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Cross-Layer Routing for Outage Minimization in Multihop Ad-Hoc Networks

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Abstract: In this study, cross-layer approach for joint routing and power allocation problem is formulated in an optimization framework for end-to-end outage minimization under the constraint of total permissible transmission power. A closed form solution for optimal transmission power is obtained following the extraction of routing metric. The scheme is referred as minimum end-to-end outage probability (MEO) strategy. A distributed implementation of the proposed strategy is also presented. Simulation results prove that our proposed MEO routing and power allocation strategy succeeds in achieving significant improvement of end-to-end outage probability over MEO routing and equal power allocation scheme.
Keywords: Energy conservation; outage probability; cross-layer; joint routing and power allocation; multi-hop ad-hoc networks.

I. INTRODUCTION

Mobile ad-hoc network, which are also called a wireless ad-hoc network or ad-hoc wireless network that usually has a routable networking environment on top of a link layer ad hoc network [1]. They consist of a set of mobile nodes connected wirelessly in a self-configured, self-healing network without having a fixed infrastructure. Each node behaves as a router as they forward traffic to other specified nodes in the network. This can be used in road safety (VANET), ranging from sensors for the environment, home, health, disaster rescue operations, air/land/navy defense, weapons, robots, etc. [2-3]. The existing routing protocols in mobile ad-hoc network can be categorized into proactive, reactive and hybrid protocols [4].

Energy conservation [5] is a limiting feature in the mobile ad-hoc network, since nodes are probable to depend on manageable, power sources are limited. Also, energy saving is really demanding multi-hop environment; wherever the wireless nodes must to save energy to route packets for another nodes & toward secure connectivity of the network [6].

In real time applications, notions of outage are often used to quantify the time periods when the performance of a system is below what is desired. For instance, in mobile telephony, outages could correspond to times where the audio quality is very poor, and in tracking applications outages might correspond to instances where the location of a target cannot be determined to a desired accuracy [7].

To the best of our knowledge, the issue of joint routing and power allocation strategy for total permissible transmission power restricted mobile ad hoc networks has not been well studied. Therefore, in this paper energy conservation is considered which has a great importance towards green communication. Our aim is to minimize the end-to-end outage probability with sum power constraint. The routing problem is coupled with the power allocation problem. So, first power allocation problem is derived. A closed form expression of optimal transmission power is obtained and from that the path weight function is also extracted. The scheme is referred as minimum end-to-end outage probability (MEO) strategy. Further, an implementation issue for the MEO strategy is also discussed. Simulation results demonstrate that our proposed MEO routing and power allocation strategy provides significant improvement of end-to-end outage probability in comparison with MEO routing and equal power allocation scheme.

The rest of the paper is organized as follows. In the section I we describe the Introduction and, in the section II we describe the System Model. The joint routing and power allocation for MEO strategy is described in section III. In section IV we have proposed a strategy of distributed implementation scheme. In section V we have given the simulation performance contains simulation settings, simulation parameters with values and simulations results. At the end we made the conclusion in the section VI.

II. SYSTEM MODEL

A. Network Model

A wireless multi-hop ad-hoc network model is considered that is represented by a unidirectional graph $G(V,E)$ where V represents the vertex set indicating set of nodes in the network and E represents the edge set indicating the set of links used in the network. All the nodes are distributed in a two-dimensional geographic area and assumed to have an Omni-directional antenna and a battery energy supply. All the nodes are assumed to work on a particular mode which is called Time Division Duplex (TDD) mode; so, the transmission and reception cannot be occurred simultaneously.

A series of messages is transmitted continuously. So, for the transmission, a path is required; the path by which the messages are transmitted is; Path ($\wp$), $\wp$=S_1+S_2+.... + S_{N+1} with N+1 nodes where S_1, S_2,….., S_{N+1} are the wireless nodes. These nodes are the type of relay nodes containing source and destination pair in it. An exemplification of the system model is depicted in Fig. 1. To avoid the un-wanted interference during message transmission, Time Division Multiple Access (TDMA) protocol of equal time slot is employed. The Path '$\wp$' as mentioned before, consists of multiple hops. The intermediate relaying nodes are assumed to use decode-and-forward (DF) strategy to process the messages and signals.

