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Capacity of Wireless Ad-Hoc Broadcast Networks under Realistic Channel Models

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Abstract—In a wireless broadcasting scenario, some of the nodes can help the source node by forwarding the received information. Due to the interference from multiple transmissions, selection of these nodes directly affects the performance of the system under a given total power and hop constraint. In this paper, we first analytically find the number and the positions of the rebroadcasting nodes that achieve the optimal broadcast capacity under the continuum model. Following the results of this part, we propose two heuristics, one centralized and another distributed, for relay selection in practical scenarios. Then, we discuss the broadcast capacity performances of these algorithms under different system settings. The results illustrate that using a distributed relay selection method brings significant gains to the broadcast capacity under a realistic system model.

I. INTRODUCTION

In a wireless ad-hoc network, a broadcasting service has to deliver all the information to all nodes successfully. In addition, it has to utilize the available capacity while satisfying maximum delay and total power consumption constraints. In such a service, the capacity of the whole network is determined by the bottleneck capacity of the channel associated with the worst user. To improve the broadcast capacity of the network, some of the nodes can be selected as rebroadcasting nodes. However, this leads to an increase in both total power consumption of the network and pre-roll delay for some of the receiving nodes. Also, allowing retransmissions from multiple cooperating relay nodes in addition to the source node creates interference for the receiving node since wireless transmission using an omnidirectional antenna is broadcast in nature. Given a network topology, link capacities between each user and a total power constraint, selecting the set of rebroadcasting nodes that maximizes the broadcast capacity is already a difficult problem without taking the interference into account [1]. Thus, it is important to analyze the broadcast capacity of a wireless network under total power and hop constraints when interference is taken into consideration.

In the literature, much of the study on wireless ad-hoc networks focused on capacity limits [2], [3] and scaling laws [4], [5] of source-destination pairs. All of these works consider the theoretical computation of achievable unicast capacities with different assumptions and constraints. On the other hand, the studies on the capacity of wireless multi-hop ad-hoc networks in broadcast mode are scarce. To our knowledge, there are two papers focusing on the capacity limits of wireless multi-hop networks for broadcasting. [6] presents the definition of broadcast capacity and proves that multi-hop broadcasting is more beneficial than single-hop transmission in extended networks while the reverse is true for dense networks. The second paper [7] develops bounds for the broadcast capacity of arbitrarily connected networks under different channel models and power regimes. However, both of these papers analyze the broadcast capacity using theoretical analysis and asymptotic bounds without taking into practical considerations. In order to measure the achievable broadcast capacity of a multi-hop ad-hoc network, total power consumption, interference from multiple transmissions, total transmission delay as well as receiver capabilities are all need to be taken into account. In this paper, we first find the optimal broadcast capacity of the network under the continuum model and then propose practically implementable rebroadcasting node selection algorithms in order to improve the broadcast capacity of the network.

Here, we present a study questioning how the broadcast capacity of a multi-hop ad-hoc network can be improved under practical considerations. As there are no papers studying wireless multi-hop broadcast capacity analysis with realistic assumptions, this work tries to fill this gap and proposes solutions for practical scenarios. The problem is to find the maximum capacity achieving subset of nodes that rebroadcasts the decoded message as the broadcast capacity of a wireless multi-hop network depends on the selection of these rebroadcasting nodes. When there are finite users in the network and even the channel is defined by a simple path-loss model, this problem is shown to be an NP-complete problem [1]. As an alternative approach, one can solve the problem when there are infinitely many users in the network. Moreover, additional constraints and practical considerations can be injected into this problem. Subsequently, heuristic algorithms, which are suboptimal but practical solutions, can be proposed for the finite user scenario.

The rest of the paper is organized as follows. In Section II, we define the wireless multi-hop network model and assumptions. Then, a method for computing the capacity for the system with infinitely many nodes is presented in Section III. For finite population networks, we propose two distinct relay selection methods in Section IV. Simulation results to assess the performances of the proposed heuristics are provided in...
Section V. Finally, conclusions are drawn in Section VI.

