MAXIMIZING TRANSPORT CAPACITY FOR GEOGRAPHIC TRANSMISSION ON NAKAGAMI-m CHANNELS

Tathagata D. Goswami, John M. Shea, Tan F. Wong
Wireless Information Networking Group,
University of Florida, Gainesville, Florida 32611
Email: tdg@ufl.edu,{jshea,twong}@ece.ufl.edu

Murali Rao and Joseph Glover
Department of Mathematics,
University of Florida, Gainesville, Florida 32611
Email:{rao,glover}@math.ufl.edu

***Abstract*—In mobile ad hoc networks (MANETs), conventional packet forwarding schemes that pre-select the next-hop receivers for a packet may fail if the channel coherence time is on the order of the typical packet duration because the pre-selected node may often suffer a deep fade for the duration of the packet. An alternative approach is geographic transmission, in which the packet is transmitted in the direction of the destination, but the next-hop forwarding node is selected among those nodes that are in the direction of the destination and that correctly recover the message. This approach takes advantage of multi-user diversity to significantly improve the probability of the packet being correctly received by a forwarding agent. However, this approach places additional burden on the energies of the mobile nodes if the forwarding scheme requires all of the next-hop neighbors of the transmitter (that are in the direction of the destination) attempt to receive a transmitted message. In this paper, we consider the joint design of node-activation strategies and transmission rates to maximize the expected value of transport capacity over a Nakagami-m channel under a constraint on the expected number of nodes that attempt to receive a packet. We show that our approach offers better performance than other approaches.**

I. INTRODUCTION

Mobile, wireless communications channels are often subject to random channel variations, such as fading or shadowing, that limit communications over such channels. One approach to overcome these limitations is to exploit multi-user diversity [1] that exists in many multi-terminal communication systems. Since different channels experience different (and often independent) channel conditions, a transmitter can choose to communicate with a receiver that is experiencing good channel conditions. However, this requires channel state feedback from the potential receivers which may produce significant overhead, particularly for use in MANETs.

An alternative approach in MANETs is to exploit multi-user diversity by generalizing the concept of routing. Conventional routing schemes preselect a single node to act as the next forwarding agent for a packet. A scheme which exploits multi-user diversity by allowing any of a list of candidate nodes to become the forwarding agent was proposed in [2] and later extended in [3]. In [4], a joint MAC/routing approach is proposed that retains the choice of a preferred next-hop forwarding agent while removing the need to provide an explicit list of alternative agents.

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Since channel variations are often much faster than the routing protocol updates, the concept of network topology begins to fail under randomly varying channels where there are significant outages related to link availability. Geographic transmission has only recently been suggested as a way to opportunistically exploit random channel variations (*c.f.* [5]). In [6] and [7], the authors present Geographic Random Forwarding (GeRaF) a geographic transmission scheme that is designed to overcome unsynchronized sleep schedules of the receiving nodes. We have shown in [8] that random channel fading can help to increase the single-hop transmission distance for geographic transmissions in which all of the nodes surrounding a transmitter attempt to receive a packet. For mobile radios, energy is often an important constraint, and thus it is desirable to limit the number of receivers that attempt to recover a packet. A simplistic approach is to only turn on receivers within a radius that achieves the desired constraint on the expected number of active receivers. However, this approach can produce poor performance because it may turn on many receivers close to the transmitter, and thus the packet makes very little progress toward the destination. On the other hand, only turning on receivers far away from the transmitter will also produce poor performance, as the average signal-to-noise ratio at large distances is small, and thus the receivers will have a low probability of recovering the packet. Thus, in [9], we propose a distance-based probabilistic node activation protocol that is designed to approximately maximize the expected value of the transmission distance to the most distant receiver that can receive a message under a constraint on the expected number of nodes that activate.

