Uncoordinated Cooperative Truncated ARQ Schemes in Wireless Systems

Chao Zhai, Wei Zhang
School of Electrical Engineering & Telecommunications
The University of New South Wales
Sydney, NSW 2052, Australia
Email: chao.zhai@student.unsw.edu.au; wzhang@ee.unsw.edu.au

Guoqiang Mao
School of Electrical & Information Engineering
The University of Sydney
Sydney, NSW 2006, Australia
Email: guoqiang.mao@sydney.edu.au

***Abstract*—In this paper, we propose two uncoordinated cooperative truncated ARQ schemes based on node position or local SNR information. If the original transmission between a source and a destination fails, the source and all the potential relays that have correctly received the data packet will contend for the channel to retransmit the packet without coordination. The competition for the channel access is governed by the retransmission probability which is computed in a distributed fashion using the stochastic geometry theory. Theoretical system success probabilities of both schemes are derived. Compared with the scheme in which only the source retransmits, the uncoordinated schemes are shown to achieve better performance, particularly when the distance between the source and the destination is large.**

I. Introduction

Cooperative automatic repeat request (ARQ) with the best relay selection [1] [2] [3] is an attractive technique that can significantly improve the link throughput by forwarding the data using the best available relay node only when the original transmission between the source and the destination fails. Moreover, space diversity can be achieved by allowing relays to do the retransmission. This is because the relay-destination and source-destination channels are independent and the probability that all the channels undergo deep fading is very small. However, for the explicit relay selection [4], a global knowledge of all relay channels is needed for the source to determine which relay is the best. If the channel coherence time is short, it may not be accurate to use the best relay based on the channel information in the previous time slot for retransmission in the current time slot. Moreover, extra coordination is required to select the best relay or to allocate resource among source and relay nodes. In the opportunistic relaying scheme [5], an implicit back-off mechanism is executed to automatically select the best relay for cooperative retransmission. However, there are still lots of overheads for the coordination, which becomes unacceptable when the network size is large, as the frequent coordination may negate any potential performance gains.

With a priori knowledge about the spatial distribution of the nodes, an optimal uncoordinated cooperation method is studied in [6] to maximize the system performance. In [6], a relay is autonomously selected to do the retransmission without any coordination, and the performance is shown to be comparable to the best relay selection scheme. In [7], R. K. Ganti *et al.* proposed some decentralized relay selection methods to forward the source data to the destination for a two-hop TDMA wireless system.

In this paper, two uncoordinated cooperative truncated ARQ schemes are proposed that exploit the local information of relay position or channel SNR. The retransmission probabilities of potential relays are judiciously computed in a distributed way using the stochastic geometry theory and each potential relay makes the retransmission decision independently without any coordination. System success probability is derived for both schemes. Numerical results show that the proposed schemes achieve better performance, compared with the conventional scheme in which only the source retransmits, particularly when the Euclidean distance between the source and the destination is large.

The rest of this paper is organized as follows. In Section II, the system model is introduced. Two uncoordinated cooperative truncated ARQ schemes are proposed and retransmission probabilities are studied in Section III. Section IV derives the system success probabilities for both schemes. Numerical and simulation results are given in Section V. Finally, section VI concludes this paper.

II. System Model

A. Channel Model

Consider a wireless network with nodes placed on a two-dimensional plane following a homogeneous Poisson Point Process (PPP) $\Phi = \{x_i \in \mathbb{R}^2, i \in \mathbb{Z}_+\}$ with known intensity λ. Assume a source node (denoted by S) transmits to a destination node (denoted by D) at Euclidean distance R apart.

