Distributed Scheduling Algorithm for Cooperative Transmission with Multiple Relays

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***Abstract*— Cooperative transmission can improve the performance of wireless ad-hoc systems due to its spatial multiplexing gain. Given that multiple cooperative relays which belong to the same source-destination pair can transmit simultaneously in the cooperative transmission, it is different from normal data transmission in which only one source node transmits in a single source-destination pair. Therefore, a new distributed scheduling algorithm for wireless ad-hoc systems should be devised. To this end, we propose a distributed scheduling algorithm for wireless ad-hoc systems with cooperative transmission in which multiple cooperative relays can transmit at the same time by using Amplify-and-Forward or Decode-and-Forward scheme. By using the elastic exclusive distance which is the minimum distance between two active cooperative transmission sets, the outage probability of cooperative transmissions can be greatly reduced compared to that of conventional scheduling scheme. Through performance analysis and simulation results, we show that the proposed scheme can enhance the performance of the system.**

I. Introduction

In this paper, we study a distributed scheduling algorithm for wireless ad-hoc systems that utilizes cooperative transmission in which multiple cooperative relays are utilized [1] to increase the quality of link between a source node and a destination node. This kind of user cooperation has been extensively studied in previous literatures [1] [2]. By utilizing user cooperation, spatial diversity gain can be obtained in single antenna systems because multiple nodes can transmit the same signal at the same time [1] and hence the performance of the system can be greatly improved.

In the cooperative transmission, cooperative relays should relay the signal transmitted from a source node to a destination node. To this end, Amplify-and-Forward (AF) or Decode-and-Forward (DF) relay scheme can be used, which are one of the most popular relaying protocol. In the AF scheme, each cooperative relay simply amplifies the received signal and retransmits this amplified signal, thus this scheme has low complexity [2]. On the other hand, in the DF scheme, each cooperative relay decodes the received signal and retransmits the decoded signal, thus this scheme will require higher complexity compared to the AF scheme [2]. In this paper, we consider both the case in which the AF scheme is used and the case in which the DF scheme is used.

Many studies on the distributed scheduling algorithm for wireless ad-hoc systems have been carried out [3] [4]. In [3], the authors considered CSMA-based distributed scheduling algorithm for MIMO multi-hop network. In this paper, the authors used a MIMO pipe line model and a SINR model to reduce computational complexity and improve the performance of system. In [4], the authors proposed an REX scheduling algorithm for WPAN devices which utilize a directional antenna. By using the concept of exclusive region, significant multiplexing gain can be achieved [4]. However, little work has been done on the distributed scheduling for wireless systems which utilize cooperative transmission, although the system has distinct characteristics compared to the system without the cooperative transmission. Given that multiple cooperative relays will transmit at the same time when the cooperative transmission is used, interference caused by a single source-destination pair will increase compared to that without the cooperative transmission, and this effect should be taken into account in scheduling.

To this end, we propose a new distributed scheduling algorithm for wireless ad-hoc systems with cooperative transmission. In our proposed scheme, we use the concept of exclusive distance so that two nodes cannot be active at the same time if the distance between two nodes is less than the exclusive distance. The exclusive distance varies according to a relaying scheme used and the number of cooperative relays. By using our proposed scheme, the outage probability of cooperative transmissions can be reduced compared to the conventional scheduling which does not consider the cooperative transmission.

This paper is organized as follows. In Section II, we describe the problem of distributed scheduling that we consider, and describe our proposed distributed scheduling scheme. In Section III and IV, we derive exclusive distance for the cases when DF and AF are used in cooperative relays. Simulation results are shown and discussed in Section V, and conclusions follow in Section VI.

II. Problem Description and Proposed Scheme

In this paper, we consider the problem of distributed scheduling for wireless ad-hoc systems in which nodes can utilize cooperative transmission. In general, a centralized entity which manages the scheduling of nodes does not exist in wireless ad-hoc systems and the node scheduling should be done in distributed manner. A CSMA-based scheduling scheme is one of the most widely used distributed scheduling

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scheme for wireless ad-hoc systems. This kind of scheduling scheme can be used without any problem if all the transmission pairs are composed of only two nodes, which are a source node and a destination node. However, when the nodes utilize cooperative transmission, transmission pairs will be composed of more than just two nodes due to cooperative relays and conventional CSMA-based scheduling schemes may not work properly. In this paper, we refer the transmission set which is composed of one source node, one destination node and multiple cooperative relays as a cooperative transmission set to distinguish it from a normal transmission set without the cooperative relays.

