Secure Ad-hoc Routing Scheme for Cooperative Multihop Wireless Networks

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Abstract—This paper investigates on the problem of combining routing scheme and physical layer security in multihop wireless networks with cooperative diversity. We propose an ad-hoc natured hop-by-hop best secure relay selection in a multihop network with several relays and an eavesdropper at each hop which provides a safe routing scheme to transmit confidential message from transmitter to legitimate receiver. The selection is based on the instantaneous channel conditions of relay and eavesdropper at each hop. A theoretical analysis is performed to derive new closed form expressions for probability of non-zero secrecy capacity along with the exact end to end secrecy outage probability at a normalized secrecy rate. Furthermore, we provide the asymptotic expression to gain insights on the diversity gain.

I. INTRODUCTION

Multihop wireless communication between two end nodes through a series of intermediate relay nodes have been extensively studied in last few decades. Under the right circumstances, it helps to extend coverage due to multihop forwarding, enhances throughput due to shorter hops, extends battery life due to lower power duration and overcomes adverse effects of channel fading. As such, it is commonly implemented in Mobile ad-hoc networks (MANETS), wireless sensor networks (WSNs) and hybrid cellular networks [? ]. Unfortunately, routing complexity and security threats increases simultaneously with the number of hops.

A variety of routing protocols have been proposed based on point to point error free links for wireless multihop links [? ]. However, these protocols were not designed considering random behavior and broadcasting nature of wireless medium in mind. To surmount this limitation, [? ? ] investigated channel aware routing strategies and considered routing outage probability as metric for performance evaluation. In particular, [? ] provided routing strategy for multihop network with multiple relays at each hop which allows to achieve diversity gain provided by cooperation among the relays.

On a different front, there is an increasing consensus in the research community about securing wireless networks with physical layer (PHY) security based on information-theoretic constraint. Traditional cryptographic approaches are based on intractability of certain mathematical functions resulting conditional security. In contrast to cryptographic approaches, PHY security is a different paradigm where information theoretic perfect secrecy is achieved by exploiting the uncertain properties of the wireless channels such as thermal noise, interference, and the time-varying nature of fading channels. The perfect secrecy implies that for all secret message $X$ and eavesdroppers observation of secret message $Y$, $Pr(X|Y) = Pr(X)$. Seminal work in [? ] showed that secret message can be transmitted at a positive rate when eavesdropper has degraded wiretap channel. The existence of perfect secrecy even when the wiretap channel has better average signal-to-noise ratio (SNR) than the main channel was shown in [? ] under fading channels.

Several diversity techniques are often exploited to improve PHY security such as multiple-input multiple-output (MIMO) [? ? ], multiuser diversity [? ? ], and cooperative diversity [? ? ]. Most of these works consist of a small network comprising a single transmitter along with single or multiple legitimate receivers and eavesdroppers, and possibly cooperating relay nodes resulting two hop relaying system. Few works have been done on multihop network with information theoretic secure constraint using game theory [? ] and stochastic geometry [? ? ]. A PHY security enabled multi-hop system is proposed in [? ] assisted by single decode and forward (DF) relay in each hop.

In this paper, we focus on the problem of combining routing scheme and PHY security in multihop wireless networks with cooperative diversity. We consider a model consisting of single transmitter and receiver connected through series of intermediate clusters each consisting of an eavesdropper and multiple DF relays. We propose a hop-by-hop best secure relay selection from each cluster to achieve full diversity. Selection can be interpreted as a version of ad-hoc routing scheme based on instantaneous channel conditions of receiver and eavesdropper at each hop.

The rest of the paper is organized as follows. In Section II, we first present the system model for the proposed ad-hoc routing scheme considering generalized linear network and obtain the distribution of end to end SNR. The performance evaluation of the proposed scheme is investigated in terms of probability of non-zero secrecy capacity and secrecy outage probability in section IV. Numerical results are provided in Section V. Finally, conclusions are drawn in Section VI.
II. SYSTEM MODEL

We consider a generalized $K$-hop linear network model composed of a source terminal referred as Alice (A), a legitimate receiving terminal referred as Bob (B) and $K-1$ relay clusters. Each relay cluster comprises $N$ number of DF relay nodes. In each hop, there exists an eavesdropper referred as Eve (E) resulting $K$ number of eavesdroppers $(E_1, E_2, ..., E_K)$ in the entire system model. Alice and Bob lacks the direct link and communication is performed with the help of a trusted relay from each cluster. The linear network model as shown in fig. 1 is quite common in wireless communications involving as sensor and vehicular networks.

