

A Cooperative Transmission Strategy using Entropy-based Relay Selection in Mobile Ad-hoc Wireless Sensor Networks with Rayleigh Fading Environments

Beongku An¹, Tran Trung Duy², Hyung-Yun Kong²

¹Dept. of Computer & Information Communications Engineering, Hongik University
Jochiwon, Chungnam, Korea, 339-701

²School of Electrical Engineering, Ulsan University
Ulsan, Korea, 680-749

[e-mail: beongku@hongik.ac.kr, hkong@mail.ulsan.ac.kr]

*Received February 2, 2009; revised March 11, 2009; accepted March 24, 2009;
published April 25, 2009*

Abstract

In this paper, we propose a Cooperative Transmission Strategy using Entropy-based Relay Selection in Mobile Ad-hoc Wireless Sensor Networks (MAWSN) with Rayleigh Fading Environments. The main features and contributions of the proposed cooperative transmission strategy are as follows. First, entropy-based relay selection is used to improve data transmission reliability from a source node to a destination node. Second, we present a theoretical analysis model for the proposed cooperative transmission strategy with the outage probability of the end-to-end performance. The performance of our protocol is evaluated using analysis and simulation.

Keywords: Cooperative transmission, relay selection, entropy, mobile ad-hoc wireless sensor networks, rayleigh fading

1. Introduction

In mobile ad-hoc wireless sensor networks (MAWSN), a set of wireless mobile nodes form the network infrastructure in a self-organizing ad-hoc fashion [1][2] to send messages from mobile nodes in sensor fields to the gateway (sink)(or vice versa). The network layer contains randomly moving mobile sensor nodes. It has bandwidth and power limitations, and lacks fixed infrastructure. Thus, the development of efficient protocols to support the various networking operations in MAWSN presents many issues and challenges [1][2][3]. Routing protocols in MAWSN can be categorized as proactive and reactive. Proactive routing protocols, such as Destination Sequenced Distance Vector (DSDV) [4], attempt to maintain consistent up-to-date routing information from each node to every other node in the network. Reactive protocols, such as AODV [5] and DSR [6], only create the route when the source needs to communicate to the destination. A route, once established, is managed by maintenance procedures.

At the physical layer, a cooperative diversity protocol [7] has been proposed to improve the reliability of data transmission in wireless networks. Currently various cooperative transmission protocols have been studied in the literature [7][8][9][10] from the viewpoints of implementation issues and performance evaluations with outage analysis. In [11], the outage analysis of multi-hop diversity protocol has been analyzed. In this protocol, each node in the multi-hop route listens to all of its previous nodes and combines them optimally, therefore there is no need to select a relay at each hop.

Relay selection is crucial to cooperative communication. Efficient relay selection will increase the performance of cooperative communications. [10][17] use the optimal channel state with the minimum timer; this is considered optimal. However, when each node moves continuously in MAWSN, these approaches become complex and costs increase. The relay selection strategy should consider the mobility information in MAWSN to solve these problems. This will also decrease power consumption and collisions.

In this paper, we consider a realistic approach based on mobile sensor nodes, as well as fixed sensor nodes in sensor fields, while the conventional research for sensor networks focuses on mainly fixed sensor nodes. We focus on the cooperative transmission issue from each viewpoint in MAWSN. The proposed cooperative transmission can select the stable relay node at each hop along the routing route using an entropy-based strategy from the viewpoint of the node mobility in MAWSN [2][12][13]. In addition, the proposed cooperative transmission can increase the packet delivery ratio with advanced SNR [14][15][16].

The remainder of this paper is organized as follows. The proposed cooperative transmission strategy is described in section 2 and the theoretical analysis of the cooperative transmission is presented in section 3. The performance evaluation of the cooperative transmission is presented in section 4 and section 5 concludes this paper.

2. The Cooperative Transmission

2.1 Basic Concepts and Overview

Fig. 1 describes the basic concepts and overview of the proposed cooperative transmission. The main goals of the proposed cooperative transmission strategy are to show how to select the relay node to improve the reliability of data transmission and how to theoretically analyze

the cooperative transmission, together with the outage probability, between a source node and a destination node. A cooperative communications strategy that can support both SNR efficiency and network resources (i.e., power, bandwidth) efficiency between a source node and a destination node can increase transmission efficiency. In the cooperative transmission strategy, data messages are forwarded over the constructed route as well as the neighbor nodes (i.e., relay nodes) together. The relay nodes also forward the data message to the next node.