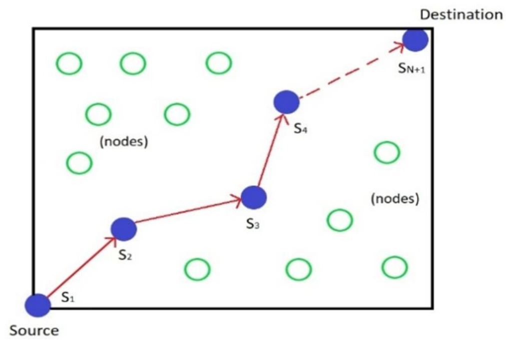

Fig1. System model

B. Channel Model

The large-scale path loss with small-scale Rayleigh fading characterizes the wireless link between two nodes. We assume that channel fading for different links is to be statistically independent. For all receiving nodes, we use zero mean complex Gaussian random variable to represent the additive noise. The expression to represent the instantaneous signal-to-noise ratio (SNR) over $i-th$ hop is:

$$\gamma_i = \frac{P_{ti}\alpha_i}{M_l G_1 N_0} d_i^{-k} \quad (1)$$

where P_{ti} is the permissible transmission power of each node along the optimal route, α_i is the instantaneous channel power gain factor which is exponentially distributed with unit mean, M_l is the link margin, G_1 is the gain factor of reference distance 1m, the additive noises of all receiving nodes are assumed to be zero-mean complex Gaussian random variables with variance N_0, d_i is the transmission distance over the $i-th$ hop, $k \geq 2$ is the path loss constant.

The outage probability characterizes the link quality $p_i = P_r(\gamma_i < \beta)$ where β represents the threshold SNR for successful reception. Here, the cumulative density function of γ_i represents the outage probability following [8] Therefore, using (1)

$$p_i = 1 - e^{(\frac{-\beta}{\gamma_i})} = 1 - e^{(-l\frac{d_i^k}{P_{ti}})} \quad (2)$$

Where l=$M_l G_1 N_0\,\beta$. In a multi-hop ad hoc networks with DF relays, end-to-end outage occurs when SNR of any link in the route fall below β. The expression that represents the end-to-end outage probability for DF multi-hop network is as,

$$P_{out} = 1 - \prod_{i=1}^{N} e^{(\frac{-\beta}{\gamma_i})} = 1 - \prod_{i=1}^{N} e^{(-l\frac{d_i^k}{P_{ti}})} \quad (3)$$

III. JOINT ROUTING AND POWER ALLOCATION FOR MEO STRATEGY

The term joint routing and power allocation means routing strategy coupled with power allocation solution. So, first we derive the power allocation problem for minimum end-to-end outage probability for a given path $\wp$ with the constraint of total transmission power P_{max}.

A. Power Allocation Problem

Minimum end-to-end outage probability (MEO) strategy aims at minimizing the end-to-end outage probability of the path $\wp$ for total transmission power constraint P_{max}. Let the transmit power of node i is denoted by P_{ti} where i € {1, 2,,,,N}. Then the power allocation problem is,

$$min \sum_{i=1}^{N} \frac{l d_i^k}{P_{ti}} \quad (4)$$

$$s.t. \sum_{i=1}^{N} P_{ti} \leq P_{max}$$

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Since the objective function is convex and the constraint is a linear function, the optimization problem is a convex optimization problem and has a unique optimal solution and using Lagrangian multiplier method,

$$\text{Here, } L(P_{t1}, P_{t2}, .., P_{tN}) = \sum_{i=1}^{N}\left(\frac{l d_i^k}{P_{ti}^2}\right) + \lambda \left(\sum_{i=1}^{N} P_{ti} - P_{max}\right) \quad (5)$$

where λ is the Lagrangian multiplier. Therefore the KKT conditions for nodes i=1,2,..,N with nonzero values of transmit power are,

$$\frac{\partial}{\partial P_{ti}} L(P_{t1}, P_{t2}, .., P_{tN}) = -\left(\frac{l d_i^k}{P_{ti}^2}\right) + \lambda = 0 \quad (6)$$

$$\frac{\partial}{\partial \lambda} L(P_{t1}, P_{t2}, .., P_{tN}) = \left(\sum_{i=1}^{N} P_{ti} - P_{max}\right) = 0 \quad (7)$$

