A Distributed Relay-Assignment Algorithm for Cooperative Communications in Wireless Networks

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Abstract—**A crucial challenge in the implementation of a cooperative diversity protocol is how to assign source-relay pairs. In this paper, we address this problem under the knowledge of the users' spatial distribution and we propose a distributed relay-assignment algorithm for cooperative communications. In the proposed algorithm, the relay is chosen to be the nearest-neighbor to the user towards the base-station (access-point). An outage analysis for the proposed scheme is provided under a random spatial distribution for the users, and an approximate expression for the outage probability is derived. Simulation results for indoor wireless local area networks (WLAN) are provided. By utilizing the proposed protocol, simulation results indicate a significant gain in coverage area over the direct transmission scheme under fairly the same bandwidth efficiency and fixed average transmitted power. A 350% increase in the coverage area can be achieved by the distributed Nearest-neighbor protocols. This coverage increase can also be translated to energy efficiency over direct transmission when fixing the total coverage area.**

I. INTRODUCTION

Cooperative diversity has recently emerged as a new and effective technique to combat fading in wireless networks [1], [2], [3], [4], [5], [6], [7]. The basic idea is to explore the broadcast nature of the wireless channel. Laneman *et al.* [1], proposed different cooperative diversity protocols for single relay scenarios and analyzed their outage performance. Specifically, the authors in [1] proposed fixed and adaptive relaying protocols. Adaptive relaying protocols comprise selection relaying, in which the relay applies threshold tests on the measured channel state information to decide whether to transmit or not, and incremental relaying, in which limited feedback from the destination is employed in the form of automatic repeat request (ARQ).

In most of the previous works, the cooperating relays are just assumed to exist and are already coupled with the source nodes in the network. These works also assumed fixed *channel variances* between all of the nodes in the network, which implies a fixed network topology. If the random users' spatial distribution, and the associated propagation path losses between different nodes in the network are taken into consideration, then these assumptions, in general, are no longer valid.

In this paper, we address the relay-assignment problem for implementing cooperative diversity protocols to extend coverage area in wireless networks. We consider an uplink scenario where a set of users are trying to communicate to a base-station (BS) or access point (AP) and propose practical algorithms for the relay assignment. We propose a distributed relay-assignment protocol which we refer to as the Nearest-neighbor protocol. In this protocol, the helping user (relay) is chosen such as to be the nearest neighbor to the source towards the BS/AP. Although this choice might not be optimal in all scenarios, it is very simple to implement in a distributed manner and can achieve good performance as we will demonstrate later. Once the relay is assigned, *any* cooperation scheme can be employed. In this paper, we consider a modified version of the incremental relaying protocol proposed in [1]. In our modified scheme, if a user's packet is not captured by the BS/AP, the BS/AP is going to feedback a bit indicating the transmission failure. In this case, if the assigned relay has received the source's packet correctly, it will forward this packet to the BS/AP. Moreover, we do not assume the storage of the analog signal of the first transmitted packet to the BS/AP. As will be demonstrated later, the loss in the bandwidth efficiency is negligible in incremental relaying compared to that of direct transmission for practical ranges of the signal to noise ratio [1].

Furthermore, simulations are carried out to validate the theoretical results derived for the described protocol. We consider the application of the proposed protocol in coverage area extension in wireless networks. We consider an indoor WLAN scenario, and simulations show that up to 350% increase in the coverage area can be achieved by the proposed protocol. The rest of the paper is organized as follows. In Section II, we present the system model and describe the cooperation protocol. In Section III, we introduce the Nearest-Neighbor protocol and provide outage performance analysis for its performance. Simulation results are conducted in Section IV, and finally conclusions are drawn in Section V.