For the data transmission between any pair of nodes x and y, the signal-to-noise ratio (SNR) of the received signal at node y from node x is given by

$$\gamma_{xy} = P_0 h_{xy} g_{xy} / N_0, \tag{1}$$

where P_0 is the transmission power, N_0 denotes the power of AWGN, h_{xy} represents the small-scale fading which is exponentially distributed with unit mean, and g_{xy} is the path-loss coefficient given by $g_{xy} = C\|x-y\|^{-\alpha}$ with C denoting a frequency-dependent constant, $\|x-y\|$ being the Euclidean distance between x and y, and α being the path loss exponent.

This work was supported in part by the Australian Research Council Discovery Project DP120102030.

For notational brevity, we set $C = 1$ and $\alpha = 2$ without loss of generality. The data transmission between nodes x and y is deemed correct if $\gamma_{xy} \geq T_0$, with T_0 denoting the SNR threshold.

B. Relay Protocol

We consider that the communication between S and D is assisted by some intermediate nodes if necessary and that each intermediate node makes decision independently on whether to participate in the cooperative communication without any coordination with other nodes.

Before starting a data transmission from the source S to the destination D, RTS/CTS frames are broadcast successively to reserve the channel between S and D. If the channel is successfully captured, then a data packet is sent by S. Due to the broadcast nature of wireless channels, the intermediate nodes and the destination can all possibly receive the packet. Those intermediate nodes that correctly receive the packet are referred to as *potential* relays and denoted by

$$\Phi_r = \{x_i | x_i \in \Phi, \gamma_{si} \geq T_0\}, \tag{2}$$

where γ_{si} is the instantaneous SNR of the channel between S and node x_i.

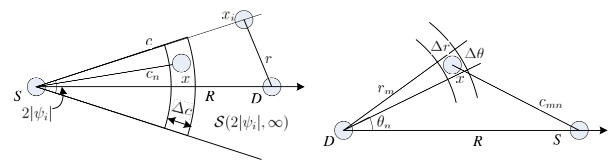
If the data packet is correctly received by the destination, then a positive acknowledgment (ACK) packet will be released. After receiving the ACK packet, all the potential relays in Φ_r will flush their memory of the stored packet and the source will continue to transmit a new data packet.

If the data packet is erroneously received by the destination, then a negative ACK (NACK) packet will be sent by the destination. On receiving the NACK packet, all the potential relays and the source S will try to retransmit the data packet to the destination. Whether a potential relay or the source should retransmit the packet is determined independently by the retransmission probabilities of the relay and the source, respectively.

A retransmission is considered to be successful only if exactly one node (either the source or a potential relay) retransmits the packet and the instantaneous SNR at the destination is larger than T_0. Of course, if no node retransmits, the data retransmission is deemed unsuccessful. If more than one nodes retransmit the packet simultaneously, then collision inevitably occurs and the retransmission is considered to be unsuccessful. Therefore, the retransmission probability of each potential relay and the source should be judiciously determined in a decentralized way to minimize collision and maximize the success probability. The retransmission probability will be investigated in the next section.

III. Uncoordinated Cooperative Transmission Schemes

As mentioned before, each potential relay or source independently decides whether it should occupy the channel or not according to its own retransmission probability. In this section, assuming the availability of prior knowledge of location or instantaneous SNR, two different retransmission schemes are presented using the stochastic geometry theory [9] [10].



(a) $r^2 = R^2 + c^2 - 2Rc\cos(|\psi|)$ (b) $c_{mn}^2 = R^2 + r_{mn}^2 - 2Rr_{mn}\cos(|\theta_n|)$

Fig. 1. The coordinate system with S or D located at the origin.

A. Sectorized Scheme

In this scheme, we assume that each potential relay knows its own position and the positions of source and destination, where the position information is obtained via GPS or wireless localization techniques [8]. Positions of S and D can be included into the control packets, e.g., RTS and CTS, which can be reliably overheard by all the nearby intermediate nodes.