At each hop, the best secure relay is selected to forward confidential message. The selected intermediate relay digitally decodes and re-encodes the received signal from the immediately preceding relay before retransmission over a wireless fading channel which we hereafter refer as a main channel. Meanwhile, the eavesdropper attempts to decode the message over wiretap channel at each hop. For simplicity, we assume that the eavesdroppers do not collude and try to decode the message independently. All the nodes are assumed to be equipped with a single antenna. Also, we assume that the distance between each clusters is much larger than the distance between the relay nodes in any one cluster. Therefore, the channel gains of the hops are independently and identically distributed. We further assume that a transmitter has full channel state information (CSI) of both the corresponding main channel and wiretap channels which is a widely adopted assumption in the literature for communication systems under secrecy constraints [?].

Let us denote $\gamma_{M_{r1,r2}}^{(k)}$ as the instantaneous SNR for main channel from relay $r1$ to relay $r2$ at hop $k$ where, $r1, r2 = 1, 2, ..., N$ and $k = 1, 2, ..., K$. Then, the cumulative distribution function (CDF) of instantaneous SNR for hop $k$ of main channel can be expressed as

$$F_{\gamma_{M_{r1,r2}}^{(k)}}(x) = 1 - e^{-\frac{x}{\bar{\gamma}_{M_k}}}, \quad (1)$$

where $\bar{\gamma}_{M_k}$ represent the average SNR for all links at hop $k$. In the first hop, there is only one transmitter (i.e. Alice) resulting $r1 = A$ for $k = 1$. Similarly, in the last hop, there is only one receiver (i.e. Bob) resulting $r2 = B$ for $k = K$.

On the other hand, each eavesdropper receives the same confidential message in two phases except the last one. We consider $E_1, E_2, ..., E_{K-1}$ apply maximal ratio combining (MRC) to decode the confidential message received in two phases. We denote $\gamma_{W_{r1,E_i}}^{(k)}$ as the instantaneous SNR for wiretap channel from relay $r1$ to Eve $(E_i)$ at hop $k$ where, $r1 = 1, 2, ..., N$ and $k, i = 1, 2, ..., K - 1$. Then, the probability density function (PDF) of instantaneous SNR for hop $k$ of wiretap channel can be [?] expressed as

$$f_{\gamma_{W_{r1,E_i}}^{(k)}}(y) = \frac{y}{\bar{\gamma}_{W_k}^{(k)}} e^{-\frac{y}{\bar{\gamma}_{W_k}^{(k)}}}, \quad (2)$$

where $\bar{\gamma}_{W_k}^{(k)}$ represent the average SNR at hop $k$ for $E_k$. In this case also, there is only one transmitter (i.e. Alice) at the first hop resulting $r1 = A$ for $k = 1$.

The PDF of instantaneous SNR for the last hop at $E_K$ is given by

$$f_{\gamma_{W_{r1,E_K}}^{(k)}}(y) = \frac{1}{\bar{\gamma}_{W_K}^{(k)}} e^{-\frac{y}{\bar{\gamma}_{W_K}^{(k)}}}, \quad (3)$$

where $\bar{\gamma}_{W_K}^{(K)}$ represent the average SNR at hop $K$ for $E_K$. 

Fig. 1. Linear network model with $K$ hops and $N$ relays in each hop.
The secrecy capacity at hop $k$ is given by [7]

$$ C_{S,r,1,2}^{(k)} = \begin{cases} \log \left( \frac{1 + \gamma_{M,r,1,2}^{(k)}}{1 + \gamma_{W,r,1,2}^{(k)}} \right) & \text{if } \gamma_{M,r,1,2}^{(k)} > \gamma_{W,r,1,2}^{(k)} \\ 0 & \text{otherwise.} \end{cases} $$

(4)

We assume logarithm on a base 2 scale unless stated. To facilitate the analysis, we define a term secrecy SNR as

$$ \gamma_{S,r,1,2}^{(k)} = \frac{1 + \gamma_{M,r,1,2}^{(k)}}{1 + \gamma_{W,r,1,2}^{(k)}}. $$

(5)