Solving (5) and (6), we get the minimum total transmit power given by

$$P_{ti} = \frac{P_{max}\sqrt{d_i^k}}{\sum_{i=1}^{N}\sqrt{d_i^k}} \quad (8)$$

Putting the value of (8) in (3), the minimum end-to-end outage probability is

$$P_{out} = 1 - \prod_{i=1}^{N} e^{\left[-l\frac{\left(\sum_{i=1}^{N}\sqrt{d_i^k}\right)^2}{P_{max}}\right]} \quad (9)$$

B. Routing Problem

In MEO strategy, the path which requires minimum total power to maintain outage probability constraint is to be selected. From (9) we can find the path weight function as

$$\omega_{MEO}(\wp) = \sum \sqrt{d_i^k} \quad (10)$$

To minimize total power in the network, we need to search for the path that has minimum path weight as given in (10). Therefore, the routing problem for MEO strategy is

$$\min_{\wp \in \wp(S_N, S_{N+1})} \omega_{MEO}(\wp) \quad (11)$$

IV. DISTRIBUTED IMPLEMENTATION

Before the routing protocol or routing technique, the property of routing metric is to be checked whether it is monotonicity property [9]. A set of elements (ω,⊕,≤) can represent a routing metric where ω is the path weight, '≤' is the order relation and '⊕' is the path concentration operation from a link. For any path like $\wp_1$, $\wp_2$, $\wp_3$ in the network if ω ($\wp_1$) < ω ($\wp_2$) implies that ω ($\wp_1 \oplus \wp_3$) ≤ ω ($\wp_2 \oplus \wp_3$) and other side implies that ω ($\wp_3 \oplus \wp_1$) ≤ ω ($\wp_3 \oplus \wp_2$) then that routing metric is called as Isotonic. If any path $\wp_1$, $\wp_2$, $\wp_3$ in the network we have ω ($\wp_1$) ≤ ω ($\wp_1 \oplus \wp_2$) and ω ($\wp_1$) ≤ ω ($\wp_2 \oplus \wp_1$) or ω ($\wp_1$) ≤ ω ($\wp_1 \oplus \wp_3$) and ω ($\wp_1$) ≤ ω ($\wp_3 \oplus \wp_1$) the that routing metric is called as Monotonic. Our proposed routing metric (10) follows both isotonic and monotonic. Therefore, we can use link-state, path vector routing strategy or distance vector routing protocols to implement the routing strategy for our metric. Now DSDV (Destination Sequenced Distance Vector Routing) [10] or AODV (Ad-hoc On-demand Distance Vector Routing) [11] based routing protocol can be easily modified to implement the routing scheme. These routing protocol can used $\sqrt{d_i^k}$ link metric to solve (11).

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V. SIMULATION PERFORMANCE

A. Simulation Settings

A fully connected wireless network is considered in result of outage minimizing, joint routing and power allocation in multihop wireless network routing strategy; where there are N nodes in which all nodes can directly communicate with each other. There is a square area of size (50 × 50)m and the nodes are located here randomly. Here the location of source and destination nodes are fixed in (0,0) and (50,50) respectively. Binary Phase Shift Keying (BPSK) modulation is adopted here for the evaluation. Route is obtained from a routing metric and then power is allocated in each node of the route according to a power allocation strategy in case of network realization.. The MEO scheme is considered for making a comparison between power allocation strategy performance for a fixed routing metric and routing metric performance for a fixed power allocation strategy. We consider the possible combination of the – i) MEO-R and PA, In this scheme route is determined following (11) and the power is obtained (8) and ii) MEO-R and EPA, route is determined following (11) and each node in the route is allocated to an equal power. The simulation parameters are shown in Table 1 and the simulation results are averaged over 10^4 randomly generated network topologies.