Given that nodes in the same cooperative transmission set should be active at the same time, conventional CSMA-based scheduling schemes cannot be directly applied when cooperation is used. And unlike the conventional CSMA-based scheduling which considers that only one node transmits in one source-destination pair, multiple nodes can transmit the same signal at the same time when cooperative transmission is used. Therefore, interference which is caused by active source-destination pair will become larger. Thus, the outage probability of links will increase due to increased interference if we utilize the conventional CSMA-based scheduling. Therefore, a new distributed scheduling algorithm which considers the cooperative transmission is needed and we propose a new scheduling scheme which will be given in the following.

Before describing our proposed scheme, we will describe assumptions that we used. In this paper, we assume two hop relay systems as shown in Fig.1 and assume that N cooperative relays exist for one cooperative transmission set. The value of N can be different for each cooperative transmission set. And we assume that these relays can use either AF or DF scheme and the cooperative relays operate in half-duplex manner, so that a source node transmits data to cooperative relays first and then these relays retransmit the data from the source node to a destination node. In half-duplex case, interference between active cooperative transmission sets can be caused by the single source node or N cooperative relays. However, we only consider the interference when N cooperative relays transmit to reflect the interference in worst case. Also, our proposed scheme can easily be extended to full-duplex case.

We also assume that the transmission power of nodes is normalized to one and assume that nodes in the same cooperative transmission set are closely located to each other so that the distance between the nodes in the same cooperative transmission set is much smaller compared to the distance between nodes which belong to the different cooperative transmission sets. Therefore, we assume that the distance between nodes in the same cooperative transmission set is one and that the distance between nodes in the different cooperative transmission sets is d where $d \gg 1$, as shown in Fig.1.

In this paper, we propose a distributed scheduling scheme which guarantees the interference from a neighboring cooperative transmission set to be less than $\gamma \cdot N_0W$, which is the tolerable interference level [3], with probability $1-P_{out}$ where N_0W is the noise power. To this end, we define exclusive distance, d^{ex}, which is the minimum distance between two cooperative transmission sets to be active at the same time.

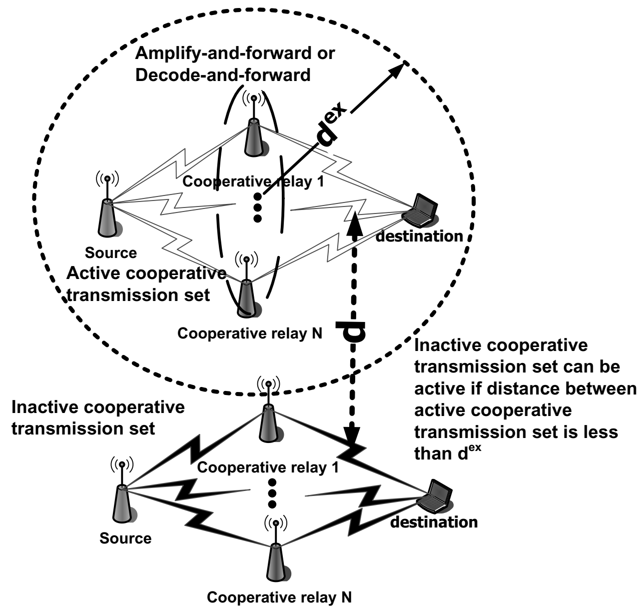

Fig. 1. System description that we consider in this paper

It is similar to the exclusive region in [4]. The value of d^{ex} changes according to the number of cooperative relays, N. If N is large, d^{ex} should become larger because the interference between active cooperative transmission sets becomes larger.

In our proposed scheme, active cooperative transmission sets periodically broadcast the location information and information related to d^{ex}, so that neighboring inactive cooperative transmission sets can derive d^{ex} from this information. Given that d^{ex} is related to γ and γ can be changed according to the environmental changes such as interference level, d^{ex} should be updated periodically according to the environmental changes. The value of d^{ex} can be different for each inactive cooperative transmission set depending on its N. Then, an inactive cooperative transmission set checks whether the distance between it and its neighboring active cooperative transmission set is larger than d^{ex}, and it becomes active if the distance is larger than d^{ex}, as shown in Fig.1. Therefore, determining proper d^{ex} value which makes the interference from a neighboring cooperative transmission set to be less than $\gamma \cdot N_0W$ with probability $1 - P_{out}$ is important. In the following two sections, we will find a proper d^{ex} for the case when cooperative relays utilize a DF scheme and for the case when cooperative relays utilize an AF scheme.