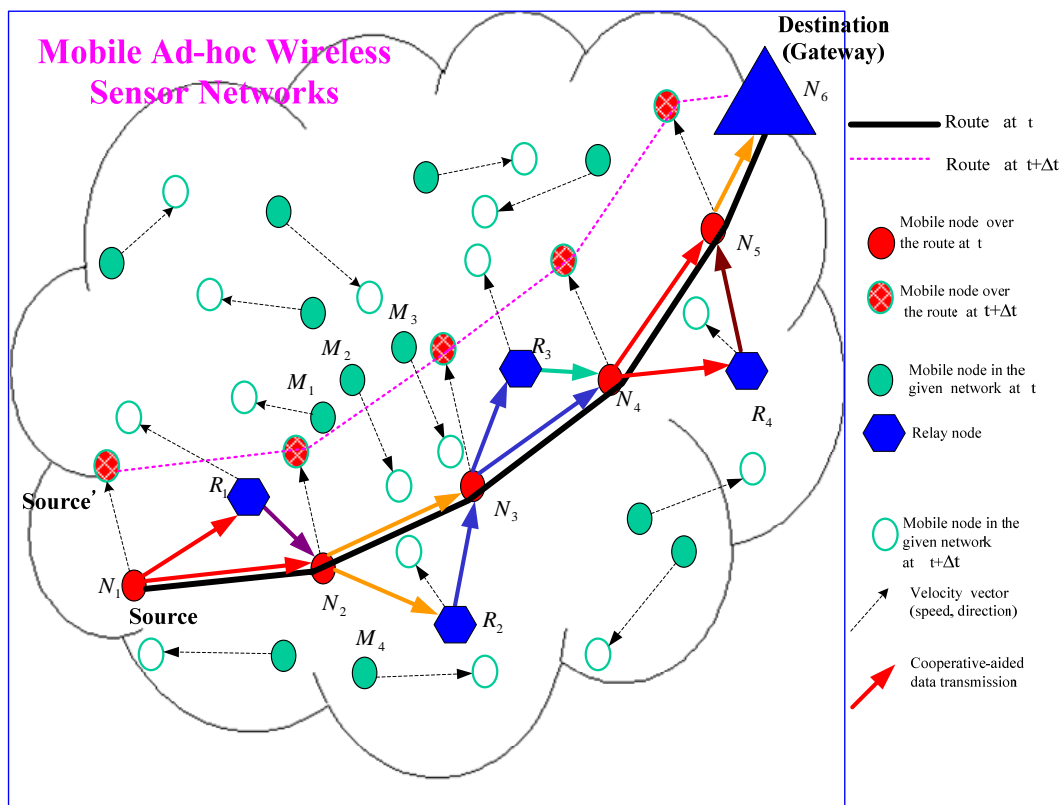


Fig. 1. Basic concepts and overview of cooperative transmission

Relay selection is one of the most important tasks for cooperative communications. However, due to the random movement of nodes in MAWSN, the bandwidth and power limitations, and the lack of fixed infrastructure, the development of efficient relay selection methods presents many issues and challenges [10][17][18][19]. Even if we can select a good relay node between a node N_i and a node N_{i+1} at time t , the selected relay node may be disconnected during some time interval Δ_t due to the location uncertainty of mobile nodes in MAWSN. In this paper, we propose a relay selection strategy that can choose the stable relay node from the viewpoint of node mobility to improve the packet delivery ratio, as well as the outage probability, by cooperative data transmission. The proposed relay selection uses the entropy concepts utilizing node mobility information to select the stable relay node. Therefore, the proposed relay selection can improve the reliability of data transmission during some time interval Δ_t to increase the packet delivery ratio with a long route lifetime between a source and a destination in MAWSN.

Route construction is an interesting challenge, due to the mobility and location uncertainty

of mobile nodes in MAWSN. There is much research in this area; especially, stable route selection using mobility information in MAWSN has become an active research field. Even if we can find good routes between a source node and a destination node at time t , the routes can be broken during some time interval Δ_t due to the location uncertainty of mobile nodes in MAWSN. The cooperative transmission in this paper uses the routing protocol, ERPM, in the literature [20] to solve these problems. ERPM uses entropy concepts utilizing node mobility information to select the stable routing routes between a source node and a destination node.