A particular node, say node x_i ($x_i \in \Phi_r$) will retransmit the packet with probability $\tau_1(x_i)$ that no other potential relays lie in $\mathcal{S}(2|\psi_i|, c)$, which is a sector with angle spread of $2|\psi_i|$ and edge $c = \infty$. ψ_i denotes the angle $\angle(x_i - S - D)$. Therefore,

$$\tau_1(x_i) = \Pr\{x \notin \mathcal{S}(2|\psi_i|, \infty), \forall x \in \Phi_r \backslash \{x_i\}\}. \tag{3}$$

The smaller the angle $|\psi_i|$ is, the higher the retransmission probability of node x_i will be used. This is because there are less number of potential relays in the sector area with a smaller angle and consequently less collisions would be possibly encountered.

We can further write (3) into

$$\tau_1(x_i) = \prod_{x \in \Phi_r \backslash \{x_i\}} (1 - \Pr\{x \in \mathcal{S}(2|\psi_i|, \infty)\}), \tag{4}$$

which means that all potential relays except x_i are not in the infinite sector $\mathcal{S}(2|\psi_i|, \infty)$. Equivalently, (4) can also be written as,

$$\tau_1(x_i) = \prod_{x \in \mathcal{S}(2|\psi_i|, \infty) \backslash \{x_i\}} (1 - \Pr\{x \in \Phi_r\}), \tag{5}$$

which implies that all nodes except x_i in the sector area $\mathcal{S}(2|\psi_i|, \infty)$ are not potential relays.

Next, in order to evaluate $\tau_1(x_i)$ we need to calculate $\Pr\{x \in \Phi_r\}$, $\forall x \in \mathcal{S}(2|\psi_i|, \infty) \backslash \{x_i\}$. Suppose that a polar coordinate with origin at S is used and that a node $x \in \mathcal{S}(2|\psi_i|, \infty) \backslash \{x_i\}$ has a distance c_n from S, as shown in Fig. 1(a). We divide the sector $\mathcal{S}(2|\psi_i|, \infty)$ into many small strips $\mathcal{A}_n$ with inner radius c_n and outer radius $(c_n + \Delta c)$. Hence, it suffices to calculate $\Pr\{x \in \Phi_r, x \in \mathcal{A}_n\}$, $\forall n$ with $0 < c_n < \infty$. It can be computed as $\lambda P_{sx}(c_n)\Delta v + o(\Delta v)$, where $\Delta v \approx 2|\psi_i| c_n \Delta c$ denotes the approximate area of the strip, and $P_{sx}(c_n) = \exp(-T_0 N_0 c_n^2 / P_0)$ is the probability of x correctly receiving the original signal from S.

With $\Delta v \to 0$, $\tau_1(x_i)$ in (5) is given by

$$\tau_1(x_i) = \prod_n \left[1 - \lambda P_{sx}(c_n)\Delta v\right], \ \ 0 < c_n < \infty. \tag{6}$$

As $\Delta v \to 0$, $\tau_1(x_i)$ in (6) can be further written as

$$\begin{aligned}\tau_1(x_i) &= \exp\left[\sum_n \ln\left(1-\lambda P_{sx}(c_n)\Delta v\right)\right] \\ &= \exp\left[\sum_n \left(-\lambda P_{sx}(c_n) 2|\psi_i| c_n \Delta c\right)\right], \quad (7)\end{aligned}$$

where $\lim_{z\to 0}\ln(1-z) = -z$ is used. As $\Delta c \to 0$, the above summation is reduced to integration and we can get

$$\tau_1(x_i) = \exp\left(-\frac{\lambda|\psi_i|}{T_0 K_0}\right), \quad (8)$$

where $K_0 = N_0/P_0$. It can be seen from (8) that, the retransmission probability is a monotonically decreasing function of the absolute angle $|\psi_i|$.

B. Local SNR Based Scheme

In this scheme, we assume that each potential relay x ($x \in \Phi_r$) only knows the instantaneous SNR of the channel between itself and the destination. It is assumed that pilot signals are transmitted with a constant power over the same frequency band with the data packet. Due to the reciprocity of wireless channels, the SNR information can be obtained by measuring the strength of the pilot signals [5].