III. Exclusive Distance in Decode-and-Forward

When cooperative relays utilize a DF scheme, each cooperative relay decodes the signal received from a source node and retransmits the decoded signal to a destination node. Given that all the cooperative relays and the destination node should decode the signal, we use exclusive distance, d^{ex}, which makes the interference from neighboring cooperative transmission relays to be less than $\gamma \cdot N_0W$ with the probability $1 - P_{out}$, for all the cooperative relays and the destination node.

For DF case, interference which is received by the cooperative relays and the destination node, I_{co}, which is caused by neighboring active cooperative transmission relays can be written as follows:

$$I_{co} \quad = \quad (|\sum_{i=1}^{N} h_i|)^2 \cdot \kappa \cdot d^{-\alpha} \tag{1}$$

where κ is the path loss constant, α is the path loss exponent, and h_i is the fading coefficient between i-th interfering cooperative relay and the node which receives the interference. We assume that h_i is an independent zero-mean circularly symmetric complex Gaussian random variable with variances one. Then, $|\sum_{i=1}^{N} h_i|$ becomes a random variable h_{sum} which has Rayleigh distribution with $\sigma^2 = \frac{N}{2}$ [7].

Given that the purpose of our proposed scheduling scheme is to maintain the amount of interference from neighboring active cooperative transmission relays to be less than $\gamma \cdot N_0 W$ with the probability $1 - P_{out}$, following equation should be satisfied:

$$1 - e^{-(\frac{\gamma \cdot N_0 \cdot W}{\kappa \cdot d^{-\alpha}})/N} \quad \geq \quad 1 - P_{out} \tag{2}$$

Then, d^{ex} can be found by using the following inequality:

$$\begin{array}{lll} \log(P_{out}) & \geq & -(\frac{\gamma \cdot N_0 \cdot W}{\kappa \cdot (d^{ex})^{-\alpha}})/N \\ N \log(\frac{1}{P_{out}}) & \leq & (d^{ex})^{\alpha} \cdot \frac{\gamma \cdot N_0 \cdot W}{\kappa} \\ d^{ex} & \geq & N^{\frac{1}{\alpha}} \cdot \sqrt[\alpha]{\log(\frac{1}{P_{out}}) \cdot \frac{\kappa}{\gamma \cdot N_0 \cdot W}} \end{array} \tag{3}$$

Thus, the d^{ex} can be calculated as $N^{\frac{1}{\alpha}} \cdot \sqrt[\alpha]{\log(\frac{1}{P_{out}}) \cdot \frac{\kappa}{\gamma \cdot N_0 \cdot W}}$. Thus, neighboring inactive cooperative transmission sets can calculate d^{ex} based on $\sqrt[\alpha]{\log(\frac{1}{P_{out}}) \cdot \frac{\kappa}{\gamma \cdot N_0 \cdot W}}$ even though they have different N values. Therefore active cooperative transmission sets only need to broadcast its own $\sqrt[\alpha]{\log(\frac{1}{P_{out}}) \cdot \frac{\kappa}{\gamma \cdot N_0 \cdot W}}$ which is the same as d^{ex} when $N = 1$, and a neighboring inactive cooperative transmission set can calculate d^{ex} based on $\sqrt[\alpha]{\log(\frac{1}{P_{out}}) \cdot \frac{\kappa}{\gamma \cdot N_0 \cdot W}}$ and its N. And the neighboring inactive cooperative transmission set becomes active if the distance between it and the neighboring active cooperative transmission set is larger than d^{ex}.

IV. Exclusive Distance in Amplify-and-Forward

When cooperative relays utilize an AF scheme, each cooperative relay amplifies the signal received from a source node and retransmits this amplified signal to a destination node. Given that only the destination node decodes the signal, we find d^{ex} by considering the decodability of the destination node only.