ERPM [20] is an active (on-demand) and non-tree (mesh) based routing protocol. The basic problems, goals and concepts of ERPM are as follows. Stable route selection in mobile ad-hoc wireless networks is an interesting challenge, due to the mobility and location uncertainty of mobile nodes. There is currently much research in this area. Especially, stable route selection using mobility information in mobile ad-hoc wireless network has become an active research field. Even if we can find a good routes between a source node and a destination node at time t , the routes can be broken during some time interval Δ_t due to the location uncertainty of mobile nodes in the mobile ad-hoc wireless networks. Thus, ERPM's goals are to construct stable routes that will be active at least during time interval Δ_t , to increase packet delivery ratio with a long route lifetime, as well as to quantitatively evaluate the stability of the routes, to select the most stable route between a source and a destination, in an environment where multiple paths are available in mobile ad-hoc wireless sensor networks.

The basic motivations of the proposed ERPM stem from the commonality observed in the location uncertainty in mobile ad-hoc wireless networks and the concept of entropy. These common characteristics have motivated our work in developing ERPM using entropy concepts and utilizing mobility information as the corresponding variable features. Thus ERPM can select stable routes and quantitatively evaluate route stability in self-organizing mobile ad-hoc wireless networks.

2.2 Entropy-based Relay Selection

The entropy concept is defined in [12] and is used to evaluate the stability and availability of a route. We use this concept to choose the most stable relay node. Fig. 2 considers the second hop of the route established in Fig. 1. Let us denote S_{R2} ($S_{R2} = \{M_1, M_2, M_3, M_4, M_5\}$) as the set of nodes existing in the neighborhood of nodes N_2 and N_3 (or the set of relay nodes in the second hop). In this paper, two nodes are called neighbors if they can reach each other in a single hop (i.e., direct transmission). Each node of the set S_{R2} knows the mobility information (including velocity and direction) of node N_2 and node N_3 and the distance to node N_2 and node N_3 due to route construction. Relying on the entropy concept in [12], we define a new entropy concept using both relative mobility and distance. The entropy $H_i(t, \Delta_t)$ at node M_i during the time interval Δ_t can be calculated as follows,

$$H_i(t, \Delta_t) = \frac{-P_{M_i, N_2}(t, \Delta_t) \log P_{M_i, N_2}(t, \Delta_t) - P_{M_i, N_3}(t, \Delta_t) \log P_{M_i, N_3}(t, \Delta_t)}{\log 2} \quad (1)$$

where,

$$P_{M_i, N_2}(t, \Delta_t) = \frac{d_{M_i, N_2} \cdot a_{M_i, N_2}}{d_{M_i, N_2} \cdot a_{M_i, N_2} + d_{M_i, N_3} \cdot a_{M_i, N_3}}, \quad P_{M_i, N_3}(t, \Delta_t) = \frac{d_{M_i, N_3} \cdot a_{M_i, N_3}}{d_{M_i, N_2} \cdot a_{M_i, N_2} + d_{M_i, N_3} \cdot a_{M_i, N_3}}$$

a_{M_i, N_2} , a_{M_i, N_3} defined as [12], are the relative mobility between node M_i and node N_2 and between node M_i and node N_3 , respectively. d_{M_i, N_2} , d_{M_i, N_3} are the distance from node M_i to node N_2 and to node N_3 , respectively. We will explain a_{M_i, N_2} , a_{M_i, N_3} and d_{M_i, N_2} , d_{M_i, N_3} as follows.

