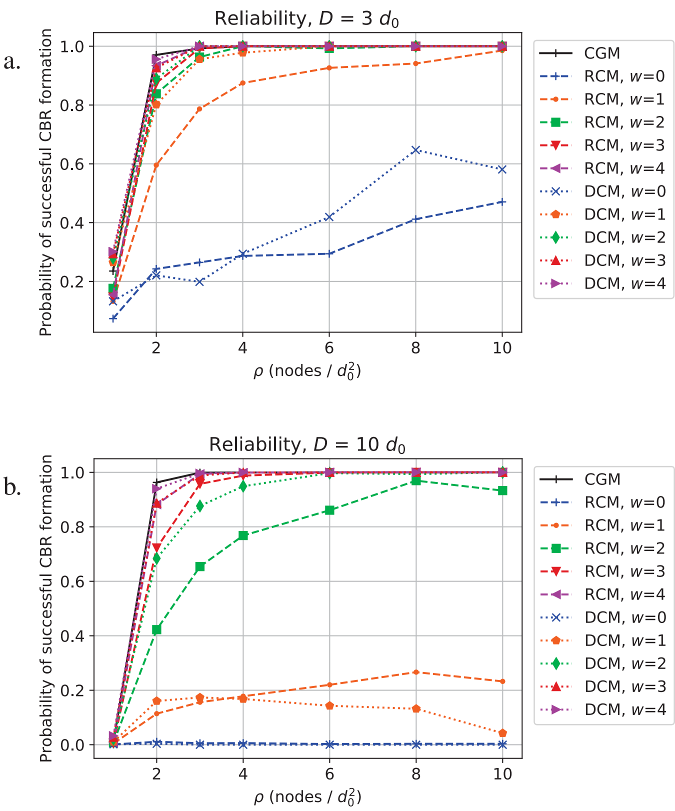

Fig. 2. Fraction of successful formation of CBRs for each model, as function of node density, with (a) $D = 3$ and (b) $D = 10$, varying excess width, w.

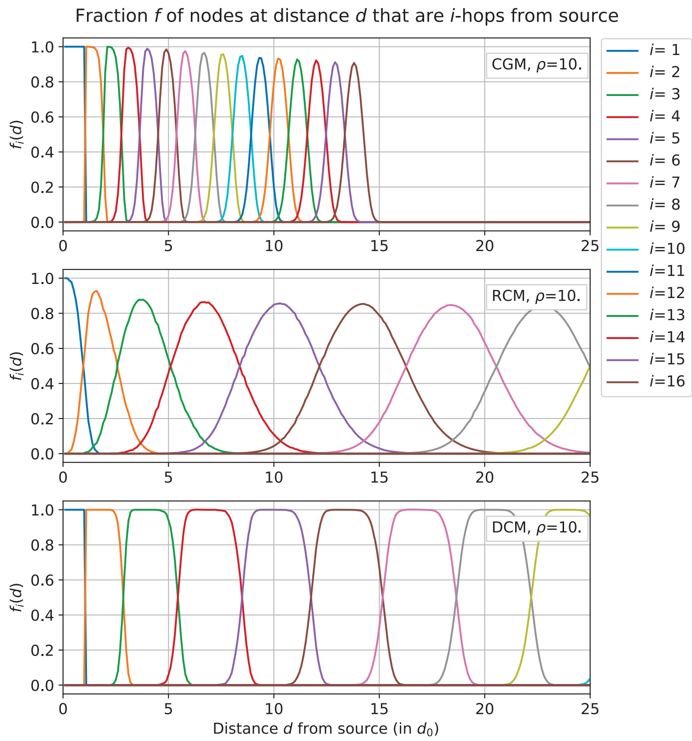

Fig. 3. Probability that a receiving node R, within a given distance $d^h_{R,S}$ from the source node, is i-hops from S, with $i \in \{1, 2, 3, 4, 5, 6\}$. These statistics were generated using an average over the same 4000 network ensembles for density $\rho = 10$, with the source chosen as the node nearest the center of the simulation domain of side length $L = 75$.