Table 1: Simulation Parameters

Description with Symbols	Values
Path loss Constant, k	3.5 [8]
Link Margin, M_l	$10^4 dB$
Gain Factor, G_1	$10^3 dB$
Gaussian Random Noise with variance, N_0	$10^{-14} dB$
Threshold SNR for successful reception, β	$10^7 dB$
Total Transmission Power Constraint, P_{max}	$10^4 watt$ [Fig. 2]
Network size, N	25 [Fig. 3]

B. Simulation Results

Fig. 2 represents average end to end outage probability of all power allocation and routing strategy combination for different network sizes where total transmission power P_{max} constraint is considered as 10^4. It can be observed from the figure that as the network size increases end-to-end outage probability of each candidate becomes increasing. The reason is explained as follows. With increase in network size each node along the route requires less transmission power to meet the sum power constraint. As expected, our proposed MEO-R and PA scheme provides the best performance comparing with MEO-R and EPA scheme. The highest improvement of MEO-R and PA scheme is 8.9 % when the network size 25.

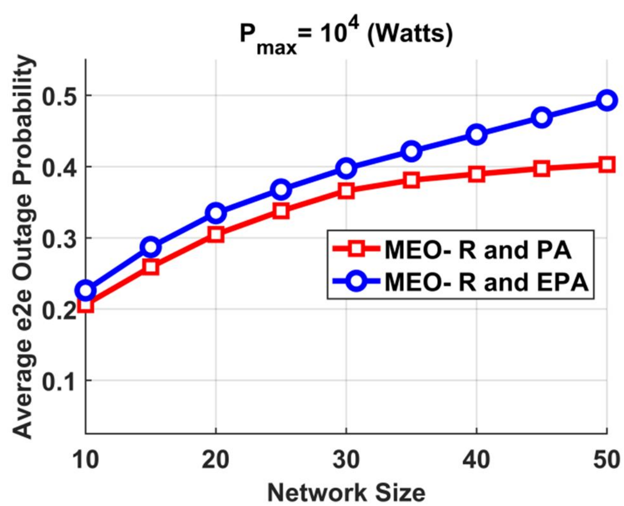

Fig. 2: Average end-to-end outage probability vs. network size

Fig. 3 depicts the plot of average end to end outage probability versus total transmission power P_{max} constraint when the network size is fixed at 25. For a fixed network size, permissible transmission power for each candidate along the route become increases following (15) causes improvement of end-to-end outage probability for all the candidates. From the figure, it can be observed that our proposed MEO-R and PA scheme provides the best performance among another scheme. The highest improvement of end-to-end outage probability is 3.74 % when P_{max} is 10^4 for MEO-R and PA scheme.

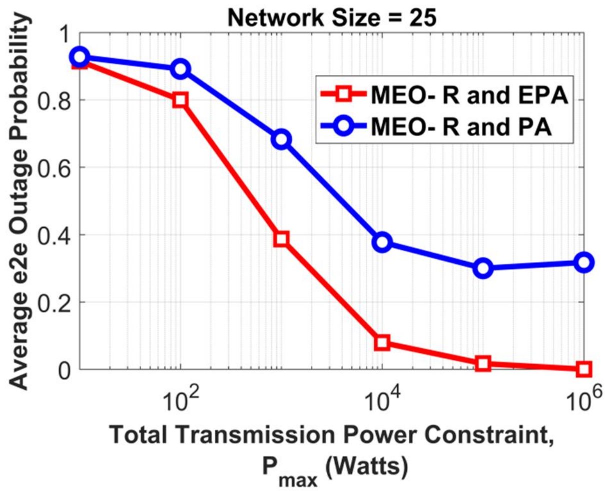

Fig. 3: Average end-to-end outage probability vs. P_{max}

VI. CONCLUSION

In this paper, the problem of end-to-end outage minimizing joint routing and power allocation problem in multi-hop wireless network is studied under the constraint of total transmission power. A closed form expression of optimal power allocation is obtained and subsequently, an optimal path weight function is extracted. Distributed implementation is also feasible for the proposed routing metric. Simulation results validate the effectiveness of our proposed scheme.