The results in [9] use transmission distance as the performance metric and only hold for Rayleigh fading channels. Transmission distance can be viewed as a transport capacity [10] with a fixed transmission rate. In this work, we consider the joint design of node-activation functions and transmission rate to maximize the transport capacity. We show that the objective of maximizing transport capacity decomposes into two separate objectives of selecting the optimal transmission rate and selecting an optimal node activation function to maximize the transmission distance. We generalize the results in [9] to design node-activation function for the Nakagami-m channel. Recently in [11], channel-adaptive routing schemes has been suggested to maximize information efficiency in a wireless network. However, these schemes

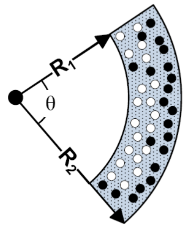

Fig. 1. Node activation region: Transmitter at center. White circles indicate nodes that are asleep, black circles indicate active nodes.

require complete knowledge of the channel gains and/or the location information of the nodes at the transmitter and hence consume significant network resources.

II. System Model Description

We consider geographic transmission in a wireless network in which the channels from a transmitter to the neighboring radios are subject to exponential path loss and fading. We model the positions of the radios using a two-dimensional homogeneous Poisson point process with intensity λ nodes per unit area. Thus, the probability density function for the distance to an arbitrary receiver, denoted $f_X(x)$ is given by

$$f_{X_i}(x) = \frac{2x}{R_2^2 - R_1^2}, \quad R_1 < x \leq R_2. \tag{1}$$

Radios transmit at fixed unit power, and the amplitude of the fading gain is modeled according to the Nakagami-m distribution. Let H_i denote the square of the fading gain to receiver i. Then H_i is a Gamma random variable with distribution function

$$F_H(h) = \frac{1}{\Gamma(m)} \int_0^{mh} t^{m-1} \exp(-t)\, dt, \; h > 0 \tag{2}$$

where $\Gamma(m) = \int_0^\infty t^{m-1} \exp(-t)\, dt$, and we have taken $\mathbb{E}[H_i] = 1$ to provide unit average power gain. In (2), the parameter m, called the *fading figure* is defined as $m = (\mathbb{E}[H_i^2] - 1)^{-1}, \; m \geq \frac{1}{2}$. We assume the channel varies slowly enough that the fading is constant over a packet transmission. To achieve multi-user diversity, a geographic transmission scheme is used in which any of the neighbors of a transmitter that are within some angle θ around the line joining the transmitter to the destination, may act as the next-hop forwarder for the packet. Since receiving also requires energy, the number of receivers that activate (keeps their receivers on) to try to receive a packet should be constrained. We consider the design of a strategy to determine whether a node activates. In [9], we develop a strategy that activates receivers in some finite region $[R_1, R_2]$, and thus we assume a similar model here as shown in Fig. 1. We consider a system in which the transmitter does not know the number or location of the receiving nodes or their fading gains, and the receivers do not know their fading gains prior to the transmission of each packet. For instance, nodes in a certain area of the network that wish to transmit a packet may communicate to coordinate transmission schedules during one period, and the communications occur during a later period, where the channel is not guaranteed to remain constant across the two periods. We assume that nodes know their geographical location and thus can determine their distances from a radio that is scheduled to transmit at a certain time. We consider the design of distributed node activation functions in which the radios independently decide whether they should keep their receivers active or turn them off.

III. Design of Node Activation Functions

A. Optimum Transport Capacity

In wireless communications, there is always a tradeoff between transmission rate and transmission distance: increasing the transmission rate requires a higher signal-to-noise ratio (SNR) at the receiver, which means that the receiver generally has to be closer to the transmitter. One approach to combining both of these measures is *transport capacity* [10], which is the product of the transmission rate and the distance traveled for a message. In the context of geographic transmission, we define this distance to be the distance from the transmitter to the farthest node that successfully receives the transmission. We consider the design of a node-activation function to maximize the expected value of transport capacity for geographic transmissions under a constraint on the expected number of receivers that activate.