For AF case, the received signal of k-th relay can be written as follows:

$$y_k \quad = \quad f_{S,k} \cdot x + f_{I,k} \cdot x^I + n_k \tag{4}$$

where x is the transmitted signal, x^I is the interference signal and n_k is the noise which can be modelled as an additive white Gaussian noise whose mean is zero and variance is $N_0 W$. Given that we normalize the transmission power to one, $E|xx'| = E|x^I (x^I)'| = 1$. Moreover, $f_{S,k}$ and $f_{I,k}$ denote the channel coefficient terms for the link between the source node and the k-th relay, and the link between the interferer and the k-th relay, respectively. The terms $f_{S,k}$ and $f_{I,k}$ can be represented as $\frac{\sqrt{\kappa} h_{S,k}}{d_{S,k}^{\frac{\alpha}{2}}}$ and $\frac{\sqrt{\kappa} h_{I,k}}{d_{I,k}^{\frac{\alpha}{2}}}$, respectively, where $d_{S,k}$ and $d_{I,k}$ are the distance between the source node and k-th relay and the distance between the interferer and k-th relay, respectively [5]. As we have stated above, we assume $d_{S,k}$ to be one and $d_{I,k}$ to be d to simplify the analysis. Moreover, $h_{S,k}$ and $h_{I,k}$ are the fading coefficient which we assume to be independent zero-mean circularly symmetric complex Gaussian random variables with variances one and N, respectively. Given that N cooperative relays in neighboring cooperative transmission set transmit the same signal, the variance of $h_{I,k}$ should be N.

The y_k in eq.(4) is amplified by the amplification factor G and then transmitted to the destination node. In general, $G = \sqrt{\frac{1}{|f_{S,k}|^2 + |f_{I,k}|^2 + N_0 W}}$ [2]. However, for simplicity, we assume that G is fixed and all the cooperative relays have the same G value. Based on eq.(4), received signal at the destination node can be written as follows [2]:

$$\begin{array}{lll} y_D & = & \sum_{k=1}^{K} f_{k,D}(G y_k) + f_{I,D} \cdot x^I + n_D \\ & = & (\sum_{k=1}^{K} f_{k,D}(G f_{S,k})) \cdot x \\ & & +(\sum_{k=1}^{K} f_{k,D}(G f_{I,k}) + f_{I,D}) \cdot x^I \\ & & +(\sum_{k=1}^{K} f_{k,D}(G n_k)) + n_D \end{array} \tag{5}$$

where n_D is the noise which can be modelled as an additive white Gaussian noise whose mean is zero and variance is $N_0 W$. Moreover, $f_{k,D}$ and $f_{I,D}$ denote the channel coefficient terms for the link between the destination node and the k-th relay, and the link between the destination node and the interferer, respectively. Although the interference signal x^I at the destination nodes can be different from that at the relay, we assume that these two x^I are the same to consider the worst interference case. The terms $f_{k,D}$ and $f_{I,D}$ can be represented as $\frac{\sqrt{\kappa} h_{k,D}}{d_{k,D}^{\frac{\alpha}{2}}}$ and $\frac{\sqrt{\kappa} h_{I,D}}{d_{I,D}^{\frac{\alpha}{2}}}$, respectively, where $d_{k,D}$ and $d_{I,D}$ are the distance between the destination node and k-th relay and the distance between the interferer and the destination node, respectively. We assume $d_{k,D}$ to be one and $d_{I,D}$ to be d. Moreover, $h_{k,D}$ and $h_{I,D}$ are the fading coefficient which we assume to be independent zero-mean circularly symmetric complex Gaussian random variables with variances of one and N, respectively.