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II. SYSTEM MODEL

We consider a wireless network, that can be a cellular system or a WLAN, with a circular cell of radius ρ. The BS/AP is located at the center of the cell, and N users are uniformly distributed within the cell. The probability density function of the user's distance r from the BS/AP is thus given by

$$q(r) = \frac{2r}{\rho^2}, \qquad 0 \le r \le \rho, \tag{1}$$

and the user's angle is uniformly distributed between $[0, 2\pi)$. The wireless link between any two nodes in the network is subject to narrowband Rayleigh fading, propagation path-loss, and additive white Gaussian noise (AWGN). The channel fades for different links are assumed to be statistically mutually independent. This is a reasonable assumption as the nodes are usually spatially well separated. For medium access, the nodes are assumed to transmit over orthogonal channels, thus no mutual interference is considered in the signal model. All nodes in the network are assumed to be equipped with single-element antennas, and transmission at all nodes is constrained to the half-duplex mode, i.e., any terminal cannot transmit and receive simultaneously [1].

In the direct transmission scheme, which is employed in current wireless networks, each user transmits his signal directly to the BS/AP. The signal received at the destination d (BS/AP) from source user s, can be modeled as

$$y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}} h_{sd} x + n_{sd}; \tag{2}$$

where P_{TD} is the transmitted signal power in the direct transmission mode, x is the transmitted data with unit power, h_{ij} is the channel fading gain between two terminals i and j-i, j are any two terminals in the network. The channel fade of any link is modeled throughout the paper as a zero mean circularly symmetric complex Gaussian random variable with unit variance. In (2), K is a constant that depends on the antennas design, η is the path loss exponent, and r_{sd} is the distance between the two terminals. K, η, and P_{TD} are assumed to be the same for all users. The term n_{sd} in (2) denotes additive noise. All the noise components throughout the paper are modeled as white Gaussian noise (AWGN) with variance N_o.

In this paper we characterize the system performance in terms of outage probability. Outage is defined as the event that the received SNR falls below a certain threshold γ, hence, the probability of outage P_O is defined as,

$$\mathcal{P}_O = \mathcal{P}(\mathrm{SNR}(r) \le \gamma). \tag{3}$$

The SNR threshold γ is determined according to the application and the transmitter/receiver structure. If the received SNR is higher than the threshold γ, the receiver is assumed to be able to decode the received message with negligible probability of error. If an outage occurs, the packet is considered lost. The main drawback of direct transmission is that the BS/AP receives only one copy of the message from the source, which makes the communication susceptible to failure due to fading. On the other hand, when cooperative diversity is employed, the BS/AP can receive more than one copy of the message. Cooperative transmission, in general, comprises two stages: in the first stage the source transmits and both the relay and the destination receive, and in the second phase the relay, if necessary, forwards to the destination.

In this work, we adopt for the cooperating protocol a modified version of the incremental relaying protocol in [1]. In this modified protocol, if a user's packet is lost, the BS/AP broadcasts negative acknowledgement (NACK) so that the relay assigned to this user can re-transmit this packet again. The relay will only transmit the packet if it is capable of capturing the packet, i.e., if the received SNR at the relay is above the threshold. In practice, this can be implemented by utilizing a cyclic redundancy check (CRC) code in the transmitted packet. This is the first difference between the modified and original incremental relaying protocol in [1] which employs amplify-and-forward at the relay. The signal received from the source to the destination d and the relay l [1] in the first stage can be modeled as,

$$\begin{aligned} y_{sd} &= \sqrt{P_{TC} K r_{sd}^{-\eta}} h_{sd} x + n_{sd}, \\ y_{sl} &= \sqrt{P_{TC} K r_{sl}^{-\eta}} h_{sl} x + n_{sl}, \end{aligned} \tag{4}$$

where P_{TC} is the transmission power in the cooperative mode and will be determined rigourously later in order to ensure the same average transmitted power in both the direct and cooperative scenarios. If the SNR of the signal received at the destination from the source falls below the threshold γ, the destination asks for a second copy from the relay. Then if the relay was able to receive the packet from the source correctly, it forwards it to the destination