DCM, the probability of successful CBR formation for a given D is dependent on ρ and w. This is caused by a mismatch between the distance between nodes in hops, as defined in (8), and the distance between nodes in Cartesian space. The simultaneous broadcast of the same signal from multiple nodes extends the broadcast range beyond that of a single node; if the node density is uniform, as we assume here, successive CTS or RTS hops include an increasing number of nodes in any given direction, increasing the strength of the broadcast signal of RTS or CTS packets. This effect is captured by the RCM and DCM, but not the CGM. Fig. 3 illustrates this by showing the probability that a receiving node, R, at physical distance $d^i_{R,S}$ from the source, is i-hops from the source at the center of a square network with for $\rho = 10$ and $L = 75d_0$, averaged over 4000 random networks, for each model. Tracking the RTS and CTS packets within individual simulations, we find that for low values of w CTS packets do not find acceptable nodes close to their origin, due to these changing distances, but higher values of w enable the CTS stage to find acceptable paths. The further analysis of the geometric factors driving this effect is outside the scope of this paper, but will be investigated in a future paper.

To examine node utilization, U, we consider the three separate models on ensembles of random networks for varying ρ and w, including only samples for which a CBR is formed. In Fig. 4, we show the median utilization divided by the node density, U/ρ. In Fig. 5, we represent the distributions of utilization results over the network ensembles of using box plots, showing the results for $w = 3$. There are four main observations that can be drawn from these figures. First, at low node densities, the medians are similar for all three models, with the CGM having the broadest distributions, but also the highest reliability. This may be understood as being due to the stronger influence of the individual, random positions of nodes at lower densities. Second, the RCM and DCM results are similar for almost all scenarios, aside from much broader distributions for the RCM. Third, the CGM has significantly lower utilization in general, that appears to converge to be mildly superlinear with respect to node density. Fourth, the utilizations by the RCM and DCM increase much faster than the CGM with respect to node density, for $w > 1$. It is of particular note that for high node densities and $w > 1$, U/ρ increases rapidly with density. This magnifies the need, common to all wireless networks, for medium access control when many devices operate in the same channel.

IV. Discussion

The presented simulation results demonstrate the importance of studying BRN routing in the presence of channel effects, and also show concerns for the use of BRNs in dense networks. In a general sense, they also show the importance of using statistical simulation to validate results inferred from

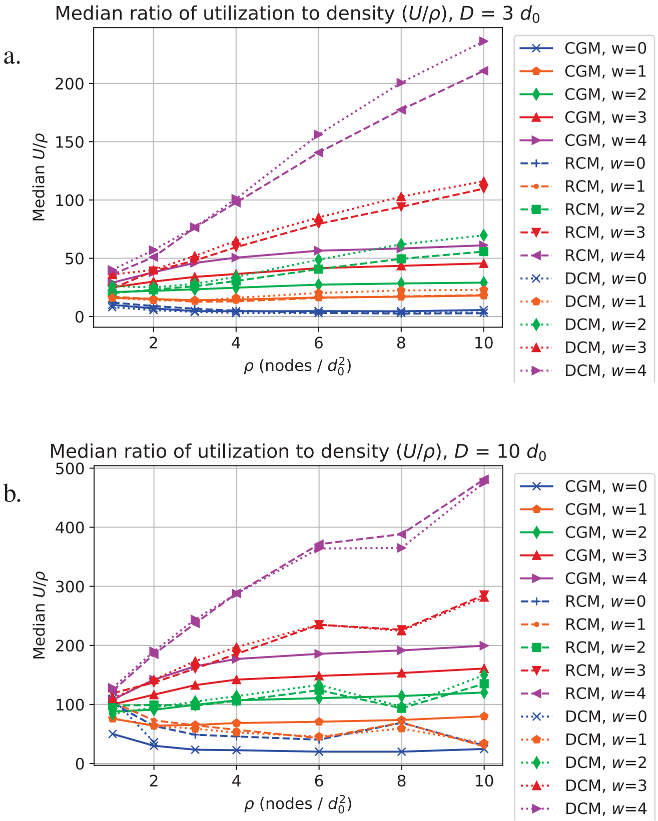

Fig. 4. Median values of utilized nodes in CBR divided by density as function of density, $U(\rho)/\rho$, indexed by model type and excess width, with (a) $D = 3$ and (b) $D = 10$.