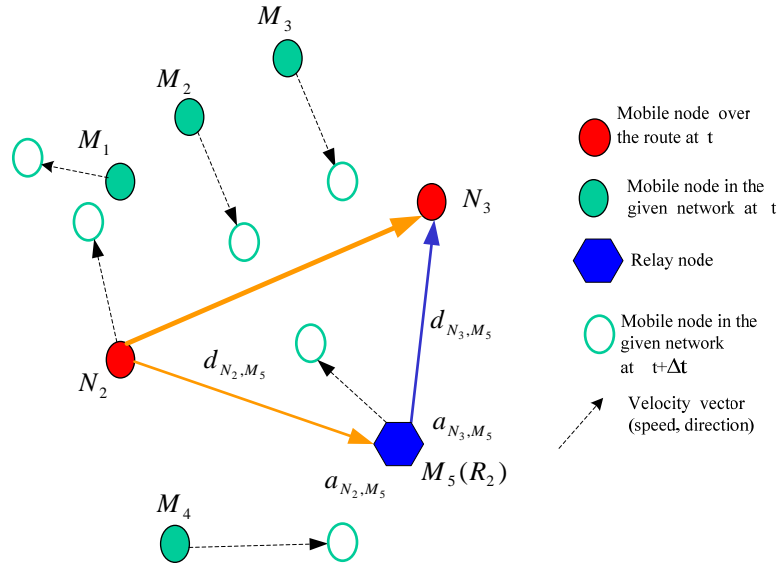


Fig. 2. Basic concepts of relay selection

The variable features a_{M_i, N_2} represent a measure of the relative speed between two nodes M_i and N_2 . Any change in the system can be described as a change of variable values a_{M_i, N_2} over the course of time t , such as $a_{M_i, N_2}(t) \rightarrow a_{M_i, N_2}(t + \Delta_t)$. Let us also denote $v(M_i, t)$, the velocity vector of node M_i and $v(N_2, t)$, the velocity(mobility) vector of node N_2 at time t . **Velocity vectors $v(M_i, t)$ and $v(N_2, t)$ have two parameters, speed and direction.** Therefore, the relative velocity $v(M_i, N_2, t)$ between nodes M_i and N_2 and the relative velocity $v(M_i, N_3, t)$ between nodes M_i and N_3 at time t are defined respectively as:

$$v(M_i, N_2, t) = v(M_i, t) - v(N_2, t)$$

$$v(M_i, N_3, t) = v(M_i, t) - v(N_3, t).$$

We consider the variable features, the relative mobility between two nodes. Therefore, we have:

$$a_{M_i, N_2} = |v(M_i, N_2, t)|$$

$$a_{M_i, N_3} = |v(M_i, N_3, t)|.$$

d_{M_i, N_2} and d_{M_i, N_3} are defined as follows:

$$d_{M_i, N_2} = \sqrt{(x_{N_2} - x_{M_i})^2 + (y_{N_2} - y_{M_i})^2}$$

$$d_{M_i, N_3} = \sqrt{(x_{N_3} - x_{M_i})^2 + (y_{N_3} - y_{M_i})^2}$$

where (x_{M_i}, y_{M_i}) , (x_{N_2}, y_{N_2}) , (x_{N_3}, y_{N_3}) are positions of nodes M_i , N_2 , N_3 respectively.

We can see that $H_i(t, \Delta_t)$ always takes non-negative values and equals 0 when the relative mobility a_{M_i, N_2} or a_{M_i, N_3} equals 0. If a_{M_i, N_2} and a_{M_i, N_3} equal 0, node N_2 , M_i and N_3 have the same mobility, an ideal case for relay selection. In addition, if d_{M_i, N_2} (or d_{M_i, N_3}) is high then a_{M_i, N_2} (or a_{M_i, N_3}) must be small in order to avoid disconnection between node M_i and N_2 (N_3) during time interval Δ_t . Therefore, similarly to [12], we propose a relay selection strategy: the relay node that provides the maximum entropy value among the set S_{R2} nodes is selected as the stable relay for cooperation. Now, we describe the operation of the entropy-based relay selection as follows. Initially, the source generates Route Request packet (RREQ). The RREQ packet is forwarded to destination, or intermediate nodes that know the route to the destination. In MAWSN, the RREQ and RREP packets consist of the additional elements, such as the position and mobility information of the node that sends them. Since node M_i is a neighbor of node N_2 , it can receive the RREQ packet from node N_2 and calculate the relative mobility a_{M_i, N_2} , as well as the distance d_{M_i, N_2} . When the destination receives RREQ, it replies to the source by sending a Route Reply packet (RREP) along the chosen path. In addition, node M_i can receive the RREP packet from node N_3 and calculate the relative mobility a_{M_i, N_3} and the distance d_{M_i, N_3} . Now, node M_i can calculate the entropy $H_i(t, \Delta_t)$ as in the equation (1) and send this value to node N_2 . Node N_2 collects the received entropy values and chooses the neighbor with the maximum entropy (for example node M_5 is chosen by node N_2 as in Fig. 2). Similarly, this strategy is used for other hops. Then, when the source receives RREP from the destination, it can send the data packets to the destination and at each hop, cooperative transmission is used to transmit data packets. The chosen relay node at each hop should be used during the lifetime of that route to decrease the overhead and complexity. However, when a route is broken, the source finds the new route to the destination. The relay at each hop is also updated following this new route.