$$y_{ld} = \sqrt{P_{TC} K r_{ld}^{-\eta}} h_{ld} x + n_{ld}, \tag{5}$$

A second difference between our modified protocol and the conventional incremental relaying in [1], is that in case of packet failure in the first transmission from the source, the BS/AP does not store this packet to combine it later with the packet received from the relay. Storing the packet from the first transmission was assumed in most of the previous works on cooperative diversity, as it enhances the received SNR by applying a maximal ratio combiner, for example. However, a crucial implication of this assumption is that the destination has to store an analog form of the signal, which is not practical. This could be practically solved, for example, by storing a quantized version of the signal, and the quantization noise should then be taken into account in the analysis. Note that the relay-assignment algorithm that we develop in this paper can be applied with *any* cooperation scheme not only the modified incremental relaying that we discussed above.

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[1] We denote the relay by l not to confuse with r that denotes distance.

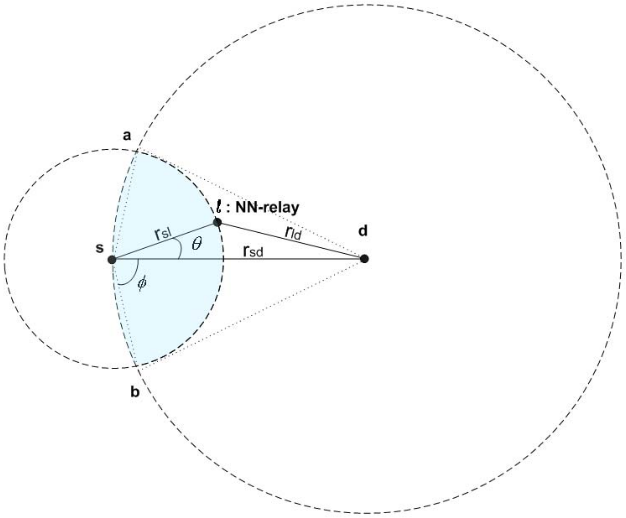

Fig. 1. Illustrating cooperation under nearest neighbor protocol: The nearest neighbor is located inside the circle of radius r_{sd} at a distance r_{sl} from the source. Therefore, the shaded area should be empty from any users.

III. NEAREST-NEIGHBOR PROTOCOL

We propose a simple distributed relay-assignment protocol. We assume that each user can know his distance to the BS/AP through, for example, calculating the average received power. According to this protocol, the assigned relay is chosen to be the nearest neighbor to the user towards the BS/AP. This can be done by a simple distributed protocol in which each relay sends out a "Hello" message searching for his nearest neighbors. This can be done using time of arrival (TOA) estimation for example, see [9] and [8]. The user selects the nearest neighbor node with a distance closer to the BS/AP than the user himself. For example, as illustrated in Fig. 1, a user at a distance r_{sd} from the BS/AP will choose his nearest neighbor inside the circle of radius r_{sd} with the BS/AP as its center. In this figure, the nearest neighbor is at a distance r_{sl} from the source. Each user will be assigned a relay to help him, and this nearest neighbor discovery algorithm can be run periodically according to the mobility of the users and how often they change their locations.

First, we derive an outage probability expression for the direct transmission scheme. As discussed before, the outage is defined as the event that the received SNR is lower than a predefined threshold which we denote by γ. From the received signal model in (2), the received SNR from a user at a distance r_{sd} from the BS/AP is given by

$$\text{SNR}(r_{sd}) = \frac{\mid h_{sd} \mid^2 K r_{sd}^{-\eta} P_{TD}}{N_o}, \tag{6}$$

where $\mid h_{sd} \mid^2$ is the magnitude square of the channel fade and follows an exponential distribution with unit mean. Hence, the outage probability for the direct transmission mode P_{OD} conditioned on the user's distance can be calculated as

$$\mathcal{P}_{OD}(r_{sd}) = \mathcal{P}\left(\text{SNR}(r_{sd}) \leq \gamma\right) = 1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{K P_{TD}}). \tag{7}$$