Different from the aforementioned location-aware scheme where nodes lying in Φ_r can all possibly participate in the retransmission, for this scheme only those nodes lying in the retransmission candidate set $\Phi_N = \{x_i | x_i \in \Phi_r, \gamma_{id} \geq T_0\}$ have the opportunity to assist in the retransmission. Thus, the potential relays in this scheme refer to those nodes belonging to $\Phi_N \subseteq \Phi_r$.

In the retransmission phase, a potential relay x_i ($x_i \in \Phi_N$) retransmits with probability $\tau_2(x_i)$ that no other nodes in Φ_N having a larger SNR than γ_{id}, i.e., x_i ($x_i \in \Phi_N$) has the largest SNR among all the potential relays.

$$\tau_2(x_i) = \Pr\left\{\gamma_{id} \geq \gamma_{xd}, \forall x \in \Phi_N \backslash \{x_i\}\right\}. \quad (9)$$

The higher the instantaneous SNR is, the higher the retransmission probability is set for the potential relay node x_i. Eq. (9) can be rewritten as

$$\tau_2(x_i) = \prod_{x \in \Phi_N \backslash \{x_i\}} \left(1 - \Pr\left\{\gamma_{xd} > \gamma_{id}\right\}\right). \quad (10)$$

Next, in order to calculate $\tau_2(x_i)$ we need to calculate $\Pr\{\gamma_{xd} > \gamma_{id}\}$, $\forall x \in \Phi_N \backslash \{x_i\}$. Suppose that a polar coordinate with origin at D is used and that a node x has a polar coordinate (r_m, θ_n) as shown in Fig. 1(b). The infinite plane is divided into small arc regions $\mathcal{G}_{m,n}$, which are the intersections of rings with outer radius r_m ($r_m \leq a_i$) and inner radius $(r_m - \Delta r)$ and sectors with angle from θ_n to $(\theta_n + \Delta\theta)$. Then, it suffices to calculate $\Pr\{\gamma_{xd} > \gamma_{id}, x \in \Phi_N, x \in \mathcal{G}_{m,n}\}$, $\forall m, n$ with $0 < r_m < \infty$ and $-\pi \leq \theta_n < \pi$. It can be computed as $\lambda P_{sx}(r_m, \theta_n)\Pr(\gamma_{xd} > \gamma_{id})\Delta v + o(\Delta v)$, where $\Delta v \approx r_m \Delta\theta \Delta r$ denotes the area of the small arc region, and

$$P_{sx}(r_m, \theta_n) = \Pr(\gamma_{sx} \geq T_0) = \exp\left(-T_0 N_0 c_{mn}^2 / P_0\right), \quad (11)$$

where $c_{mn} = \sqrt{r_m^2 + R^2 - 2Rr_m \cos|\theta_n|}$ is the distance between S and x.

With $\Delta v \to 0$, $\tau_2(x_i)$ in (10) is written as

$$\begin{aligned}\tau_2(x_i) &= \prod_{m,n}\left[1 - \lambda P_{sx}(r_m, \theta_n)\Pr(\gamma_{xd} > \gamma_{id})\Delta v\right], \\ & \quad 0 < r_m < \infty, \ -\pi \leq \theta_n < \pi. \quad (12)\end{aligned}$$

Similar to the derivation of (8), Eq. (12) can be derived as

$$\tau_2(x_i) = \exp\left[-\frac{\beta}{\gamma_{id} + T_0}\exp\left(\frac{u}{\gamma_{id} + T_0}\right)\right], \quad (13)$$

where $\beta = \pi\lambda\exp(-T_0 K_0 R^2)/K_0$ and $u = K_0 T_0^2 R^2$. It can be seen from (13) that, the retransmission probability is a monotonically increasing function of the local SNR γ_{id}.