For a given transmission rate, there is a target SNR κ, which is identical at every receiver. A node is a successful receiver if the received SNR is greater than a target SNR and also if it is active (turns on its receiver) to recover the transmission. The maximum achievable rate of transmission over a complex Gaussian channel at SNR κ is given by

$$s(\kappa) = \log_2(1 + \kappa), \quad \kappa > 0. \tag{3}$$

Denote the distance to an arbitrary receiver by the random variable X_i. Let $\zeta_i = 1$ denote the event that node i located at distance X_i from the transmitter is active. We use an approach called node-activation based on link-distance (NA-BOLD) to determine whether a particular receiver should be active. Define $\psi(x)$, the node activation function, as $\psi(x) \triangleq P(\zeta_i = 1 | X_i = x)$. Furthermore, given that $X_i = x$, the node activation function ψ also depends on the target SNR κ. Intuitively, the higher the target SNR is, the less likely a node located at some distance from the transmitter is going to get activated. Hence, we have,

$$\zeta_i = \begin{cases} 1, & \text{with probability } \psi(x, \kappa), \\ 0, & \text{with probability } (1 - \psi(x, \kappa)). \end{cases} \tag{4}$$

Node i decides to stay awake probabilistically if $U_i < \psi(X_i, \kappa)$ where U_i is a uniformly distributed random variable on $[0, 1]$. If we denote the path-loss exponent as n, the instantaneous received SNR is $\gamma_i = H_i X_i^{-n}$. If we substitute $Y_i(\kappa) = \sqrt[n]{(H_i \kappa^{-1})}$ and denote $\tilde{F}_Y(y_i; \kappa) = P(Y(\kappa) > y)$, then using (2), we find

$$\tilde{F}_Y(y; \kappa) = \frac{1}{\Gamma(m)} \int_{m\kappa y^n}^{\infty} t^{m-1} \exp(-t) dt, \quad y > 0. \tag{5}$$

Let $V_i(\psi, \kappa)$ denote the distance to a node if it is awake ($\zeta_i = 1$) and has sufficient received SNR ($\gamma_i > \kappa$); otherwise let$V_i(\psi, \kappa) = 0$. Thus, we have,

$$V_i(\psi, \kappa) = \begin{cases} X_i, & X_i < Y_i(\kappa) \quad \cap \quad U_i < \psi(X_i, \kappa) \\ 0, & \text{otherwise.} \end{cases} \quad (6)$$

Note that X_i, H_i and U_i are mutually independent. We can express the distribution of $\{V_i\}$, denoted $F_V(t; \psi, \kappa)$ as,

$$\begin{aligned} F_V(t; \psi, \kappa) &= 1 - P(V_i(\psi, \kappa) > t) \\ &= 1 - \int_t^{\infty} \psi(x, \kappa) \tilde{F}_Y(x; \kappa) f_X(x) dx \quad (7) \end{aligned}$$

Let us denote the transmission distance to the farthest successful receiver by the random variable as $V_{max}(\psi, \kappa)$ and condition on a total of L nodes (awake and asleep) in the geographic region. We define transport capacity denoted by the random variable $T(\psi, \kappa)$ as the product of the maximum achievable rate of transmission and the transmission distance to the farthest successful receiver. Hence,

$$T(\psi, \kappa) = s(\kappa) V_{max}(\psi, \kappa) \quad (8)$$

Using (3) in (8), and taking expectation, we have,

$$\mathbb{E}\left[T(\psi, \kappa)\right] = \log_2(1+\kappa)\ \mathbb{E}\left[V_{max}; \psi, \kappa\right]. \quad (9)$$

Let us now assume that the number of nodes that are awake to receive a transmission inside the activation region as shown in Fig. 1 is $\aleph$ ($\aleph \leq L$) where $\aleph$ is a Poisson random variable. If we now constrain that μ nodes remain active/awake to receive a transmission, we can express our optimization problem as,

$$\max_{s(\kappa),\ \psi(x,\kappa)} \left\{ \mathbb{E}\left[T(\psi, \kappa)\right] \right\} \text{ s.t. : } \begin{cases} \kappa > 0 \\ \mathbb{E}[\aleph] = \mu \\ 0 < \psi(x, \kappa) \leq 1. \end{cases} \quad (10)$$