To find the average outage probability over the cell, we need to average over the user distribution in (1). The average outage probability is thus given by

$$\begin{aligned} \mathcal{P}_{OD} &= \int_0^{\rho} \mathcal{P}_{OD}(r_{sd}) q(r_{sd}) dr_{sd} \\ &= 1 - \frac{2}{\eta \rho^2} \left(\frac{K P_{TD}}{N_o \gamma} \right)^{\frac{2}{\eta}} \Gamma\left(\frac{2}{\eta}, \frac{N_o \gamma \rho^{\eta}}{K P_{TD}} \right), \end{aligned} \tag{8}$$

where $\Gamma(\cdot,\cdot)$ is the incomplete Gamma function, and it is defined as [10],

$$\Gamma(a, x) = \int_0^x \exp^{-t} t^{a-1} dt. \tag{9}$$

Now, we analyze the outage probability for the Nearest-Neighbor protocol. We can show that the outage probability expression, which we refer to as $\mathcal{P}_{ONN}$, for given source-relay-destination locations is given by

$$\begin{aligned} \mathcal{P}_{ONN}(r_{sd}, r_{sl}, r_{ld}) &= \left(1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{K P_{TC}}) \right) \\ &\times \left(1 - \exp(-\frac{N_o \gamma \left(r_{sl}^{\eta} + r_{ld}^{\eta} \right)}{K P_{TC}}) \right). \end{aligned} \tag{10}$$

We omit the derivation for space limitations. To find the total probability, we need to average over all possible locations of the user and the relay. The user's location distribution with respect to the BS/AP is still given as in the direct transmission case (1). The relay's location distribution, however, is not uniform. In the sequel we calculate the probability density function of the relay's location. According to our protocol, the relay is chosen to be the nearest neighbor to the user which is at a closer distance to the BS/AP, i.e., if the user is at a distance r_{sd} from the BS/AP then the relay is the nearest neighbor to the user in a circle of distance r_{sd} as illustrated in Fig. 1. The probability that the nearest neighbor is at distance r_{sl} from the source is equivalent to calculating the probability that the shaded area in Fig. 1 is empty.

Denote this area, which is the intersection of the two circles with centers s and d, by $A(r_{sd}, r_{sl})$. The area of intersection between the two circles can be divided into two parts: A_1 which is the sector $< asb >$ from the circle s, and A_2 which is the addition of the two small areas in circle d enclosed by the arcs $\widehat{as}$ and $\widehat{sb}$. The area of the sector $< asb >$ is given by

$$A_1 = \phi r_{sl}^2, \tag{11}$$

where ϕ is the angle $\angle dsb$. From the isosceles triangle $\triangle dsb$, it is straightforward to see that this angle is given by $\phi =$

$\arccos(r_{sl}/(2r_{sd}))$. The second part A_2 from circle d can be calculated from the total sector area $< dsa >$ less the triangular area $\triangle dsa$. Hence, area A_2 can be given as

$$A_2 = 2\left[(\frac{\pi}{2} - \phi)r_{sd}^2 - \frac{r_{sl}}{2}\sqrt{r_{sd}^2 - \frac{r_{sl}^2}{4}}\right]. \qquad (12)$$

Adding the two areas together, we get the total area expression as follows

$$\begin{aligned} A(r_{sd}, r_{sl}) =& r_{sl}^2 \arccos\left(\frac{r_{sl}}{2r_{sd}}\right) + \pi r_{sd}^2 \\ & - 2r_{sd}^2 \arccos\left(\frac{r_{sl}}{2r_{sd}}\right) - r_{sl}\sqrt{r_{sd}^2 + \frac{r_{sl}^2}{4}}. \end{aligned} \qquad (13)$$