IV. System Success Probability

The system success probability includes two parts. The first part is the success probability of original data transmission between S and D and the second part is the probability that the source or relays successfully retransmit the packet if the original transmission fails. Denoted by P the system success probability, it can be shown that

$$P = P_1 + (1 - P_1)(P_2 + P_3), \quad (14)$$

where $P_1 = \exp\left(-T_0 K_0 R^2\right)$ is the success probability of original data transmission over link $S \to D$, P_2 and P_3 denote the success probability of retransmission from the source and relays, respectively.

A. Success Probability of Sectorized Scheme

In order to compute P_2 and P_3, we divide the network area into small grids of size Δv. Suppose that each node lies in the center of a grid [6]. The probability that a potential relay x ($x \in \Phi_r$) exists in the grid centered with location v and retransmits the packet is given by $\lambda P_{sx}(v)\tau_1(v)\Delta v + o(\Delta v)$, where $P_{sx}(v)$ is the probability that node x correctly receives the original packet given in (11).

If the source retransmits the original packet and all the potential relays keep silent, the success probability P_2 is given as follows with $\Delta v \to 0$.

$$P_2 = \tau_1(s) P_{sd} \prod_v \left[1 - \lambda P_{sx}(v)\tau_1(v)\Delta v\right], \quad (15)$$

where $\tau_1(s) = \exp\left[-\pi\lambda/(T_0 K_0)\right]$ is the probability that S retransmits, and $P_{sd} = \exp\left(-T_0 K_0 R^2\right)$ is the probability that the destination correctly receives the packet from S. Then, similar to the derivation of (8), Eq. (15) can be derived as

$$P_2 = \exp\left[-\frac{\pi\lambda}{T_0 K_0} - T_0 K_0 R^2 - 1 + \exp\left(-\frac{\pi\lambda}{T_0 K_0}\right)\right]. \quad (16)$$

If the source is silent, we consider the success probability of potential relays doing the retransmission. The probability that one potential relay x ($x \in \Phi_r$) lies in the grid centered at location v, retransmits the packet, and the retransmission is successful is given by $\lambda P_{sx}(v)\tau_1(v)P_{xd}(v)\Delta v + o(\Delta v)$, where $P_{xd}(v)$ is the success probability of retransmission from x.

If only one potential relay retransmits and no other potential relays retransmit, with $\Delta v \to 0$, the success probability P_3 is derived as

$$\begin{aligned} P_3 &= [1-\tau_1(s)] \sum_v [\lambda P_{sx}(v)\tau_1(v)P_{xd}(v)\Delta v] \\ &\times \prod_{v' \neq v} [1-\lambda P_{sx}(v')\tau_1(v')\Delta v], \end{aligned} \quad (17)$$

where $1-\tau_1(s)$ is the probability of source remaining silent. With $\Delta v \to 0$, we have

$$\begin{aligned} &\prod_{v' \neq v} [1-\lambda P_{sx}(v')\tau_1(v')\Delta v] \\ &= \exp\left\{-\int_{\mathbb{R}^2} \lambda P_{sx}(v')\tau_1(v')\mathrm{d}v'\right\}. \end{aligned} \quad (18)$$

The function becomes independent of v, which reflects the infinitesimal impact of a single excluded point in a continuous space [6]. In fact, (18) is the conditional PGFL (probability generating functional) of the PPP, which equals to the PGFL according to Slivnyak's Theorem [9] [10]. Hence, it can be further shown that

$$\begin{aligned} P_3 &= \lambda\left[1-\exp\left(-\frac{\pi\lambda}{T_0K_0}\right)\right] \quad (19) \\ &\times \exp\left[-1-T_0K_0R^2+\exp\left(-\frac{\pi\lambda}{T_0K_0}\right)\right] \\ &\times \int_0^\infty c\exp(-2T_0K_0c^2) \\ &\times \left[\int_{-\pi}^{\pi} \exp\left(-\frac{\lambda|\psi|}{T_0K_0}+2T_0K_0Rc\cos|\psi|\right)\mathrm{d}\psi\right]\mathrm{d}c. \end{aligned}$$

A closed form expression of the two-dimensional integral over ψ and c is not easy to obtain but can be computed numerically.