Since we do not assume any feedback from the nodes back to the source, $s(\kappa)$ does not depend on the node activation function ψ. However, ψ depends on the target SNR κ. Consequently, using (9) in (10), we have,

$$\begin{aligned} &\max_{\kappa} \left\{ \max_{\psi(x,\kappa)} \left\{ \log_2(1+\kappa)\ \mathbb{E}\left[V_{max}; \psi, \kappa\right] \right\} \right\} \\ &\text{s.t. : } \begin{cases} \kappa > 0 \\ \lambda A \int_{R_1}^{R_2} \psi(x, \kappa) f_X(x)\ dx = \mu \\ 0 < \psi(x, \kappa) \leq 1, \end{cases} \quad (11) \end{aligned}$$

under the assumption that the node activation function is concentrated in a region of the form shown in Fig. 1 with area A. If L nodes are located inside the activation region, the conditional distribution of $V_{max}(\psi, \kappa)$, denoted $F_{V_{max}}(t; \psi, \kappa | L)$ is $F_{V_{max}}(t; \psi, \kappa | L) = [F_V(t; \psi, \kappa)]^L$. Since L is Poisson with mean λA, we have,

$$F_{V_{max}}(t; \psi, \kappa) = \exp\Bigg(- \lambda A \left(1 - F_V\left(t; \psi, \kappa\right)\right) \Bigg). \quad (12)$$

Stretching/compressing distances by the factor $\sqrt[n]{\kappa}$ $(\kappa > 0)$

We find that (11) is difficult to solve because of the dependence of the objective function on both $\psi(x, \kappa)$ and κ, where even ψ depends on κ. However, we can express this objective function as a product of two functions such that one function explicitly depends on $\psi(x, 1)$ and the other on κ. Starting from (5), some algebraic manipulation yields $\mathbb{E}[V_{max}(\psi, \kappa)] = \sqrt[n]{\kappa^{-1}}\ \mathbb{E}[V_{max}(\psi, 1)]$. Therefore (11) becomes,

$$\begin{aligned} &\max_{\kappa} \left\{ \sqrt[n]{\kappa^{-1}}\ \log_2(1+\kappa) \right\} \max_{\psi(x,1)} \left\{ \mathbb{E}\left[V_{max}; \psi, 1\right] \right\} \\ &\text{s.t. : } \begin{cases} \kappa > 0 \\ \lambda A \int_{R_1}^{R_2} \psi(x, \kappa) f_X(x)\ dx = \mu \\ 0 < \psi(x, \kappa) \leq 1. \end{cases} \quad (13) \end{aligned}$$

If the node activation function is confined to be nonzero only on an annular activation region as shown in Fig. 1, we can express $\mathbb{E}[V_{max}(\psi, 1)]$ as,

$$\begin{aligned} \mathbb{E}\left[V_{max}; \psi, 1\right] &= R_2 - R_1 \exp\left(-\lambda A\ \sigma(R_1; R_2)\right) \\ &\quad - \int_{R_1}^{R_2} \exp\left(-\lambda A\ \sigma(t; R_2)\right) dt, \quad (14) \end{aligned}$$

where

$$\sigma(t; R_2) = \int_t^{R_2} \psi(x, 1) \tilde{F}_Y(x; 1) f_X(x) dx \quad (15)$$

It is very difficult to solve (13) in closed form because of the double integrals in (14) and (15) and also because $\psi(x, 1)$ appears inside the integration in one of the constraints. Following the approach we developed in [9], we suggest an analytically tractable but suboptimal approach to finding $\psi(x, 1)$ in the next section.

B. Node Activation Based on Fixed Number of Nodes

Suppose we have a fixed number, N, of nodes inside the shaded region in Fig. 1 that are awake to listen to a transmission. We consider the following independent optimization problems:

$$\max_{\kappa} \left\{ \sqrt[n]{\kappa^{-1}}\ \log_2(1+\kappa) \right\} \text{ s.t. : } \kappa > 0 \quad (16)$$

$$\max_{F(x,1)} \left\{ \mathbb{E}\left[V_{max,N}; F(x, 1)\right] \right\}. \quad (17)$$

Since we do not have a solution to (10), hereafter we refer to the solution of (16) as the NA-BOLD approach. For a fixed SNR target κ, $\mathbb{E}\left[V_{max,N}; F(x, \kappa)\right]$ denotes the expected value of the transmission distance to the farthest successful receiver and $F(x, \kappa)$ denotes the distribution of link distance, assuming that N nodes are awake to receive a transmission. Thus, we have changed the problem from finding a probabilistic node activation function to finding the distribution function for the node locations. In (17), $\mathbb{E}\left[V_{max,N}, F(x, \kappa)\right]$ is

$$\begin{aligned} &\mathbb{E}\left[V_{max,N}; F(x, \kappa)\right] \\ &\quad = \int_0^{\infty} 1 - \left[1 - \int_t^{\infty} \tilde{F}_Y(x; \kappa) dF(x; \kappa)\right]^N dt. \quad (18) \end{aligned}$$