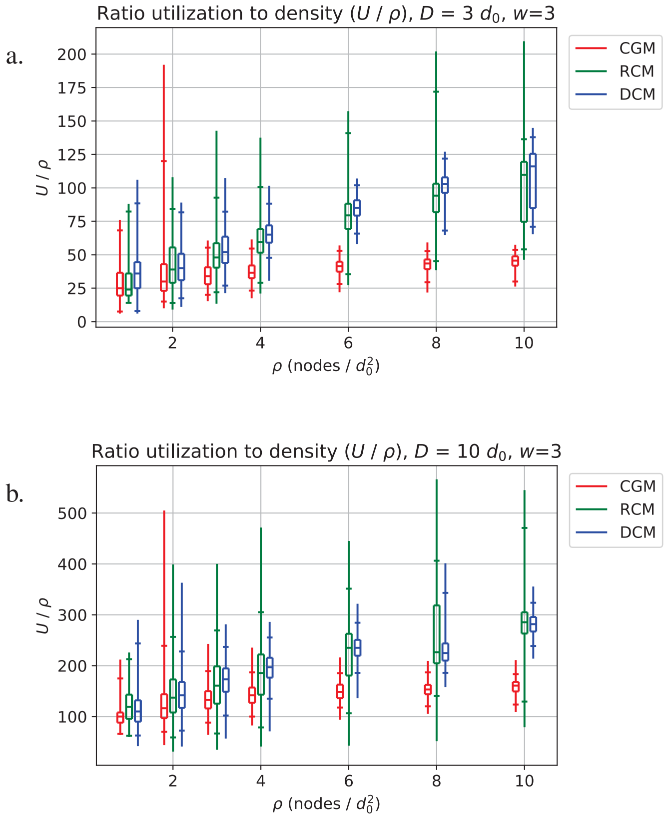

Fig. 5. Box plots representing the distributions of $U(\rho)/\rho$, for excess width of $w = 3$. In each box, the horizontal lines, from least to greatest, mark the 2.5-%, 25%, 50%, 75%, 97.5% values, while the extreme ends of the "whiskers" give the minimum and maximum values calculated. (a) $D = 3$ and (b) $D = 10$.

simplified models.

These observations are important in two ways for BRNs. First, a network in which all nodes are connected to all others via multiple hops, does not guarantee connectivity between arbitrary nodes in the BRN algorithm. Whereas the CGM finds that the algorithm is reliable, the RCM and DCM show that it often requires a greater value of w, and, hence, more resources. This failure is pronounced for dense networks and is caused by how the routing algorithm counts hops between a node and the source and receiver, not by whether or not a node receives the transmission. In other words, when there is a high density of nodes participating in a cooperative broadcast, there is larger variability in the distance of each hop. In this case, the guarantees on BRN source-destination routing, of which hop-count is crucial, break down. Second, even when connectivity between nodes is achieved, node utilization scales differently depending on the fading model, with significantly more of the network occupied by a CBR in RCM and DCM simulations compared to CGM simulations. This occurs because, with the cooperative broadcasting, each successive RTS or CTS step extends farther, covering more space. This is especially true for high density networks. While this reduces latency and improves SNR, it is at the cost of using significantly more network resources and reducing the overall throughput of the BRN when multiple unicasts are desired. This yields a trade-off, where routing success can be improved at the cost of network resources.

One possible solution to increase the routing reliability and reduce the node utilization is to derive a protocol from the BRN in which nodes have some knowledge about their relative positions. For example, nodes may be able to recognize if they are far off from the line that connects the source and destination nodes. In this case, nodes can exclude themselves from participating as a relay to reduce the node utilization of the CBR. Similar schemes and ideas utilizing relative positions have been proposed in literature such as well-known AODV or localization approaches based on received signal strength [18].

For situations where node density is anticipated to be higher than in present networks, these results suggest a second possibility of optimizing transmission power to control effective node density. In the simulations, the node density is defined in terms of d_0, but variables of the channel models which define successful communication are kept constant. Since node utilization by a CBR increases superlinearly with node density, decreasing the transmission power, and thus d_0, could help to reduce the extent of cooperative broadcasts, while simultaneously saving power on individual devices and potentially retaining the high rates of reliability.

V. Conclusion

In this work we have expanded on the analysis of BRNs, a leading algorithm for decentralized, ad hoc wireless networking in three ways: 1) we have studied the effects of fading and cooperative broadcasting on routing, 2) we have varied node density to understand how well the algorithm may scale to future applications and 3) we have used ensembles of geometric random networks to obtain statistical distributions of results. We have found that channel effects and node density can significantly impact transmission reliability and network utilization. We have also found that, for dense networks, multihop routing failures can be caused from effects of fading and cooperative broadcasts, even when the graph is fully-connected in the multihop context.