B. Success Probability of Local SNR Based Scheme

To derive P_2 and P_3, the infinite plane is also divided into a cascade of small grids with area Δv. The probability that one potential relay $x \in \Phi_N$ lies in a small grid centered at location v and retransmits the packet is given as $\lambda \mathbf{1}(\gamma_{sv} \geq T_0)\mathbf{1}(\gamma_{vd} \geq T_0)\tau_2(v)\Delta v + o(v)$, where $\mathbf{1}(\gamma_{sv} \geq T_0)$ is the indicator random variable, which outputs 1 when $\gamma_{sv} \geq T_0$, and 0 otherwise.

If the source has a larger SNR than T_0 and does the retransmission, while all the potential relays keep silent, the success probability P_2 is given as follows with $\Delta v \to 0$.

$$\begin{aligned} P_2 &= \mathbb{E}\Big\{\mathbf{1}(\gamma_{sd} \geq T_0)\tau_2(s) \quad (20) \\ &\times \prod_v [1-\lambda \mathbf{1}(\gamma_{sv} \geq T_0)\mathbf{1}(\gamma_{vd} \geq T_0)\tau_2(v)\Delta v]\Big\}, \end{aligned}$$

where the expectation $\mathbb{E}\{\cdot\}$ is taken over all the channel realizations. As the channels between any two nodes are assumed to be independent, we can get

$$P_2 = \overline{\tau}_2(s)\prod_v [1-\lambda P_{sx}(v)\overline{\tau}_2(v)\Delta v], \quad (21)$$

where $\overline{\tau}_2(s) = \mathbb{E}[\tau_2(s)|\gamma_{sd} \geq T_0]$ and $\overline{\tau}_2(v) = \mathbb{E}[\tau_2(v)|\gamma_{vd} \geq T_0]$ represent the average retransmission probability of source and potential relay x, respectively. Note that, $\overline{\tau}_2(v)$ is related to the average SNR of the channel $v \to D$, which is modeled as a function of distance between x and D. With $\Delta v \to 0$ and according to the PGFL of PPP [9] [10], we can further derive P_2 as

$$P_2 = \overline{\tau}_2(s)\exp\left\{-\int_{\mathbb{R}^2} \lambda P_{sx}(v)\overline{\tau}_2(v)\mathrm{d}v\right\}. \quad (22)$$

On the infinite plane, after taking the integral over θ and r respectively, (22) can be written as

$$P_2 = \overline{\tau}_2(s)\exp\left\{-\lambda\int_0^\infty r\overline{\tau}_2(r)\left[\int_{-\pi}^{\pi} P_{sx}(r,\theta)\mathrm{d}\theta\right]\mathrm{d}r\right\} \quad (23)$$

Next, if the source remains silent in the retransmission process, collisions do not occur if only one potential relay of Φ_N occupies the channel to send the data. With $\Delta v \to 0$, the system success probability P_3 is given as,

$$\begin{aligned} P_3 &= \mathbb{E}\Big\{[1-\mathbf{1}(\gamma_{sd} \geq T_0)\tau_2(s)]\sum_v \lambda\mathbf{1}(\gamma_{sv} \geq T_0) \\ &\times \mathbf{1}(\gamma_{vd} \geq T_0)\tau_2(v)\Delta v \quad (24) \\ &\times \prod_{v' \neq v} [1-\lambda\mathbf{1}(\gamma_{sv'} \geq T_0)\mathbf{1}(\gamma_{v'd} \geq T_0)\tau_2(v')\Delta v]\Big\}. \end{aligned}$$