II. WIRELESS MULTI-HOP NETWORK MODEL

When broadcasting in a wireless multi-hop network, the common information has to be received successfully by all the nodes in the network. In our network model, we assumed a source node centered around a 2-D circular region, \( \Gamma \), \( n \) rebroadcasting nodes and \( m \) listening nodes. So, the information at the source node has to be received by all \( m + n \) nodes while \( n \) relay nodes are assisting to the broadcast by decoding-and-forwarding the received signal from the source. In order to decode a symbol, all relays process received signals for a certain duration because relays are assumed to be using symbol-by-symbol decoding as in [8]. Therefore, both propagation time and processing time are considered as done in [9] for system modeling. To achieve diversity from signals transmitted by different nodes, each node is assumed to have a Rake receiver with \( R \) fingers. Thus, the receiver can utilize signals separated by more than a chip time by locking each finger to the strongest resolvable signals. At the same time, signals that are received in the same chip duration, which are nonresolvable signals, contribute to both signal and interference power based on their phase. In this work, only large-scale path loss characteristics are considered in the channel model, which is commonly used in papers on wireless capacity analysis.

![Fig. 1. Relays forming a set of rings.](image)

In our network model, source node has transmission power \( P \) while there is a total power constraint, \( TP \), on all cooperating relay nodes in the system. However, no power adaptation is used, i.e., each rebroadcasting node transmits equally at full power, which is equal to \( TP/n \). If there are infinitely many users in the network, the optimal locations of the rebroadcasting nodes form a set of concentric circles \( \Phi = \{ \varphi_i \mid i = 1, ..., L \} \) centered around the source node with associated set of radii \( \textbf{D} = \{ \hat{r}_i \mid i = 1, ..., L \} \) as shown in Fig. 1 due to the circular symmetry. The broadcast capacity analysis is done for one-ring scenario, i.e., \( |\Phi| = 1 \) with the optimal broadcast capacity achieving radius \( \hat{r}_1 \). However, incorporating a second ring to the capacity analysis increases the complexity of the solution exponentially since at each feasible radius of the inner ring, an optimal outer ring radius has to be found. Therefore, we stick to the one-ring scenario as it improves the broadcast capacity substantially with a reasonable optimization complexity. Also, to provide full connectivity of the network, all relay nodes lock on to source’s signal. For a given total power constraint, the optimal ring radius, \( \hat{r}_1 \), which maximizes the broadcast capacity, needs to be found.

A. Broadcast Capacity

The broadcast capacity of a wireless multi-hop ad-hoc network can be formulated as the minimum of the channel capacity over all transmitter-receiver pairs. For a network with region \( \Gamma \), the broadcast capacity is:

\[
C_B(\Gamma) = C_B(S_b, R_b) = \min_{i \in N \cup M} \left[ B \log_2(1 + \Psi_i) \right] \quad (1)
\]

\[
C_B(S_b, R_b) = \min \left[ C_B(S, N), C_B(S, M_S), C_B(N, M_N) \right] \quad (2)
\]

where \( S_b \) and \( R_b \) denote the transmitter-receiver pair with the bottleneck channel capacity. \( N \) denotes set of rebroadcasting nodes while \( M_S \) and \( M_N \), where \( M = M_S \cup M_N \), denote the non-transmitting nodes receiving service from the source node and the relay nodes, respectively. Also, \( \Psi_i \) denotes the signal-to-interference-plus-noise-ratio (SINR) of user \( i \) and \( B \) is the channel bandwidth.

B. SINR Calculation

In a wireless multi-hop broadcasting scenario, a receiving node is subject to a number of signals carrying the same information with different time delays. This situation can be viewed as a unicast transmission with multipath fading. To mitigate multipath fading in a unicast transmission, multipath diversity can be employed using direct sequence code division multiple access (DS-CDMA) with Rake receiver. Using maximal-ratio-combining (MRC), a Rake receiver with \( R \) fingers (\( R \leq n + 1 \)) can achieve an SINR, which is the sum of the SINRs on each finger. At each finger, unresolvable paths contribute to both signal and interference power based on the delay difference while remaining resolvable paths contribute to the interference power. Then, the total SINR achieved at a receiver \( i \), \( \Psi_i \), can be calculated as follows:

\[
\Psi_i = \sum_{k=1}^{R} \frac{P_k d_{ij}^{-\alpha}}{N_0 B} + \sum_{w \in H_k} P_w d_{wi}^{-\alpha} \left( 1 - \frac{|\tau_{ik} - \tau_{w}|}{T_c} \right) \quad (3)
\]

where \( d_{ij} \) is the distance between node \( i \) and \( j \), \( P_i \) is the transmission power of node \( i \), \( \alpha \) is the pathloss exponent, \( N_0/2 \) is the power spectral density of the additive white Gaussian noise (AWGN), \( \tau_i \) denote the time delay of path \( i \), \( k \) is the finger index, \( t_k \) is the index of the transmitter that is locked by \( k \)th finger, \( T_c \) is the chip time (\( T_c \approx 1/B \)), and \( H_k \) and \( I_k \) denote the set of unresolvable and resolvable paths with respect to the \( k \)th finger, respectively.
III. BROADCAST CAPACITY UNDER THE CONTINUUM MODEL