From eq.(5), we can find that interference due to neighboring cooperative transmission relays can be summarized as $(\sum_{k=1}^{K} f_{k,D}(G f_{I,k}) + f_{I,D}) \cdot x^I$. Then, the interference power can be calculated as $E|((\sum_{k=1}^{K} f_{k,D}(G f_{I,k}) + f_{I,D}) \cdot x^I)((\sum_{k=1}^{K} f_{k,D}(G f_{I,k}) + f_{I,D}) \cdot x^I)'| = |(\sum_{k=1}^{K} f_{k,D} G f_{I,k} + f_{I,D})(\sum_{k=1}^{K} f_{k,D} G f_{I,k} + f_{I,D})'|$. Given that the purpose of our proposed scheduling scheme is to maintain the interference power from neighboring cooperative transmission relays to be less than $\gamma \cdot N_0 W$ with probability $1 - P_{out}$, we need to find the CDF of $|(\sum_{k=1}^{K} f_{k,D} G f_{I,k} + f_{I,D})(\sum_{k=1}^{K} f_{k,D} G f_{I,k} + f_{I,D})'|$. Since maintaining the interference power to be less than $\gamma \cdot N_0 W$ is equivalent to maintaining $|\sum_{k=1}^{K} h_{k,D} h_{I,k} + \frac{h_{I,D}}{G}|$ to be less than $\frac{\sqrt{\gamma \cdot N_0 W \cdot d^{\alpha}}}{\sqrt{\kappa} \cdot G}$, we need to find the CDF of $|\sum_{k=1}^{K} h_{k,D} h_{I,k} + \frac{h_{I,D}}{G}|$. Given that $h_{k,D}$, $h_{I,k}$ and $h_{I,D}$ are complex values, it is hard to obtain the CDF. Therefore, we relax the equation and assume that the phase of $h_{k,D}$, $h_{I,k}$ and $h_{I,D}$ are all the same and only consider the magnitude of these random variables. In this case, $|\sum_{k=1}^{K} h_{k,D} h_{I,k} + \frac{h_{I,D}}{G}|$

becomes $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$. Given that $h_{k,D}$, $h_{I,k}$ and $h_{I,D}$ are the independent zero-mean circularly symmetric complex Gaussian random variables, $|h_{k,D}|$, $|h_{I,k}|$ and $|h_{I,D}|$ will have Rayleigh distribution with $\sigma^2=\frac{1}{2}$, $\sigma^2=\frac{N}{2}$, and $\sigma^2=\frac{N}{2}$, respectively. Then, the pdf of $|h_{k,D}|\cdot|h_{I,k}|$ can be found as follows [6]:

$$\frac{2r}{N}\cdot K_0\left(\frac{r}{\sqrt{N/2}}\right) \tag{6}$$

where K_0 is the modified Bessel function of second kind. And the moment generating function of eq.(6) can be found as follows:

$$\frac{\sqrt{\frac{N}{2}}\cdot s\log(\sqrt{\frac{N}{2}}\cdot s+\sqrt{\frac{N}{2}\cdot s^2-1})-\sqrt{\frac{N}{2}\cdot s^2-1}}{(\frac{N}{2}\cdot s^2-1)^{\frac{3}{2}}} \tag{7}$$

Then, the moment generating function of the random variable $|\frac{h_{I,D}}{G}|$ can be found as follows [7]:

$$G\cdot(1+G\cdot\sqrt{\frac{N}{2}}\cdot s\cdot e^{\frac{(G\cdot\sqrt{\frac{N}{2}}\cdot s)^2}{\pi}}(erf(\frac{G\cdot\sqrt{\frac{N}{2}}\cdot s}{\sqrt{\pi}})+1) \tag{8}$$

where $erf(x)$ is the error function which can be represented as $erf(x)=\frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$. By using eq.(7) and eq.(8), the moment generating function of $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$ can be easily derived, because $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$ is the sum of random variables and the moment generating function of $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$ can be found by multiplying the moment generating function of the random variables [7]. Therefore, the moment generating function of $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$, which we denote as $H_{cum}(s)$, can be found as follows:

$$\begin{aligned} H_{cum}(s) &= \prod_{k=1}^{K}\frac{\sqrt{\frac{N}{2}}\cdot s\log(\sqrt{\frac{N}{2}}\cdot s+\sqrt{\frac{N}{2}\cdot s^2-1}-\sqrt{\frac{N}{2}\cdot s^2-1}}{(\frac{N}{2}\cdot s^2-1)^{\frac{3}{2}}} \\ &\times G\cdot(1+G\cdot\sqrt{\frac{N}{2}}\cdot s\cdot e^{\frac{(G\cdot\sqrt{\frac{N}{2}}\cdot s)^2}{\pi}}(erf(\frac{G\cdot\sqrt{\frac{N}{2}}\cdot s}{\sqrt{\pi}})+1)) \end{aligned} \tag{9}$$