A promising future research direction is to study improvements to the BRN routing algorithm for use in high density networks. We have found that under the random and deterministic channel models, the number of network resources required for a unicast route are more than that predicted on the connected graph model. Furthermore, the node density can significantly impact the node utilization under these fading models. We also have identified a trade-off by adjusting the excess width of the routing protocol to trade network resources for increased routing reliability. It will be interesting to study variations of BRN routing where nodes have access to more information, such as relative positions, so they can form more efficient multihop routes, or vary power output to scale the power of cooperative broadcasts, to maximize reliability while minimizing node utilization.

References

[1] D. G. Reina, S. L. Toral, F. Barrero, N. Bessis, and E. Asimakopoulou, "Evaluation of ad hoc networks in disaster scenarios," in *2011 third international conference on intelligent networking and collaborative systems*. IEEE, 2011, pp. 759–764.

[2] Y. Jin, X. Tan, W. Feng, J. Lv, A. Tuerxun, and K. Wang, "Manet for disaster relief based on ndn," in *2018 1st IEEE International Conference on Hot Information-Centric Networking (HotICN)*. IEEE, 2018, pp. 147–153.

[3] J. Burbank, P. Chimento, B. Haberman, and W. Kasch, "Key challenges of military tactical networking and the elusive promise of MANET technology," *IEEE Communications Magazine*, vol. Nov. 2006, pp. 39–45.

[4] J. L. Burbank, P. F. Chimento, B. K. Haberman, and W. T. Kasch, "Key challenges of military tactical networking and the elusive promise of manet technology," *IEEE Communications Magazine*, vol. 44, no. 11, pp. 39–45, 2006.

[5] K. Poularakis, G. Iosifidis, and L. Tassiulas, "Sdn-enabled tactical ad hoc networks: Extending programmable control to the edge," *IEEE Communications Magazine*, vol. 56, no. 7, pp. 132–138, 2018.

[6] I. Akyildiz, "A survey on sensor networks," *IEEE Communications Magazine*, vol. 40, no. 2, pp. 102–114, 2002.

[7] M. Hammoudeh and R. Newman, "Adaptive routing in wireless sensor networks: QoS optimisation for enhanced application performance," *Information Fusion*, vol. 22, pp. 3–15, 2015.

[8] M. Green, A. Thomas, A. Chachich, W. Fehr, and N. Towery, "FHWA white paper on mobile ad hoc networks," Tech. Rep. FHWA-HRT-18-027, US Department of Transportation, Federal Highway Administration, McLean, Virginia, 2018.

[9] T. Halford and K. Chugg, "Barrage relay networks," in *2010 Information Theory and Applications Workshop (ITA)*. IEEE, 2010, pp. 1–8.

[10] T. Halford, K. Chugg, and A. Polydoros, "Barrage relay networks: System & protocol design," in *21st Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*. IEEE, 2010, pp. 1133–1138.

[11] T. Halford, T. Courtade, and K. Turck, "The user capacity of barrage relay networks," in *MILCOM 2012-2012 IEEE Military Communications Conference*. IEEE, 2012, pp. 1–6.

[12] P. Gupta and P.R. Kumar, "The capacity of wireless networks," *Information Theory, IEEE Transactions on*, vol. 46, no. 2, pp. 388–404, 2000.

[13] T. Halford and K. Chugg, "The reliability multihop routes with autonomous cooperation," in *UCSD Inf. Theory and Appl. Workshop*, 2011.

[14] S. Talarico, M. Valenti, and T. Halford, "Unicast barrage relay networks: Outage analysis and optimization," in *2014 IEEE Military Communications Conference*. IEEE, 2014, pp. 537–543.

[15] S. Talarico, M. Valenti, and T. Halford, "Controlled barrage regions: Stochastic modeling, analysis, and optimization," in *MILCOM 2016-2016 IEEE Military Communications Conference*. IEEE, 2016, pp. 466–472.

[16] A. Kott, A. Swami, and B. West, "The internet of battle things," *Computer*, vol. 49, pp. 70–75, 2016.

[17] D. Tse and P. Viswanath, *Fundamentals of wireless communication*, Cambridge Univ Pr, 2005.

[18] B. Kraczek, "Decentralized network assembly for positioning and coordination of ad hoc networks," in *SPIE Proceedings: Disruptive Technologies in Information Sciences II*, 2019, vol. 11013.