By taking the expectation over all the channel realizations we can derive

$$\begin{aligned} P_3 &= [1-\overline{\tau}_2(s)]\sum_v \lambda P_{sx}(v)\overline{\tau}_2(v)\Delta v \\ &\times \prod_{v' \neq v} [1-\lambda P_{sx}(v')\overline{\tau}_2(v')\Delta v]. \end{aligned} \quad (25)$$

According to the Campbell's Theorem and PGFL of PPP [9] [10], we can obtain

$$\begin{aligned} P_3 &= [1-\overline{\tau}_2(s)]\int_{\mathbb{R}^2} \lambda P_{sx}(v)\overline{\tau}_2(v)\mathrm{d}v \\ &\times \exp\left[-\int_{\mathbb{R}^2} \lambda P_{sx}(v)\overline{\tau}_2(v)\mathrm{d}v\right]. \end{aligned} \quad (26)$$

The integral over the infinite plane can be done similar to the derivation of P_2 given by (23).

V. Numerical and Simulation Results

In this section, simulation results are presented and comparisons are made between the uncoordinated schemes and the source retransmission scheme. In the simulation process, a circular area with radius 100m is considered with the destination being located at the origin, the source is located R away from the destination, the transmitter side SNR is set as 40dB and the SNR threshold $T_0 = 5$ is used. All the relay nodes are uniformly distributed in the circular area. The number of relays follows poisson distribution with mean value $\lambda\pi 100^2$.

Fig. 2 shows the system success probability with respect to node density for the proposed uncoordinated schemes and the

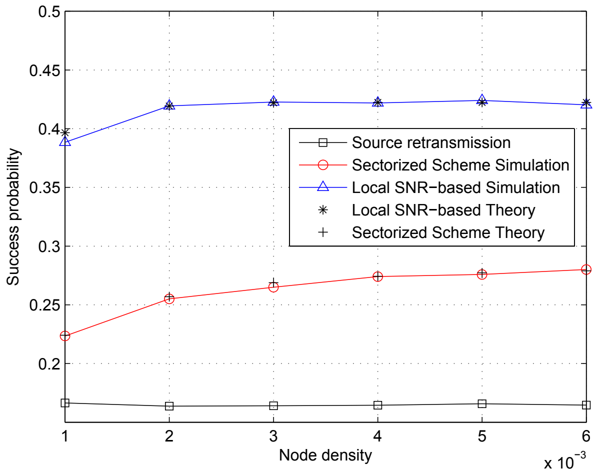


Fig. 2. Performance comparison over node density with $R = 70$m.

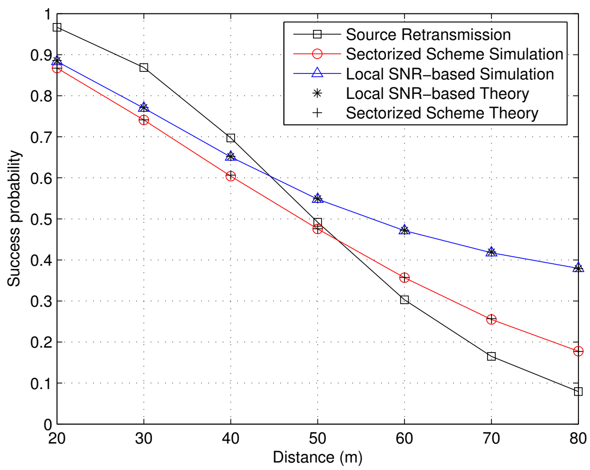


Fig. 3. Performance over $S - D$ distance with $\lambda = 0.002$.

conventional source retransmission scheme. The distance between source and destination is set as $R = 70$m. It can be seen that the local SNR based scheme has the best performance, because collisions can be greatly alleviated by allocating the retransmission task only to the nodes that have good instantaneous channel state towards the destination. Moreover, as the retransmission is opportunistically performed by a group of uncoordinated relays that are distributed in dispersive locations, the spatial diversity gain can also be achieved which obviously contribute to the superior performance of the local SNR based scheme. The sectorized scheme outperforms the source retransmission scheme, because fewer collisions and more space diversity can be brought by allocating higher retransmission probabilities to the potential relays in the direction of destination. It can also be observed that the theoretical success probabilities match well with the simulation results.