Let the probability density function (PDF) of the nearest neighbor be denoted by the function $\mathcal{P}_{r_n}$, where r_n is a random variable denoting the nearest neighbor distance. Since we have N users uniformly distributed in a circular area of radius ρ, the probability of finding no users in an area $A(r_{sd}, r_{sl})$ is given by

$$\mathcal{P}_{r_n}(r_n \geq r_{sl}) = \left(1 - \frac{A(r_{sd}, r_{sl})}{\pi\rho^2}\right)^N. \qquad (14)$$

Hence the PDF of r_n can be calculated as

$$\begin{aligned} \mathcal{P}_{r_n}(r_{sl}) =& \frac{\partial \mathcal{P}_{r_n}(r_n \leq r_{sl})}{\partial r_{sl}} \\ =& \frac{N}{\pi\rho^2}\left(1 - \frac{A(r_{sd}, r_{sl})}{\pi\rho^2}\right)^{N-1} \frac{\partial A(r_{sd}, r_{sl})}{\partial r_{sl}}. \end{aligned} \qquad (15)$$

To find the outage probability as a function of the source distance r_{sd}, we need to average over all possible relay locations, which is specified by the pair of distances (r_{sl}, r_{ld}). Since a relay at a distance r_{sl} from the source is uniformly distributed over the angle $\theta = \angle dsl$ as in Fig. 1, it is much easier to determine the location of the relay in polar form with the source s being the origin. In this case the angle θ takes values between $-\arccos(\frac{r_{sl}}{2r_{sd}}) \leq \theta \leq \arccos(\frac{r_{sl}}{2r_{sd}})$. Hence, we can write the conditional outage probability in (10) in terms of θ instead of r_{ld} by substituting

$$r_{ld} = \sqrt{r_{sd}^2 + r_{sl}^2 - 2r_{sd}r_{sl}\cos(\theta)}. \qquad (16)$$

The value of r_{sl} can take values between 0 and $2r_{sd}$. Now, let us average the outage probability expression in (10) over all possible relay locations

$$\begin{aligned} \mathcal{P}_{ONN}(r_{sd}) = \int_0^{2r_{sd}} \frac{1}{2\arccos(\frac{r_{sl}}{2r_{sd}})} \int_{-\arccos(\frac{r_{sl}}{2r_{sd}})}^{\arccos(\frac{r_{sl}}{2r_{sd}})} \\ \mathcal{P}_{ONN}(r_{sd}, r_{sl}, \theta)\mathcal{P}_{rn}(r_{sl})d\theta d{r_{sl}}^2, \end{aligned} \qquad (17)$$

where $\mathcal{P}_{ONN}(r_{sd}, r_{sl}, \theta)$ is defined as the conditional outage probability in (10) after substituting for r_{ld} as a function of θ as in (16). The term $\mathcal{P}_{rn}(r_{sl})$ in (17) is defined in (15). To find the unconditional outage probability of the cell we average over all possible source locations

$$\mathcal{P}_{ONN} = \int_0^{\rho} \frac{2r_{sd}}{\rho^2}\mathcal{P}_{ONN}(r_{sd})dr_{sd}. \qquad (18)$$

The outage probability expression in (18) can only be calculated numerically. In the sequel, we derive an approximate expression for the outage probability under the following two assumptions. Since the relay is chosen to be the nearest neighbor to the source, the SNR received at the relay from the source is rarely below the threshold γ, hence, we assume that the event of the relay being in outage is negligible. The second assumption is that the nearest neighbor always lies on the intersection of the two circles, as points a or b in Fig. 1. This second assumption is a kind of worst case scenario, because a relay at distance r_{sl} from the source can be anywhere on the arc $\widehat{bla}$, and a worst case scenario is to be at points a or b because these are the furthest points from the BS/AP on the arc $\widehat{bla}$. This simplifies the outage calculation as the conditional outage probability (10) is now only a function of the source distance r_{sd} as follows

$$\mathcal{P}_{ONN}(r_{sd}) \simeq \left(1 - \exp(-\frac{N_o\gamma r_{sd}^{\eta}}{KP_{TC}})\right)^2 \qquad (19)$$