The broadcast capacity of a wireless multi-hop network is determined by the minimum channel capacity among all transmitter-receiver pairs. Under the continuum model, where there are infinitely many nodes in the network, we can find the geographical points with the minimum capacity. According to circular symmetry, the optimal broadcast capacity of a circular region is equal to the optimal broadcast capacity of a pie slice between 0 and $\pi/n$-degree when no more than one hop is allowed. Although this property simplifies the analysis, we need to consider the chip time and the number of fingers at the receiver. At a given geographical point, the Rake receiver utilizes some part of the signal delayed by less than $T_c$ other than the intended transmission according to its phase difference given by (3). Let us call these geographical points as the region of utilization. The region of the utilization for two transmitting nodes, $i$ and $j$, $\Lambda_{ij}$, is a set of points that satisfy the following inequality:

$$\Lambda_{ij} = \{ p \in \Pi \mid |d_{i,p} - d_{j,p}| < c.T_c \} \quad (4)$$

where $c$ is the speed of light. A simple demonstration of this utilization region for nodes 1 and 2, depicted with grey color, is shown in Fig. 2.

In a practical scenario, each user is equipped with a Rake receiver which has more than one fingers. However, as MRC is used to combine signals from each finger of the Rake receiver, the capacity analysis for more than one-finger case becomes complex. However, SINR is a smooth, continuous, and well-behaving, i.e., includes no rapid fluctuations and abrupt changes, function except at points that are very close to any transmitter. So, the critical points of a region can be found using a method, which we call as feasible direction method (FDM), that converges to a local critical point (LCP), which is the nearest critical point to the initial guess, of the region.

A. Feasible Direction Method (FDM)

In general, FDM iterates over geographical points in a network and converges to a point with the worst channel capacity depending on the guess point. At the initialization phase, a guess point is fed to FDM and the associated capacity is computed. Then, a ball around this initial point is defined by $\epsilon$ and a set of direction vectors $d_i$ with $||d_i|| = 1$ for $i = 1, ..., k$, where $k$ denotes the number of intervals on the ball. Then, FDM computes the capacity of the points on this ball and records the point with the worse channel capacity. This point is used in the next iteration as the center of the new ball. If there is no point with the worse capacity, then $\epsilon$ can be decreased (e.g. halved) for a finer-grained search. Ultimately, a critical point is found when $\epsilon < \epsilon_l$, where $\epsilon_l$ is a lower bound on $\epsilon$.

The feasible direction method finds the local critical point for a given initial guess. In order to select an initial guess, the region at hand has to be divided into subregions. We used both Voronoi tessellations [10] and Delaunay triangulation, which corresponds to the dual graph for the Voronoi diagram, for determining these subregions. Then, we can find the local critical point of a subregion for a given system setting as shown in Fig. 2. The convergence of FDM from an initial guess (IG) to an LCP for different guesses is also shown in the same figure. Yellow lines denote the Voronoi tessellations, red lines denote the Delaunay triangulation while grey area is the utilization region. As we can see, different initial guesses in the same subregion converges to the same local critical point.

As a result, we can use FDM to locate the local critical points of a given region. Then, the maximum achievable broadcast capacity is the minimum over the capacity of those local critical points and the capacity between source and relays, according to (2).

IV. PROPOSED HEURISTICS FOR FINITE USER CASE

In this section, we describe the details of two proposed relay selection procedures. For a given user placement and power levels, there exists an optimal set of relay nodes, which maximizes the broadcast capacity of the network. However, the complexity of the optimal selection procedure is not polynomial-time. Therefore, the proposed heuristics are suboptimal but practical solutions to this problem.

One of the goals of these algorithms is to select the rebroadcasting users using minimal system resources and time so that these methods can be invoked periodically. The second goal of these algorithms is to increase the broadcast capacity of the network. To accomplish these goals, a relay selection strategy needs to both mitigate interference from multiple transmitters and be low-complexity for practical implementation purposes. When two or more rebroadcasting nodes are close to each other, the capacity of the channel between the source and one of these relays is highly degraded due to the interference. As broadcast capacity of a network is determined by the minimum capacity among all the users, a relay selection method has to avoid such scenarios.