Fig. 3 shows the performance comparison of various transmission schemes over different distance R between source and destination. The node density is set as $\lambda = 0.002$. When the distance R is short, the channel between source and destination may have good quality on average. In this case, the source retransmission scheme outperforms both uncoordinated cooperative schemes. However, with the increase of distance R, the average channel quality deteriorates, and thus the performance of the source retransmission scheme deteriorates. It can be seen that the local SNR based scheme has the best performance in the long distance range, because less collisions and more space diversity could be achieved simultaneously. It can also be seen that the sectorized scheme performs better than the source retransmission in the long distance range. Moreover, the theoretical results coincide with the simulation results very well, that verifies the theoretical analysis.

VI. Conclusion

In this paper two uncoordinated cooperative truncated ARQ schemes were proposed, i.e., sectorized scheme and local SNR based scheme. If the original packet is erroneously received by the destination, all the potential relays as well as the source will compete the channel for the retransmission in a distributed way without coordination. The retransmission probability is only dependent on the local information of position or channel SNR of nodes. The local SNR based scheme significantly outperforms the location-aware sectorized scheme. When the source-destination distance is long enough, the proposed schemes can achieve better performance than the source retransmission scheme without relays.

References

[1] M. Dianati, X. Ling, K. Naik, and X. Shen, "A node-cooperative ARQ scheme for wireless ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 55, pp. 1032–1044, May 2006.

[2] B. Zhao and M. C. Valenti, "Practical relay networks: a generalization of hybrid-ARQ," *IEEE J. Sel. Areas in Commun.*, vol. 23, pp. 7–18, Jan. 2005.

[3] L. Dai and K. B. Letaief, "Throughput maximization of Ad-hoc wireless networks using adaptive cooperative diversity and truncated ARQ," *IEEE Trans. Commun.*, vol. 56, pp. 1907–1918, Nov. 2008.

[4] A. S. Ibrahim, A. K. Sadek, W. Su, and K. J. Ray Liu, "Cooperative communications with relay-selection: when to cooperate and whom to cooperate with?" *IEEE Trans. Wireless Commun.*, vol. 7, pp. 2814–2827, Jul. 2008.

[5] A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *IEEE J. Sel. Areas Commun.*, vol. 24, pp. 659–672, Mar. 2006.

[6] L. Xiong, L. Libman, and G. Mao, "On cooperative communication in Ad-Hoc networks: the case for uncoordinated location-aware retransmission strategies," in *Proc. IEEE Conference on Local Computer Networks*, Zürich, Switzerland, Oct. 2009, pp. 554–561.

[7] R. K. Ganti and M. Haenggi, "Analysis of uncoordinated opportunistic two-hop wireless ad hoc systems," in *Proc. IEEE Int. Symp. Inf. Theory*, Seoul, Korea, Jun. 2009, pp. 1020–1024.

[8] G. Mao, B. Fidan, and B. D. O. Anderson, "Wireless sensor network localization techniques," *Computer Networks*, vol. 51, pp. 2529–2553, 2007.

[9] M. Haenggi, J. G. Andrews, F. Baccelli, O. Dousse, and M. Franceschetti, "Stochastic geometry and random graphs for the analysis and design of wireless networks," *IEEE J. Sel. Areas in Commun.*, vol. 27, pp. 1029–1046, Sep. 2009.

[10] M. Haenggi and R. K. Ganti, "Interference in Large Wireless Networks," *Foundations and Trends in Networking (NOW Publishers)*, vol. 3, pp. 127–248, 2008.