The PDF of $\sum_{k=1}^{K}|h_{k,D}||h_{I,k}|+|\frac{h_{I,D}}{G}|$ can be found as $\zeta^{-1}(H_{cum}(s))$ where $\zeta^{-1}(s)$ is the inverse Laplace transform. Thus, we can find τ which makes $\int_{-\infty}^{\tau}\zeta^{-1}(H_{cum}(s))=1-P_{out}$ and d^{ex} can be obtained as $(\frac{\tau\cdot G\cdot\sqrt{\kappa}}{\sqrt{\gamma N_0 W}})^{\frac{2}{\alpha}}$. Unlike DF case, when AF scheme is used in cooperative transmission relays, active cooperative transmission set should send d^{ex} for all possible values of N because neighboring cooperative transmission set cannot derive d^{ex} for arbitrary N by using single d^{ex} value. Thus, active cooperative transmission set needs to send d^{ex} for different N values and a neighboring inactive cooperative transmission set can find d^{ex}. And the neighboring inactive cooperative transmission set becomes active if the distance between it and the neighboring active cooperative transmission set is larger than d^{ex}.

V. Performance Evaluation

In the performance evaluation, we evaluate the performance of proposed scheme in the various environment. In this performance evaluation, we assume that the transmission in one link is failed when the interference is larger than $\gamma\cdot N_0W$ and assume that data transmission in cooperative transmission set is failed even if only one of the links in cooperative transmission set is failed when a DF scheme is utilized. Also, we consider conventional scheme and optimal scheme, for comparison. The optimal scheme is the optimal scheduling scheme which maximizes the number of active cooperative transmission sets without inducing the outage. Although the performance of this optimized scheme is better than any other schemes, the usage of this optimized scheme is limited because it is centralized scheduling scheme and it requires much higher computational complexity compared to other schemes. The conventional scheme is the scheduling scheme which does not consider cooperative relays and it is the same as the proposed scheme except the fact that it decides d^{ex} by assuming that N is one.

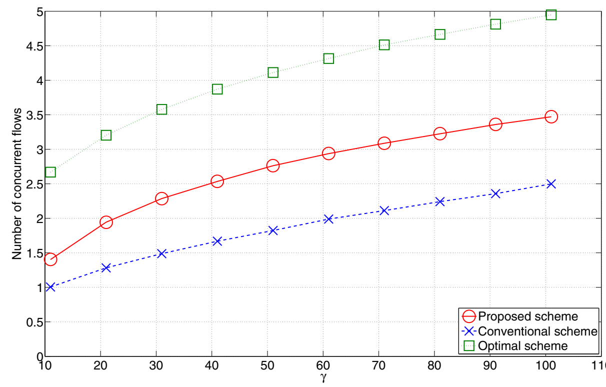

Fig. 2. Number of concurrent flows vs. γ which is the tolerable interference level when DF is used

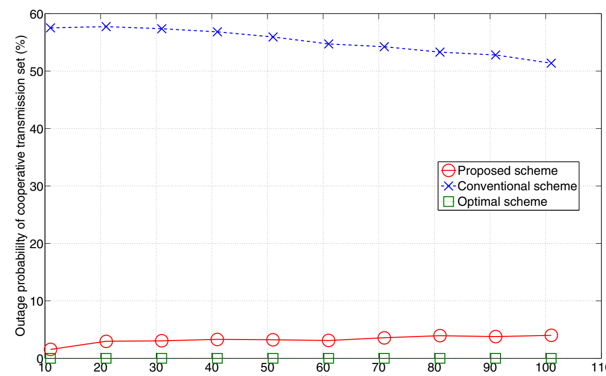

Fig. 3. Outage probability of cooperative transmission sets vs. γ which is the tolerable interference level when DF is used

First, we observe the number of concurrent flows and the outage probability of cooperative transmission sets by varying γ when the DF scheme is used. The number of concurrent flows denotes the number of cooperative transmission sets that coexist without the outage. In this simulation, we randomly place 10 cooperative transmission sets with $N=3$ in 10 x 10 square area. We also let N_0W be -30dB, $\kappa=1$, $\alpha=3$ and $P_{out}=0.1$ [5]. The simulation results are shown in Fig.2 and Fig.3.

As we can see from Fig.2, the optimal scheme shows the largest number of concurrent flows, and the proposed scheme has more concurrent flows compared to a conventional scheme.