From (1), (2), (3) and (5), the CDF of secrecy SNR at hop $k$ can be obtained as

$$ F_{S,r,1,2}^{(k)}(x) = \int_0^x f_{\gamma_{W,r,1,2}^{(k)}}(y) F_{\gamma_{M,r,1,2}^{(k)}}(x(1+y)-1)dy $$

$$ = 1 - e^{-\frac{x-1}{\gamma_{M}^{(k)}}} \left( \frac{\gamma_{M}^{(k)}}{x \gamma_{W}^{(k)} + \gamma_{M}^{(k)}} \right)^m, $$

where $m = 2$ for $k = 1, 2, ..., K-1$ and $m = 1$ for $k = K$.

III. SECURE MULTIHOP ROUTING

A. PROPOSED SCHEME

Our proposed routing scheme is ad-hoc in nature and performs opportunistic selection of relay with maximum secrecy SNR, $\gamma_{S,r,1,2}^{(k)}$ at each hop. We can know from intuition that opportunistic selection at each hop can provide a diversity gain of $N$. However, there is only one receiver at the last hop $K$. Same relay selection technique at the last hop will not provide any diversity gain. As such, we perform a joint relay selection based on the secrecy SNR in the last two hops to achieve full diversity in the last hop as well.

At hop $k = 1, ..., K-2$, the best secure relay selected is given by $r_{k-1}^* = \max_{r=1, ..., N} \{ \gamma_{S,r,k-1,r}^{(k)} \}$ where $r_{k-1}^*$ is the relay chosen at hop $k = 1$. At hop $K - 1$, instead of selecting the path with the largest $\gamma_{S,r_{K-1},r}^{(K-1)}$, a joint selection is performed as $r_{K-1}^* = \max_{r=1, ..., N} \min \{ \gamma_{S,r_{K-2},r}^{(K-2)}, \gamma_{S,r,r_{K-1}}^{(K)} \}$. It is obvious that $r_0^* = A$ and $r_K^* = B$. The routing scheme is summarized in Algorithm 1.

As pointed out in [7], although the optimal scheme would be the one which identifies the path with minimum end-to-end outage probability among all possible paths, it requires high complexity level and significant amount of feedback as CSI of all links are required along with joint optimization of all paths. The ad-hoc nature of the proposed scheme drastically reduces the feedback and complexity.

The proposed scheme can be implemented in a distributed fashion as explained in [7]. The relay sets timer which is inversely proportional to measured channel gain. As such timer of the relay with the highest SNR will expire first and send a flag signal. All other relays after listening the flag signal will back off.

Algorithm 1 Proposed Secure Routing Scheme

Set $K$ and $N$
Define $r_k^*$ as the index of selected relay node at $k$-th hop, $k = 1, ..., K - 1$
Initialization $r_0^* = A$ and $r_K^* = B$
for $k = 1 : K - 2$
do $r_k^* = \max_{r=1, ..., N} \{ \gamma_{S,r_k,r}^{(k)} \}$
end for

$\gamma_{K-1}^* = \max_{r=1, ..., N} \min \{ \gamma_{S,r_{K-2},r}^{(K-1)}, \gamma_{S,r,B}^{(K)} \}$
Result best relay $\{ r_k^* \}$

B. END TO END SNR DISTRIBUTION

We need to obtain the distribution of end to end secrecy SNR at Bob for performance evaluation. Since we assume DF relays, the instantaneous end to end secrecy rate depends on minimum of secrecy SNR between $K$ hops which acts as bottleneck. Therefore, the end to end secrecy SNR at Bob can be obtained as

$$ \gamma_{e2e} = \min_{k=1, ..., K} \gamma_{S,r}^{(k)}, $$

(7)

where $\gamma_{S,r}^{(k)}$ is denoted as $\gamma_{S,r}^{(k)}$ for $k = 1, ..., K-2$ and $\gamma_{S}^{(K)}$ for $k = K - 1$. As such, it can be expressed as below

$$ \gamma_{S,r}^{(k)} = \max_{r=1, ..., N} \{ \gamma_{S,r}^{(k)} \}, $$

(8)

$$ \gamma_{S}^{(K)} = \max_{r=1, ..., N} \min \{ \gamma_{S,r_{K-2},r}^{(K-1)}, \gamma_{S,r,B}^{(K)} \}. $$