Here, we propose two relay selection methods. In both of these algorithms, source node broadcasts two threshold modes, which are set heuristically according to the optimal capacity value found in the continuum model. The users, whose channel conditions satisfy a transmission mode in between these threshold modes, constitutes the candidate set. First method uses a centralized approach, where source selects each cooperating node randomly from the candidate set sequentially. The
second algorithm is distributed and nodes monitor their source channel SINR during the selection process.

A. Centralized Selection (CS)

In CS, source node starts pilot transmission and each node in the network reports its source-to-node CSI back to source. Depending on the upper and lower threshold modes, source node creates a candidate set, which includes users belonging any mode in between these thresholds. Source informs all of the users so that only users in the candidate set continue to send CSI reports. Then, source node selects a user randomly among the candidate set and this user starts cooperation. In the meantime, SINR values of users that are in close proximity to this selected node become highly degraded due to the strong interference caused by this node. Source node updates the candidate set and selects the next user randomly. This update and select procedure continues until there are no users in the candidate list.

B. Distributed Selection (DS)

DS procedure includes two phases, selection and stopping. At the initialization of DS, source node starts pilot transmission and broadcasts upper and lower threshold modes, similar to CS. However, users in the candidate set create random timers instead of reporting their CSI back to source. Then, these users monitor their source channel SINR during the selection phase. If a user’s channel becomes degraded, i.e., does not satisfy a SINR requirements of a mode between threshold modes, then timer is stopped. Otherwise, user starts cooperation if the channel is not degraded until timer expires. Depending on the predefined timer length and user population in the network, more than one timer may expire at the same time. This situation may cause multiple rebroadcasting nodes in close proximity. To prevent this, at the end of selection phase, each rebroadcasting node, whose source channel SINR becomes degraded, creates a second random timer for stopping cooperation. If the channel stays degraded until timer expires, the user stops cooperation, otherwise, timer is stopped. Use of two independent random timers for selection and stopping phases decreases the probability of having a degraded capacity among source-to-relay channels. The distributed relay selection method is similar to CSMA/CA [11] in a sense that both of them use random timers to prevent interference.

V. SIMULATIONS

In this section, we perform simulations to measure the achievable broadcast capacity under different system configurations. As mentioned in the previous sections, we first compute the broadcast capacity under the continuum model and then performed simulations for the proposed algorithms in a finitely many user network. In order to observe the gains of the multi-hop strategy, we consider the capacity ratio between multi-hop and direct transmission as a measure for the simulations. In a direct transmission, i.e. one-hop, there are no relays assisting to the source, therefore source is the only transmitter. The broadcast capacity for direct transmission can be computed by the following formula:

\[ C_B(\Gamma) = B \log_2 \left( 1 + \frac{P_{r_1} - \alpha}{N_0 B} \right) \]  

where \( r_{max} = \max(r), i = 1, \ldots, n + m \), i.e., \( r_{max} \) is the maximum distance between the source and all the nodes in the network.

As mentioned previously, all rebroadcasting nodes perform DF and symbol-by-symbol decoding. Thus, each relay starts transmission after one symbol duration, \( T_s \), from the successful reception of the symbol. The ratio of symbol duration to chip duration, i.e. processing gain \( N = T_s/T_c \), is set to be 100, where \( N >> 1 \) is common [12]. When computing the optimal ring radius, a lower bound, \( r_{min} = 50 \, m \), is set in order to avoid small values of \( r_1 \) as the channel model is not accurate for small distances. Transmission power of the source node is set to 1.25 mW, the pathloss exponent is 4 and the noise power spectral density is taken to be \( 2 \times 10^{-19} \, W/Hz \).

For the ease of understanding, we define a system configuration, which is a set of parameters; bandwidth, network radius and number of fingers at the receiver. Let \( \Upsilon \) be a system configuration, then according to Table I, \( \Upsilon_{in,f} = \{ B_\Upsilon, r_\Upsilon, R_\Upsilon \} \) and \( \Upsilon_{fint} = \{ B_\Upsilon, r_\Upsilon, k_\Upsilon, p_\Upsilon \} \) represent two system configurations, one in the continuum model and another in the finite user case, respectively.