3. Analysis of the Proposed Cooperative Transmission

3.1 System Model

We consider a mobile ad-hoc wireless sensor network (MAWSN) that has a selected route consisting of nodes $N_1, N_2, N_3, \dots, N_m, N_{m+1}$, as shown in Fig. 3. N_1 is a source node and N_{m+1}

is a destination node. In each hop, a relay assists the transmitting node to forward the information towards the next hop. Therefore, we exploit cooperative diversity hop by hop.

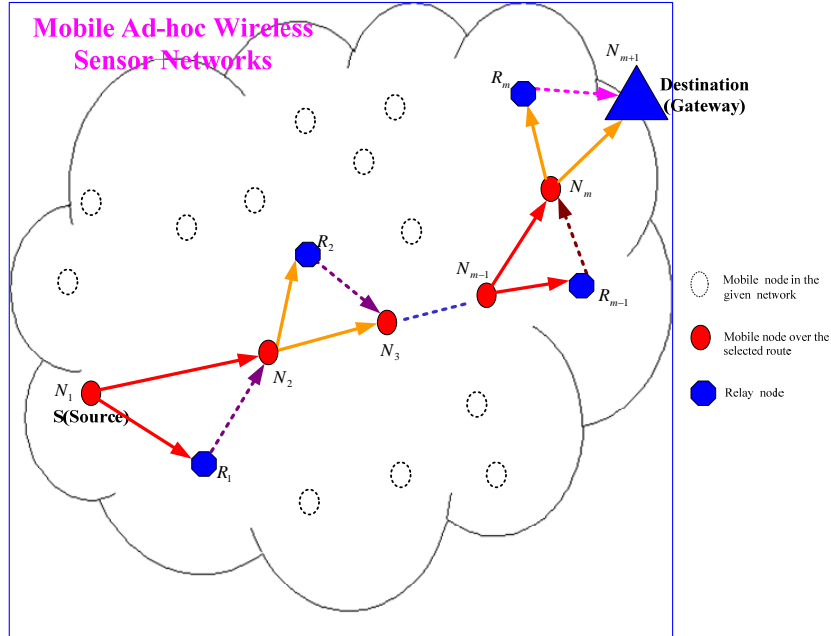


Fig. 3. System model for cooperative transmission

Consider that the nodes are randomly distributed over the network area and the channels between two nodes are subjected to flat Rayleigh fading plus AWGN. The baseband equivalent received signal at node j due to the transmission of node i for symbol n is given by

$$r_{i,j}(n) = \alpha_{i,j}s(n) + \eta_j(n) \quad (2)$$

where $\eta_j(n)$ is AWGN noise sample with variance $N_0/2$ per dimension at terminal j , $\alpha_{i,j}$ is the fading coefficient between node i and j , $s(n)$ is the signal transmitted by node i .

We consider flat Rayleigh fading, hence $\alpha_{i,j}$ is modeled as independent samples of zero mean complex Gaussian random variable with variance $\sigma_{i,j}^2$ per dimension. The fading coefficients are constant over the channel coherence time. We can model the variance of the channel coefficient between node i and node j as a function of the distance between two nodes [14], to consider path loss.

$$\sigma_{ij}^2 = d_{ij}^{-\beta} \quad (3)$$

where β is so the path loss exponent. It ranges from 2 to 6 based on the channel environment. d_{ij} is the distance between node i and j .

In cooperative transmission protocols, relays must process the signals received. However, current limitations in radio implementation preclude transmitting and receiving simultaneously using the same frequency band. In this paper, each node has a single

half-duplex radio and a single antenna. Each relay node must transmit on separate channels due to the half-duplex constraint. Hence, for medium access, a time-division channel allocation scheme is used to implement orthogonal channels. Thus, no inter-relay interference is considered in the signal model. However, the basic idea and operation of our proposed protocol does not depend on the specifics of the channel access protocol.