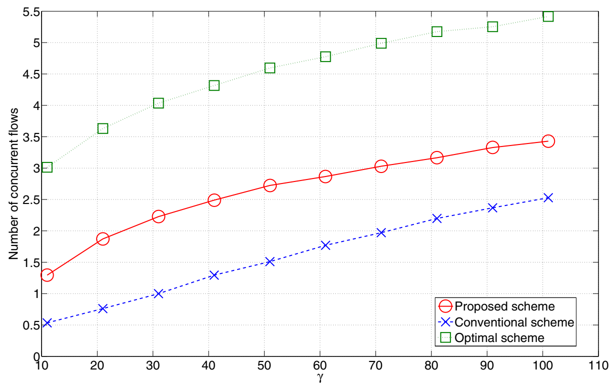

Fig. 4. Number of concurrent flows vs. γ which is the tolerable interference level when AF is used

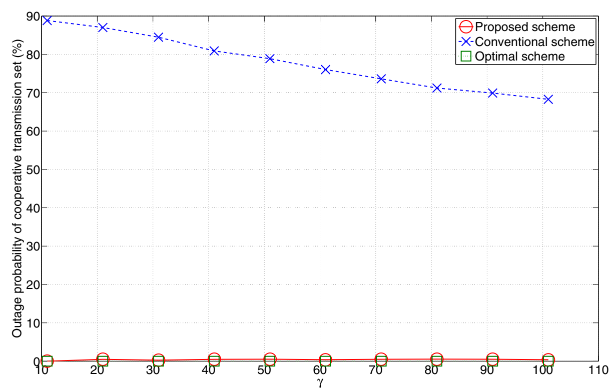

Fig. 5. Outage probability of cooperative transmission sets vs. γ which is the tolerable interference level when AF is used

By using our proposed scheme, the number of concurrent flows can be increased by 50% compared to the conventional scheme. And we can find that the number of concurrent flows increases as γ increases because as γ increases, more cooperative transmission set can coexist. And as we can see from Fig.3, our proposed scheme shows lower outage probability which is less than P_{out} while the conventional scheme shows much higher outage probability. We can also see that the outage probability of proposed scheme increases when γ is increased from 10 to 20, because when $\gamma = 10$, only one cooperative set is likely to be active and hence the outage probability becomes low.

Next, we observe the number of concurrent flows and the outage probability of cooperative transmission set by varying γ when AF is used. In this simulation, we randomly place 10 cooperative transmission sets with $N = 3$ in 20 x 20 square area and set $G = 1$. The exclusive distance for conventional scheme is the same as that in the DF case. The simulation results are shown in Fig.4 and Fig.5. As we can see from Fig.4, the number of concurrent flows in our proposed scheme is more than that in conventional scheme. By using our proposed scheme, the number of concurrent flows can be increased by 140% compared to the conventional scheme. We can also find from Fig.5 that our proposed scheme can significantly reduce the outage probability compared to the conventional scheme.

As we can see from Fig.4, the gap between the conventional scheme and the proposed scheme is increased compared to the DF case. This is due to the fact that we calculate d^{ex} based on the worst interference condition when the AF scheme is used. Given that d^{ex} is calculated based on the worst interference condition, it becomes larger than the optimal value and the number of concurrent flows decreases because the distance between active cooperative transmission sets increases. It can be checked from the outage probability of cooperative transmission set in Fig.5. The outage probability of our proposed scheme is less than 1% which is much less than our target outage probability which is 10%, because the value of d^{ex} which is used in our proposed scheme is larger than the optimal value. For example, when $\gamma = 100$, d^{ex} of our proposed scheme becomes 8.62, however, if we use 6.47 instead of 8.62, the number of concurrent flows can be increased while the outage probability is less than 10%.

VI. Conclusions

Although cooperative transmission has been studied by many researchers, a distributed scheduling algorithm which considers the cooperative transmission has not been proposed yet. Therefore, we have proposed a new distributed scheduling algorithm for wireless ad-hoc systems with cooperative transmission in which multiple cooperative relays can transmit at the same time by using an AF or a DF scheme. By using the exclusive distance which is the minimum distance between two active cooperative transmission sets, the outage probability of cooperative transmission can be reduced. Through performance analysis and simulation results, we have shown that the proposed scheme can enhance the performance of wireless ad-hoc system with cooperative transmission.

VII. Acknowledgement

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