In the continuum model, we optimize the radius of the ring on which relays are positioned for a given configuration. The optimization problem finds the optimal ring radius that achieves the maximum broadcast capacity for a given system configuration, \( \Upsilon \), and a number of cooperating peers, \( n \),

\[ \hat{r}_1 = \max_{r_1} \left( C_B(\Upsilon, n, r_1) \right) \]  

where \( r_{min} \leq r_1 \leq r_\Upsilon \) and \( C_B(\Upsilon, n, r_1) \) denotes the broadcast capacity of the network when the system parameters are defined by \( \Upsilon \) and \( n \) relays are equally spaced on the ring with a radius of \( r_1 \). To compute the broadcast capacity for a given value of \( r_1 \), FDM is used. For the optimization of the ring radius, we used a modified line search although faster algorithms can be implemented, but this is out of the scope of this paper. For a given setting, broadcast capacity is computed from \( r_{min} \) to \( r_\Upsilon \) in a discrete manner with a large step size at the first iteration. Since we want to compute \( \hat{r}_1 \) that maximizes broadcast capacity, at each iteration we find two points as new boundaries for the next iteration. These boundaries are the discrete points where broadcast capacity is maximum in between. Finding these boundary points is easy since the broadcast capacity function of ring radius is smooth and well-behaving function as mentioned previously. Then, step size is halved at each iteration to increase the accuracy of the optimal ring radius and also the corresponding optimal broadcast capacity. Finally, the computation of optimal radius is terminated when step size is 0.5 m. In the continuum model,
TABLE I
SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Set of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$</td>
<td>{2} (MHz)</td>
</tr>
<tr>
<td>$TP$</td>
<td>{1,2,3,5,10}</td>
</tr>
<tr>
<td>$r$</td>
<td>{2500,5000} (m)</td>
</tr>
<tr>
<td>$R$</td>
<td>{1,3}</td>
</tr>
<tr>
<td>$m+n$</td>
<td>{250,2500}</td>
</tr>
</tbody>
</table>

when finding critical points, FDM iterations are terminated when step size is 0.1 m.

For the finite user cases, we assume all nodes are distributed according to a uniform distribution over the geography, prior to the broadcast session. To account for the mobility effect, the movement of each node is modeled by the Gauss-Markov mobility model [13]. The tuning parameter $\alpha_m$ is taken to be 0.75 and an average velocity of 3 km/h is assumed. The Gauss-Markov mobility model can capture the time correlation of a moving node by several degrees and the movement of each user can be simulated realistically.

Two different network densities are considered, namely, scarcely populated (250 users) and highly populated (2500 users). The broadcast capacity values are averaged over 144000 and 14400 seconds respectively. After computing the broadcast capacity of the continuum model, we divided the network into modes, where minimum and maximum modes support the capacity of 1/2 and 2 times the maximum capacity of the continuum model. Then, we heuristically set the lower and upper modes to the nearest available modes that support ±15% and ±10% of this capacity for a network with 250 and 2500 users, respectively. Both of the proposed algorithms are invoked periodically in 180 secs.

A. The Continuum Model

First, we focus on how broadcast capacity behaves as the number of cooperating peers increases under the continuum model. The system configuration parameters used in the simulations are listed in Table II. The figures 3-4 show the broadcast capacity ratio (BCR), which is the normalized value of the broadcast capacity with the single-hop capacity, versus the number of cooperating peers (NCP). In each plot, there are 4 different cases, where the total power allocated to cooperating peers is 1, 2, 5, and 10 times the source power.

Graphs show that there exists an optimal NCP, which achieves the maximum BCR, in each system configuration and $TP$. The broadcast capacity computed in the continuum model is the maximum over a set of ring radii of minimum over all the source-to-relay, source-to-listener and relay-to-listener capacities. So, when NCP is very small, the maximum value of BCR can not be achieved because network can carry additional cooperating peers due the low interference power. However, at larger NCP, source-to-relay channel becomes highly degraded due to the strong interference from the neighboring relays and causes BCR to drop. Furthermore, the graphs show that higher the transmission power allocated to each node, sharper the fall in BCR. Also, this degradation is shifted towards larger NCP when the network radius grows. Because, there is more room for additional cooperating nodes and also higher capacity values can be achieved in a wider geographical region. Also, it is possible to increase BCR by 25% on average with two additional fingers at the receiver.