The solution to (16) can be obtained by solving the roots of,

$$n\kappa - (1+\kappa)\log_e(1+\kappa) = 0,\ \ \kappa > 0. \tag{19}$$

We solve (17) using an approach that has been detailed in [9]. We state some of the important results derived in [9]. Let

$$\rho(x;\kappa) = \left[\frac{f_Y(x;\kappa)}{\left(\tilde{F}_Y(x;\kappa)\right)^2}\right]^{\frac{1}{N-1}}. \tag{20}$$

For the Nakagami-m channel, $\tilde{F}_Y(x;\kappa)$ is given by (5). The optimum density of link distance $\hat{f}(x;\kappa)$ is concentrated over a finite support (equivalently, a finite activation region) that is located away from the origin; and for $N > 1$ is given by

$$\hat{f}(x;\kappa) \ = \ C\frac{\rho'(x;\kappa)}{\tilde{F}_Y(x;\kappa)}, \quad R_1 \le x \le R_2 \tag{21}$$

where $\rho'(x;\kappa)$ is the derivative of $\rho(x;\kappa)$ with respect to x. For a fixed κ, R_1, R_2, C can be obtained by solving,

$$R_1\left(f_Y(R_1;\kappa)\right) \ = \ \tilde{F}_Y\left(R_1;\kappa\right) \tag{22}$$

$$C\int_{R_1}^{R_2}\frac{\rho'(x;\kappa)}{\tilde{F}_Y(x;\kappa)}dx \ = \ 1 \tag{23}$$

$$C\rho(R_2;\kappa) \ = \ 1 \tag{24}$$

Before we derive the optimal density of link distances for the Nakagami-m channel and hence the node-activation function $\psi(x,\kappa)$ we introduce the following theorem to derive the necessary condition on $\tilde{F}_Y$ for R_1, R_2, and C given in (22), (23) and (24) to be unique for a fixed κ.

Theorem 1: Let R_1, R_2, C and $\hat{f}$ be defined as above. Suppose F_Y is the distribution of Y and denote $\tilde{F}_Y(y;\kappa) = \int_y^\infty f_Y(x;\kappa)dx = 1 - F_Y(y;\kappa)$. Then (22), (23) and (24) determine R_1, R_2, C uniquely, if $\left(\tilde{F}_Y(y;\kappa)\right)^{-1}$ is convex for a fixed κ where the function $\rho(x;\kappa)$ is defined as in (20).

Proof: Uniqueness of R_1: For a fixed κ, we first show that R_1 satisfying (22) always exists if we assume $\mathbb{E}[Y(\kappa)] < \infty$. We discuss the uniqueness of such a solution later. Indeed $\int_0^\infty \tilde{F}_Y(y;\kappa)\,dy = \mathbb{E}[Y(\kappa)] = \int_0^\infty y f_Y(y;\kappa)dy$ so that $\int_0^\infty\left[\tilde{F}_Y(y;\kappa) - y f_Y(y;\kappa)\right]dy = 0$. So, $\tilde{F}_Y(y;\kappa) - y f_Y(y;\kappa)$ cannot always have the same sign. Assuming $\tilde{F}_Y(y;\kappa)$ and $f_Y(y;\kappa)$ are continuous in y and $f_Y(y;\kappa)$ is bounded, $\lim_{y\to 0}\left[\tilde{F}_Y(y;\kappa) - y f_Y(y;\kappa)\right] = 1$. Hence, (22) has a solution. We now show that, if $\left(\tilde{F}_Y(y;\kappa)\right)^{-1}$ is convex for a fixed κ, then (22) has a unique solution. If we divide (22) by $\tilde{F}(y;\kappa)$, then this is equivalent to proving

$$\left(\tilde{F}(y;\kappa)\right)^{-1} - y\frac{d}{dy}\left[\left(\tilde{F}(y;\kappa)\right)^{-1}\right] = 0 \tag{25}$$

has a unique solution for a fixed κ. Now, differentiating the LHS of (25) with respect to y and simplifying, we get $-y\frac{d^2}{dy^2}\left[\left(\tilde{F}(y;\kappa)\right)^{-1}\right]$ which is negative because $\left(\tilde{F}_Y(y;\kappa)\right)^{-1}$ is assumed to be convex for a fixed κ. Hence, the LHS of (25) is strictly decreasing. Since we have already shown above that it vanishes, it can only vanish once.