(9)

Using order statistics, we can get CDF of $\gamma_{S,r}^{(k)}$ from (6) and (8) as

$$ F_{\gamma_{S,r}^{(k)}}(x) = \left[ 1 - e^{-\frac{x-1}{\gamma_{M}^{(k)}}} \left( \frac{\gamma_{M}^{(k)}}{x \gamma_{W}^{(k)} + \gamma_{M}^{(k)}} \right)^2 \right]^N. $$

(10)

For hop $K - 1$, the relay selection is dependent on the next $K^{th}$ hop as well. Hence, the CDF for $\gamma_{S}^{(k)}$ can be proceeded as

$$ F_{\gamma_{S}^{(k)}}(x) = Pr \left[ \max_{r=1, ..., N} \min \{ \gamma_{S,r_{K-2},r}^{(K-1)}, \gamma_{S,r,B}^{(K)} \} < x \right] $$

$$ = \prod_{r=1}^N Pr \left[ \gamma_{min(r)}^{(k)} < x \right], $$

(11)

where $\gamma_{min(r)}^{(k)} = \min \{ \gamma_{S,r_{K-2},r}^{(K-1)}, \gamma_{S,r,B}^{(K)} \}, r = 1, 2, ..., N$. We know

$$ Pr[\gamma_{min(r)}^{(k)} > x] = \left( 1 - F_{\gamma_{S,r_{K-2},r}^{(K-1)}}(x) \right) \left( 1 - F_{\gamma_{S,r,B}^{(K)}}(x) \right). $$

(12)

From (9), (11) and (12), we get

$$ F_{\gamma_{S}^{(k)}}(x) = \left[ 1 - \left( 1 - F_{\gamma_{S,r_{K-2},r}^{(K-1)}}(x) \right) \left( 1 - F_{\gamma_{S,r,B}^{(K)}}(x) \right) \right]^N. $$

(13)
After simple mathematical manipulation, we finally get the CDF of $\gamma_{S2}^{(k)}$ as

$$F_{\gamma_{S2}^{(k)}}(x) = \left(1 - e^{-x(\frac{1}{\gamma_{M}^{(k-1)}} + \frac{1}{\gamma_{M}^{(k)}})}\right) \times \frac{\frac{K}{M}}{(x\gamma_{W}^{(k)} + \gamma_{M}^{(k)}} \left(\frac{\gamma_{M}^{(k-1)}}{x\gamma_{W}^{(k)} + \gamma_{M}^{(k)}}\right)^{2^{K}}}^{N} \quad (14)$$

From (7), we can obtain the CDF of end to end secrecy SNR using order statistics as

$$F_{\gamma_{e2e}}(x) = 1 - \prod_{k=1}^{K-1}(1 - F_{\gamma_{S2}^{(k)}}(x)) \quad (15)$$

As the distribution of end-to-end secrecy SNR is different in the last two hops from the first $K-2$ hops, (15) can be rewritten as

$$F_{\gamma_{e2e}}(x) = 1 - \prod_{k=1}^{K-2}(1 - F_{\gamma_{S2}^{(k)}}(x)) \left(1 - F_{\gamma_{e2e}}^{(K-1)}(x)\right), \quad (16)$$

which can be simplified using (10) and (14).

IV. PERFORMANCE EVALUATION

A. Probability of Non-zero Secrecy Capacity

The instantaneous end-to-end secrecy capacity is expressed as

$$C_S = \frac{1}{K} \log(\gamma_{e2e}). \quad (17)$$

The factor $1/K$ accounts for the fact that the entire transmission takes place in $K$ phases. As the secrecy capacity exists only when the instantaneous SNR of main channel is greater than the instantaneous SNR of wiretap channel, we need to examine probability of existence of non-zero secrecy capacity. From (17), it can be obtained as

$$Pr(C_S > 0) = Pr(\gamma_{e2e} > 1) = 1 - F_{\gamma_{e2e}}(1). \quad (18)$$

The closed form expression for the probability of non-zero secrecy capacity can be obtained by combining (10), (14), (16) and (18) and replacing $x$ by 1 as shown below

$$Pr(C_S > 0) = \prod_{k=1}^{K-1} \left(1 - \sum_{i=0}^{N} \binom{N}{i}(-1)^{i}a_{k}^{2^{i}}\right), \quad (19)$$

where $a_{k}$ is defined as

$$a_{k} = \begin{cases} \frac{\gamma_{M}^{(k)}}{\gamma_{W}^{(k)} + \gamma_{M}} & \text{if } k < K - 1 \\
\frac{\gamma_{M}^{(K-1)}}{\gamma_{W}^{(K-1)} + \gamma_{M}} & \left(\frac{\gamma_{M}^{(K-1)}}{\gamma_{W}^{(K-1)} + \gamma_{M}}\right)^{\frac{1}{2}} & \text{if } k = K - 1. \end{cases}$$