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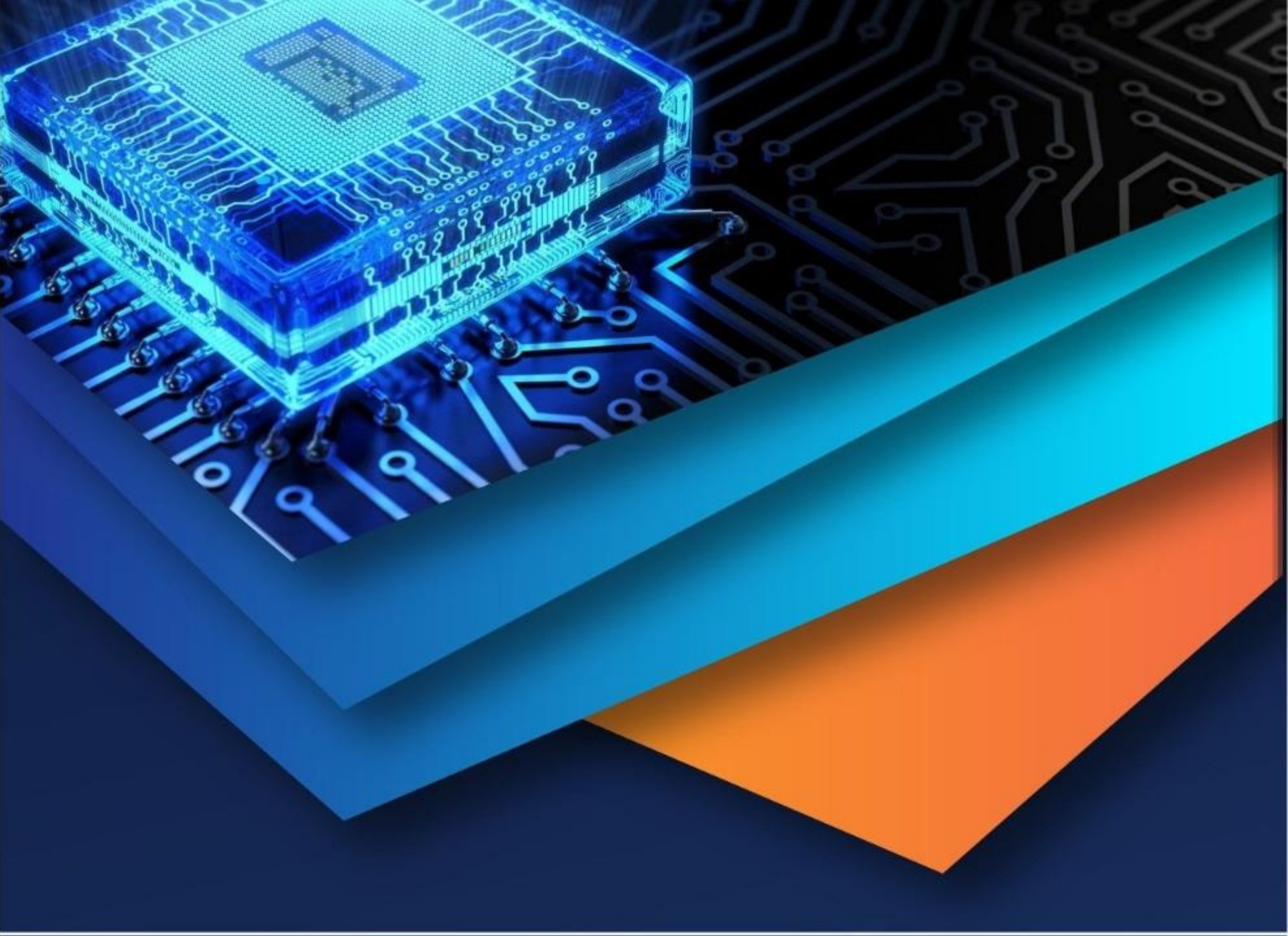

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