Uniqueness of R_2: We need to show that for any R_1 there is at most one R_2 satisfying (23). Suppose that (23) has solutions β_1, β_2 where $\beta_1 < \beta_2$. Then for a fixed κ, we have, $\rho(\beta_2;\kappa) - \rho(\beta_1;\kappa) > \frac{\rho(\beta_2,\kappa) - \rho(\beta_1,\kappa)}{\tilde{F}_Y(\beta_1;\kappa)}$ which implies that $\tilde{F}_Y(\beta_1;\kappa) > 1$. But this is a contradiction, since we know that $\tilde{F}_Y(\beta_1;\kappa)$ is a distribution function. Also, note that $\rho(\beta_2,\kappa) - \rho(\beta_1,\kappa) = 0$, is not possible because $\rho'(x;\kappa) > 0$. If $\left(\tilde{F}_Y(y;\kappa)\right)^{-1}$ is convex for a fixed κ, then $\frac{d}{dy}\left(\tilde{F}_Y(y;\kappa)\right)^{-1}$ is increasing and so is $\rho(x;\kappa)$. Hence, $\rho'(x;\kappa) > 0$.

Uniqueness of C: Since we have proved that R_2 is unique and C is related to R_2 according to (24), hence C is unique. ∎

Having obtained the optimum distribution of link distance, $\hat{F}(x,\kappa)$, the node activation probability $\psi(x,\kappa)$ is,

$$\psi(x,\kappa) = \frac{\mu}{\lambda A}\frac{\hat{f}(x;\kappa)}{f_X(x)} \tag{26}$$

where $A = \pi(R_2^2 - R_1^2)$ is the area of node activation and $\hat{f}(x;\kappa)$ is the optimum density of link distance to an arbitrary node, assuming $N = \lceil \mu - 1 \rceil$ nodes are awake to receive a transmission. Since $\psi(x,\kappa)$, is a conditional probability, there is a minimum node density $\tilde{\lambda}$ ($\lambda \ge \tilde{\lambda}$) required to be deployed. We find $\tilde{\lambda} = \frac{\mu}{A}\max_{R_1 < x \le R_2}\left\{\hat{f}(x;\kappa)(f_X(x))^{-1}\right\}$.

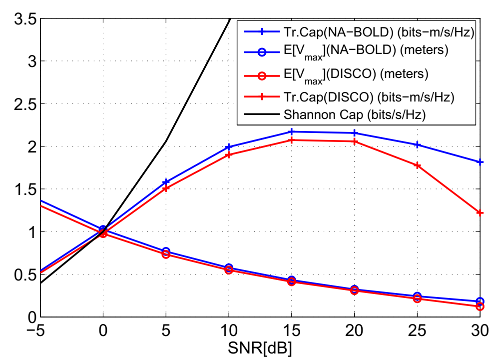

Fig. 2. Variation of (a) Shannon capacity, (b) expected value of transport capacity (Tr. Cap), (c) expected value of maximum transmission distance ($\mathbb{E}[V_{max}]$), with target SNR κ.

C. DISCO Transmission Strategy

We compare NA-BOLD with a geographic transmission scheme that turns on nodes inside a sector of radius R around the transmitter. Rather than turn on every node, as in the DISC strategy (cf. [8]), nodes inside the sector are turned on with a fixed probability p. In other words, we find the optimal p and R in (16) with $\psi(x,\kappa) = p \ \ \forall x \in [0,R]$. For transmission over angle $[0,2\pi)$ results in transmission over a disc, we refer to this strategy as the optimized DISC strategy (DISCO).