Substituting (19) into (18), and using the definition of the incomplete Gamma function in (9), we get

$$\begin{aligned} \mathcal{P}_{ONN} \simeq& 1 - \frac{4}{\eta\rho^2}\left(\frac{KP_{TC}}{N_o\gamma}\right)^{\frac{2}{\eta}} \Gamma\left(\frac{2}{\eta}, \frac{N_o\gamma\rho^{\eta}}{KP_{TC}}\right) \\ & + \frac{2}{\eta\rho^2}\left(\frac{KP_{TD}}{2N_o\gamma}\right)^{\frac{2}{\eta}} \Gamma\left(\frac{2}{\eta}, \frac{2N_o\gamma\rho^{\eta}}{KP_{TD}}\right), \end{aligned} \qquad (20)$$

This approximation is tight as will be shown by computer simulations in the next section.

IV. SIMULATIONS

We performed some computer simulations to compare the performance of the proposed relay-assignment protocol and direct transmission, and validate the theoretical results we derived in the paper. In all of our simulations, we compared the outage performance of two different transmission schemes: Direct transmission and the Nearest-Neighbor protocol. Along with the simulation curves, we also plotted the theoretical outage performance that we derived throughout the paper for the two schemes. In all of the simulations, the channel between any two nodes (either a user and the BS/AP or two users) is modeled as a random Rayleigh fading channel with unit variance.

For fairness in comparison between the proposed cooperative schemes and the direct transmission scheme, the average transmitter power is kept fixed in both cases and this is done as follows. Since a packet is either transmitted once or twice in the cooperative protocol, the average transmitted power in the cooperative case can be calculated as

$$\begin{aligned} E(\text{TX Power}) =& P_{TC}\mathcal{P}\left(\text{Source only transmits}\right) \\ &+ 2P_{TC}\mathcal{P}\left(\text{Source and Relay transmit}\right). \end{aligned} \tag{21}$$

The event that the source only transmits is the union of the events that the $s-d$ link is not in outage, or both the $s-d$ and $s-l$ links are in outage. Hence, the probability of this event can be given by

$$\begin{aligned} \mathcal{P}\left(\text{Source only transmits}\right) =& 1 - \mathcal{P}_{OD}^{sd}(P_{TC}) \\ &+ \mathcal{P}_{OD}^{sd}(P_{TC})\mathcal{P}_{OD}^{sl}(P_{TC}), \end{aligned} \tag{22}$$

where $\mathcal{P}_{OD}^{sd}(P_{TC})$ denotes the outage probability of the direct transmission between the source and the destination when the source is using transmitting power P_{TC} in the cooperative mode, and $\mathcal{P}_{OD}^{sl}(P_{TC})$ denotes the corresponding probability for the $s-l$ link. The event that both the source and the relay transmit is just the complement of the previous event-it is the event that the $s-d$ link is in outage and the $s-l$ link is not. It is thus given by

$$\mathcal{P}\left(\text{Source and Relay transmit}\right) = \mathcal{P}_{OD}^{sd}(P_{TC})(1 - \mathcal{P}_{OD}^{sl}(P_{TC})). \tag{23}$$

Substituting (22) and (23) into (21), the average transmitted power in the cooperative mode can be given by

$$\begin{aligned} E(\text{TX Power}) =& P_{TC}(1 + \mathcal{P}_{OD}^{sd}(P_{TC}) \\ &- \mathcal{P}_{OD}^{sd}(P_{TC})\mathcal{P}_{OD}^{sl}(P_{TC})). \end{aligned} \tag{24}$$

The power used in transmitting in the direct scheme P_{TD} should be set equal to the quantity in (24) in order to have the same average transmitted power. One can see that $P_{TD} \geq P_{TC}$ as expected. In our simulations, we set $P_{TD} = P_{TC}\left(1 + \mathcal{P}_{OD}^{sd}(P_{TC})\right)$ which is in favor of the direct transmission.