B. Finite User Scenario

After computing the broadcast capacity for the infinitely many user scenario, we performed simulations in order to measure the performance of the proposed algorithms. As mentioned, in each finite user simulation, the capacity found in the continuum model is taken as a reference capacity and threshold modes are adjusted according to heuristics. The BCR values obtained using CS and DS are given in Table III and IV, respectively. The results show that substantial gains in broadcast capacity are possible using both of the proposed methods.
The capacity values of the continuum model represent an upper bound for the finite user cases since it is possible to select each relay at the exact desired geographical location. Although, for a specific user placement, the broadcast capacity of a finite user case can be better than the infinite case, the time averaged capacity would be lower. Taking this into account, the BCR values show a competitive performance for suboptimal but practically implementable relay selection methods. When the network is scarcely populated, the probability of selecting users that are equally spaced on a ring structure is very low. In most cases, the algorithm chooses smaller number of peers than the optimal case because proposed algorithms mitigate interference by eliminating candidate users, whose channel becomes degraded. But, when there are enough users in the network, additional gains in BCR can be achieved as seen in the results of $k = 2500$ scenario. Because, it is possible to select users, who do not create strong interference to neighboring relays while increasing the degraded channel capacity of listening nodes, e.g. ones that are closer to the network boundary.

### Table III

<table>
<thead>
<tr>
<th>$m + n$</th>
<th>$m + n$</th>
<th>Cont. Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \geq 2 \times 10^6$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B = 2 \times 10^6$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r = 2500$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$TP = 1$</td>
<td>2.0796</td>
<td>3.7952</td>
</tr>
<tr>
<td>$TP = 2$</td>
<td>3.2478</td>
<td>4.7082</td>
</tr>
<tr>
<td>$TP = 5$</td>
<td>5.8215</td>
<td>8.5233</td>
</tr>
<tr>
<td>$TP = 10$</td>
<td>9.3758</td>
<td>12.9113</td>
</tr>
</tbody>
</table>

| $B = 2 \times 10^6$ |
| $r = 5000$ |
| $TP = 1$ | 1.7939 | 3.3991 | 5.1569 |
| $TP = 2$ | 3.0171 | 4.7639 | 6.9536 |
| $TP = 5$ | 5.1748 | 8.8255 | 11.0878 |
| $TP = 10$ | 8.6090 | 13.2842 | 16.6556 |

### Table IV

<table>
<thead>
<tr>
<th>$m + n$</th>
<th>$m + n$</th>
<th>Cont. Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \geq 2 \times 10^6$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B = 2 \times 10^6$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r = 2500$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$TP = 1$</td>
<td>1.9880</td>
<td>3.6518</td>
</tr>
<tr>
<td>$TP = 2$</td>
<td>3.0004</td>
<td>4.9195</td>
</tr>
<tr>
<td>$TP = 5$</td>
<td>4.9917</td>
<td>8.0830</td>
</tr>
<tr>
<td>$TP = 10$</td>
<td>7.4044</td>
<td>11.8521</td>
</tr>
</tbody>
</table>

| $B = 2 \times 10^6$ |
| $r = 5000$ |
| $TP = 1$ | 1.7530 | 3.5070 | 5.1569 |
| $TP = 2$ | 2.7216 | 5.2036 | 6.9536 |
| $TP = 5$ | 4.9518 | 8.9298 | 11.0878 |
| $TP = 10$ | 7.6653 | 13.0171 | 16.6556 |

On the other hand, a slight improvement in performance can be viewed when the network radius grows. Also the results in different system configurations are close to each other and the performance of CS algorithm is better than the capacities achieved by DS. Although pathloss exponent is 4, the degradation in BCR is quite low as users are moving randomly and slowly. However, if the mobility of the nodes is high, selection methods would be invoked more frequently in order to achieve a similar performance.

### VI. Conclusion

In this work, wireless multi-hop broadcast capacity is analyzed from a practical perspective. The goal is to close the existing gap between theoretical and practical studies on wireless multi-hop broadcast capacity in the literature. The idea is to investigate the behavior of the broadcast capacity with respect to the number of relays in the network. In this paper, we first compute broadcast capacity limits when there are infinitely many nodes in the network in order to simplify the relay selection problem. Then, we suggest two heuristics, one centralized and one distributed, as suboptimal but practical solutions to this selection problem. In these heuristics, the parameters are selected according to the results of the theoretical model in the infinitely many user case. The results show that both of the proposed relay selection methods bring significant capacity gains on the average, even in the worst case scenario. Also, these algorithms are robust to changes in the network topology due to the mobility and they require reasonable amount of feedback even the number of users in the network is large.

### References