B. Secrecy Outage Probability

The outage probability is the probability that the instantaneous end-to-end transmission rate falls below a threshold secrecy rate ($R_S$). Hence, the outage probability is given by

$$P_{out} = Pr(C_S < R_S) = F_{\gamma_{e2e}}(\frac{R_S}{K}). \quad (20)$$

As such, the closed form expression for outage probability can be easily obtained from (10), (14), (16) and (20) by replacing $x$ by $2R_S K$

$$P_{out} = 1 - \prod_{k=1}^{K-1}(1 - \sum_{j=0}^{N} \binom{N}{j}(-1)^{j}I_{2j}^{2j}e^{-\frac{(x-1)}{x}^{2j}}), \quad (21)$$

where

$$b_{k} = \begin{cases} \frac{\gamma_{M}^{(k)}}{\gamma_{W}^{(k)} + \gamma_{M}} & \text{if } k < K - 1 \\
\frac{\gamma_{M}^{(K-1)}}{\gamma_{W}^{(K-1)} + \gamma_{M}} & \text{if } k = K - 1, \end{cases}$$

$$\Gamma_{k} = \begin{cases} \frac{\gamma_{M}^{(k)}}{\gamma_{W}^{(k)} + \gamma_{M}} & \text{if } k < K - 1 \\
\frac{\gamma_{M}^{(K-1)}}{\gamma_{W}^{(K-1)} + \gamma_{M}} & \text{if } k = K - 1, \end{cases} \text{ and } p = 2R_S K.$$  

Although this closed-form expression enable us to evaluate the performance of proposed scheme, its complex form do not allow us to gain valuable insights on how the diversity gain is affected. Therefore, we intend to perform asymptotic analysis with high secrecy SNR approximations i.e. $\gamma_{e2e} \to \infty$ in the sequel.

Theorem 1. The asymptotic outage probability as $\gamma_{e2e} \to \infty$ is given by

$$P_{out}^{a} \approx (2K R_S - 1)^{N} \times \left[\sum_{k=1}^{K-2} \left(\frac{1}{\gamma_{M}^{(k)}}\right)^{N} + \left(\frac{1}{\gamma_{M}^{(k)} + \gamma_{M}}\right)^{N}\right]^{N}. \quad (22)$$

Proof. The end to end CDF of secrecy SNR can be simplified as

$$F_{\gamma_{e2e}}^{a}(x) = \sum_{k=1}^{K-1} F_{\gamma_{S2}^{(k)}}(x). \quad (23)$$

The approximation comes from the fact that the products of $F_{\gamma_{S2}^{(k)}}(x)$ and $F_{\gamma_{S2}^{(k)}}(x)$, $k_1 \neq k_2$, are small compared to the $F_{\gamma_{S2}^{(k)}}(x)$. We know that $\gamma_{e2e} \to \infty$ when $\gamma_{M}^{(k)} > \gamma_{W}^{(k)}$. Also, expanding the exponential term in (10) and (14) and ignoring the higher order terms, we can rewrite the CDFs as

$$F_{\gamma_{S2}^{(k)}}(x) = \left(\frac{x - 1}{\gamma_{M}^{(k)}}\right)^{N}, \quad (24)$$

$$F_{\gamma_{S2}^{(k)}}(x) = \left(\frac{(x - 1)(\gamma_{M}^{(K-1)} + \gamma_{M})}{\gamma_{M}^{(K-1)}\gamma_{M}}\right)^{N}. \quad (25)$$
From (23), (24) and (25), we finally get
\[
F_{\gamma_{2\gamma}}^{a}(x) = (x - 1)^{N} \times \left[ \sum_{k=1}^{K-2} \left( \frac{1}{\gamma_{M}^{k}} \right)^{N} + \left( \frac{1}{\gamma_{M}^{(K-1)}} + \frac{1}{\gamma_{M}^{K}} \right)^{N} \right].
\] (26)

Substituting \( x \) with \( 2^{R_{K}} \), we get (23).