A remark on the bandwidth efficiency is now in order. Note that for the cooperative scheme we either utilize the same resources as the direct transmission mode or twice these resources with the same probabilities defined in (22) and (23). This means that the relation between the bandwidth efficiency of the direct and cooperative transmissions is also governed in the same manner as for the power in (24). For practical outage performance in the range of 0.01, the loss in the bandwidth efficiency is thus negligible and we do not take it into account in our simulations.

We consider a WLAN scenario for our simulations. The cell radius is taken between 10m and 100m. The additive white Gaussian noise has variance $N_o = -70$dBm and the path loss exponent was set to $\eta = 2.6$. The number of users in the cell attached to the AP was taken to be $N = 10$. The SNR threshold γ was taken to be 20dB which is higher than that for the cellular system, since the information transmitted over a wireless LAN is usually data, which needs higher quality than voice signals usually transmitted over cellular systems.

Next, we discuss the simulation results for the wireless LAN that are demonstrated in Figs. 2-5. Figs. 2 and 3 depict the results for fixed average transmitted power of 10mW and 30mW, respectively. For the 10mW case, if we require the outage performance to be around 0.001 in this case, data quality, then the maximum cell size achieved by the direct transmission case is about 20m. The Nearest-neighbor protocol can achieve about 70m. Hence, the cooperation scheme can increase the cell size by about 350% in this case. The theoretical curves still match our expectations which validates our analysis. Fig. 3 depicts the results for the 30mw case. At 0.001 outage performance, the cell-radius can increase to 30m by direct transmission, while the Nearest-neighbor protocol can extend the cell-radius to more that 100m.

Next, we study the gains that can be achieved from the proposed protocols in terms of energy efficiency. Figures 4 and 5 depict the results for a cell radius of 50m and 100m, respectively. The average transmitted power is changed from 5mW (7dBm) to 30mW (14.7dBm). For both the 50m and 100m cases, it can be seen from the figures that the direct transmission scheme can no longer achieve the 0.001 outage performance for the whole simulated power range. For the 50m case in Fig. 4, the Nearest-neighbor can achieve this performance at less than 5mW (7dBm). For the 100m case in Fig. 5, the Nearest-neighbor requires around 14dBm.

V. CONCLUSIONS

In this paper, we propose a distributed Nearest-Neighbor protocol for relay-assignments in cooperative communications. In the proposed protocol the relay is selected to be the nearest neighbor to the user towards the BS/AP. Outage performance analysis is provided for the proposed protocol. We show that the bandwidth efficiency loss due to cooperation is negligible for practical operation conditions, for an outage probability of 0.01 the loss in the bandwidth efficiency is approximately 0.01. Moreover, simulation results are carried for a wireless LAN scenario. Under the same average transmitted power, simulation results reveal an increase in the coverage area up to 350%. Our theoretical calculations match the simulation results.

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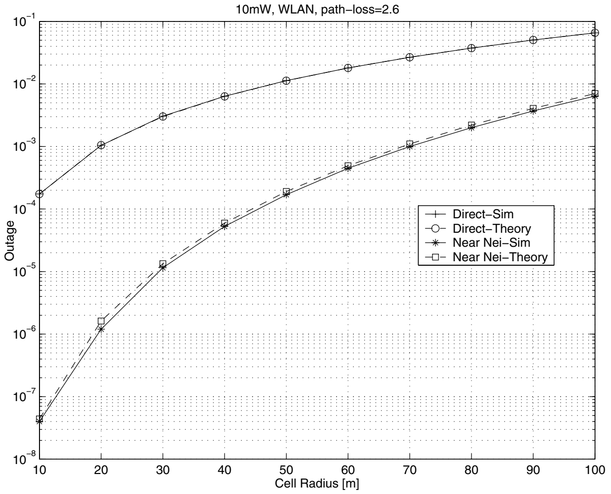

Fig. 2. Average outage probability versus the cell radius in m for direct and cooperative transmissions. Simulation curves are drawn in solid lines and theoretical curves in dotted lines. The average transmitter power is fixed to 10mW and the path loss is set to 2.6.