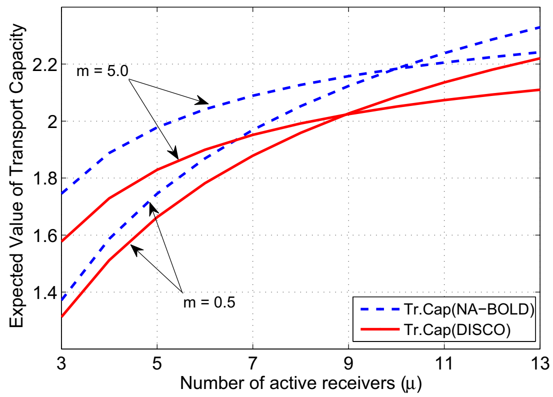

Fig. 3. Expected transport capacity vs. expected number of active receivers.

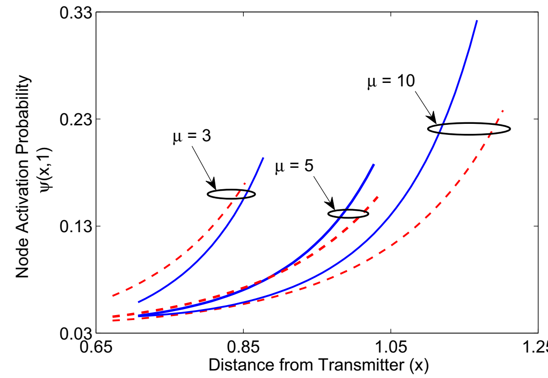

Fig. 4. Node activation probability of NA-BOLD. Red dashed line indicate $m = 0.5$, blue solid lines indicate $m = 1.0$.

IV. Performance Results

We evaluate performance in the Nakagami-m channel which can model a wide array of wireless channels, where the parameter m indicates the fading severity, with values ranging from $m = 0.5$ (most severe, half-Gaussian) to $m = \infty$ (no fading). The path loss exponent is $n = 4$ for all results. The channel capacity, expected value of the maximum transmission distance, and transport capacity are shown in Fig. 2 as a function of the target SNR κ in dB for both schemes. For these results, $\lambda = 20$.

For both the schemes, we find that the optimum target SNR only depends on the path-loss exponent n, and equals 16.9 dB when $n = 4$. This corresponds to an optimum transmission rate of 5.65 bit/s/Hz. Fig. 3 shows the maximized expected value of transport capacity as a function of μ for $\lambda = 30$ and $m = 0.5, 5.0$. The transport capacity gain of NA-BOLD over DISCO is less in a severely-faded channel $(m = 0.5)$ than in a less-faded channel with a strong LOS component $(m = 5.0)$. Note that for $\mu > 10$ receivers, the transport capacity of NA-BOLD is higher in a severely-faded channel than in a less-faded channel. This happens when $\mu > 9$ for the DISCO scheme. This is due to the multiuser diversity benefit obtained by both schemes in a fading channel in the presence of a large number of receivers.

To further investigate the effects of the number of receivers and the channel fading parameters in deciding which nodes to activate, we evaluate the node activation probability of NA-BOLD in Fig. 4 for large $(\mu = 10)$, medium $(\mu = 5)$ and small $(\mu = 3)$ numbers of receivers and for channels having fading figures $m = 0.5$ and $m = 1.0$ (Rayleigh fading). We find that for small μ, NA-BOLD is conservative for severe fading $(m = 0.5)$ and turns on more receivers close to the transmitter than for $m = 1.0$. However, for large μ, the reverse is observed. This illustrates the adaptivity of the NA-BOLD approach to the number of receivers to be activated as well as the severity of the channel fading.

V. Conclusions

We investigated the design of schemes to maximize the transport capacity on fading channels with geographic transmission and energy constraints. We extended our previously developed node activation based on link distance (NA-BOLD) from maximizing link distance on a Rayleigh channel to the more complicated problem of maximizing transport capacity on a Nakagami-m channel. We compared the NA-BOLD approach to a more-sophisticated DISCO approach than the DISC model we previously used, but still found that NA-BOLD outperformed the DISCO approach in terms of providing a higher transport capacity. We also proved some new constraints on when the fixed-node formulation can produce a unique maximizing distribution on the node distances.

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