For a special case of balanced links where average SNR in all links of main channel and wiretap channels are equal i.e. \( \tilde{\gamma}_{M} = \tilde{\gamma}_{2M} = \ldots = \tilde{\gamma}_{K} = \tilde{\gamma}_{M} \) and \( \tilde{\gamma}_{W} = \tilde{\gamma}_{2W} = \ldots = \tilde{\gamma}_{W} = \tilde{\gamma}_{W} \), the asymptotic outage expression reduces to
\[
P_{out}^{a} = (\varphi \psi)^{-\Delta},
\] (27)
where diversity order is \( \Delta = N \) and equivalent array gain is \( \varphi = (2^{K R_{s}} - 1)^{N} \times (K - 2 + 2^{N})^{\frac{1}{N}} \).

V. NUMERICAL RESULTS

In this section, we examine the performance of secrecy outage probability through numerical evaluations. A linear network with balanced links and equally spaced relay clusters is considered to evaluate the performance. Equidistant clusters are shown to be optimal configuration in [9] in the sense of minimizing the error probability when uniform power allocation is employed.

Figure 2 shows the probability of non zero secrecy capacity versus \( \tilde{\gamma}_{M} \) for different values of \( K \) and \( N \). We plot the figure for selected values of \( \tilde{\gamma}_{W} \) to avoid cluttering the figure and present the effects of \( K \) and \( N \) in the performance. This figure highlights that the probability of positive secrecy increases with \( \tilde{\gamma}_{M} \) while decreases with the increase in value of \( K \). The performance can be remarkably improved by increasing the number of relays in each cluster.

Figure 3 compares the secrecy outage probability versus \( \tilde{\gamma}_{M} \) for selected values of \( K \) and \( \tilde{\gamma}_{W} \) with \( N = 2 \) and \( R_{s} = 0.5 \text{ bits/s/Hz} \). We can notice that the secrecy outage probability increases remarkably when we increase the number of hops. Similarly, we can also observe that decrease in \( \tilde{\gamma}_{W} \) improves the secrecy outage probability. Interestingly, we can also note that the improvement in secrecy outage performance with decrease in \( \tilde{\gamma}_{W} \) is smaller compared to decrease in \( K \). But, it is clear that in both cases, the diversity gain cannot be improved as shown by parallel lines.

Figure 4 depicts the asymptotic and exact secrecy outage probability versus \( \tilde{\gamma}_{M} \) for various values of \( N \) with \( K = 3 \), \( R_{s} = 1 \text{ bits/s/Hz} \) and \( \tilde{\gamma}_{W} = -10 \text{ dB} \) to ensure \( \tilde{\gamma}_{M} >> \tilde{\gamma}_{W} \). We can observe that the secrecy outage probability decreases with increase in \( N \). Moreover, the asymptotic curve merges with exact curve in the high SNR regime. It is evident that slope of the lines are changed in fig. 3 implying the diversity
gain is affected by $N$.

To analyze the outage diversity gain, we investigate slope calculating $-\log(P_{out})$ and $\log(\bar{\gamma}_M)$ in the range of 26, 28, and 30 dB. For $N = 2, 3$ and 4, we have outage diversity of 1.9672, 2.9467, and 3.927 respectively, in the range of $\bar{\gamma}_M = 26 - 28$ dB. On the other hand, we get outage diversity of 1.9793, 2.9663 and 3.9538 for $N = 2, 3$, and 4, respectively, in the range of $\bar{\gamma}_M = 28 - 30$ dB. It is obvious that diversity gain rounds off to $N$ with the increment in main channel SNR and it is independent of of number of hops. The asymptotic diversity is found to be $N$ in the entire range.

VI. CONCLUSIONS

In this paper, we have derived the closed form expression for probability of non-zero secrecy capacity and the secrecy outage probability as a performance evaluation parameter to investigate the proposed adhoc routing scheme for a cooperative multihop wireless network. We have also presented the asymptotic diversity for the higher values of SNR of the main channel. Based on our formulation and numerical results, we have verified that the proposed routing scheme can take advantage of spatial diversity offered by number of relays in each cluster.

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