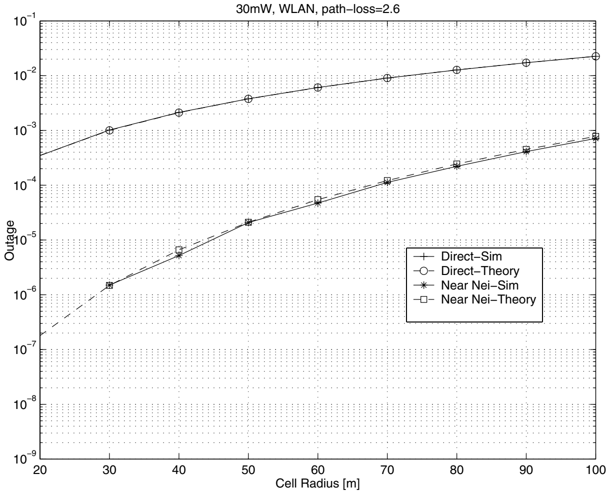

Fig. 3. Average outage probability versus the cell radius in m for direct and cooperative transmissions. Simulation curves are drawn in solid lines and theoretical curves in dotted lines. The average transmitter power is fixed to 30mW and the path loss is set to 2.6.

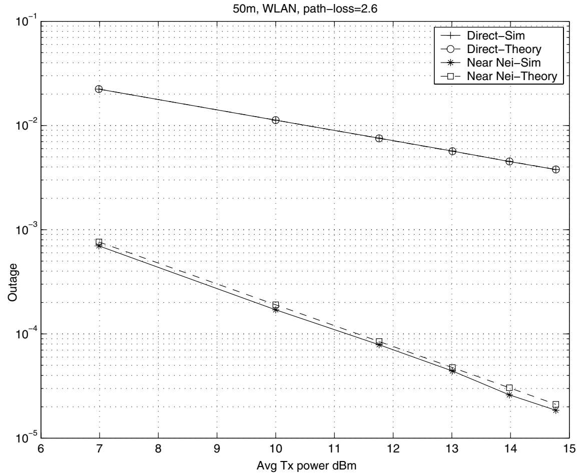

Fig. 4. Average outage probability versus the transmitted power in dBm for direct and cooperative transmissions. Simulation curves are drawn in solid lines and theoretical curves in dotted lines. The cell radius is fixed to 50m and path loss is set to 2.6.

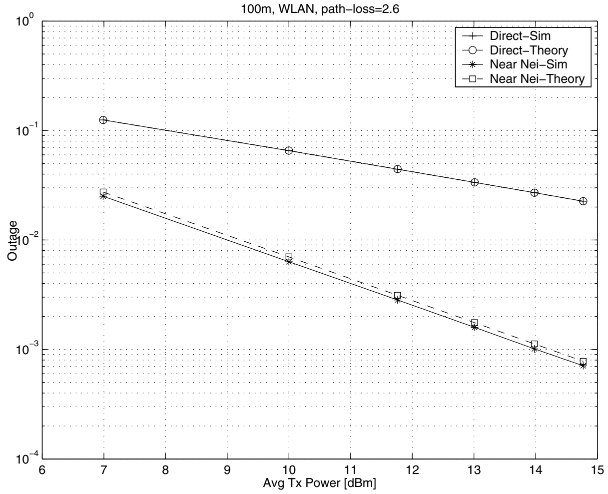

Fig. 5. Average outage probability versus the transmitted power in dBm for direct and cooperative transmissions. Simulation curves are drawn in solid lines and theoretical curves in dotted lines. The cell radius is fixed to 100m and path loss is set to 2.6.

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