3.2 Outage Probability Analysis

In this paper, we focus on the end-to-end (source node-to-destination node) outage performance of the cooperative multi-hop scenario, shown in Fig. 3. For hop i , node N_i transmits data to node N_{i+1} with the help of relay R_i . We define the outage probability of hop i between two nodes, N_i and N_{i+1} , as

$$P_{out}(i) = \Pr[I(N_i, N_{i+1}) < R] \quad (4)$$

where $I(N_i, N_{i+1})$ is the mutual information between N_i and N_{i+1} , and R is the target rate of the system.

3.2.1 Direct Transmission.

In this case, we consider the system fails to find a relay at hop i and a non-cooperative direct transmission (DT) has taken place between node N_i and N_{i+1} . Now, the outage probability of direct transmission can be given as

$$\begin{aligned} P_{out}^{DT}(i) &= \Pr[I(N_i, N_{i+1}) < R] = \Pr[\log(1 + \gamma |\alpha_{N_i, N_{i+1}}|^2) < R] \\ &= \Pr\left[|\alpha_{N_i, N_{i+1}}|^2 < \frac{2^R - 1}{\gamma}\right] \end{aligned} \quad (5)$$

where $\gamma = P/N_0$.

Now, we consider $\alpha_{i,j}$ has a Rayleigh distribution so $|\alpha_{i,j}|^2$ has an exponential distribution with parameter σ_{ij}^{-2} . Therefore, using the CDF of $|\alpha_{i,j}|^2$ we can calculate the outage probability of direct transmission as

$$P_{out}^{DT}(i) = 1 - \exp\left(-\sigma_{N_i, N_{i+1}}^{-2} \frac{2^R - 1}{\gamma}\right) \quad (6)$$

3.2.2 Cooperative Transmission

Assume a selection relaying [7] at each hop; the relay will forward the data packets when the received SNR at the relay satisfies a predefined threshold. In this protocol, the relay will forward the received packets if it satisfies the predefined rate R , otherwise it will be silent. Thus, in the first time slot, the sender transmits the data packets to receiver; then, relays that decode successfully will transmit the received packets to the receiver in the second time slot. Next, the Maximal Ratio Combining (MRC) technique is used to combine the received packets at the receiver. Therefore, the mutual information between N_i and N_{i+1} can be given as [7].

$$I(N_i, N_{i+1}) = \begin{cases} \frac{1}{2} \log(1 + \gamma |\alpha_{N_i, N_{i+1}}|^2); & I(N_i, R_i) < R \\ \frac{1}{2} \log(1 + \gamma [|\alpha_{N_i, N_{i+1}}|^2 + |\alpha_{R_i, N_{i+1}}|^2]); & I(N_i, R_i) \geq R \end{cases} \quad (7)$$

where $I(N_i, R_i)$ is mutual information between N_i and R_i , and given as

$$I(N_i, R_i) = \frac{1}{2} \log(1 + \gamma |\alpha_{N_i, R_i}|^2) \quad (8)$$

Since the two events in equation (7) are mutually exclusive, the outage probability can be written as

$$\begin{aligned} P_{out}^{CT}(i) &= \Pr[I(N_i, N_{i+1}) < R] \\ &= \Pr[I(N_i, R_i) < R] \times P_{1,i} + \Pr[I(N_i, R_i) \geq R] \times P_{2,i} \end{aligned} \quad (9)$$

where $P_{1,i} = P_{out}^{DT}(i)$ represents the outage probability of direct transmission between node N_i and N_{i+1} , and $P_{2,i}$ is the outage probability of cooperative transmission between node N_i and N_{i+1} with the help of relay R_i , and is given as

$$\begin{aligned} P_{2,i} &= \Pr\left[\frac{1}{2} \log(1 + \gamma \{|\alpha_{N_i, N_{i+1}}|^2 + |\alpha_{R_i, N_{i+1}}|^2\}) < R\right] \\ &= \Pr\left[|\alpha_{N_i, N_{i+1}}|^2 + |\alpha_{R_i, N_{i+1}}|^2 < \frac{2^{2R} - 1}{\gamma}\right] \end{aligned} \quad (10)$$

The CDF of the random variable $|\alpha_{N_i, N_{i+1}}|^2 + |\alpha_{R_i, N_{i+1}}|^2$ can be given as [7]

$$F(x) = \begin{cases} 1 - (1 + \sigma^{-2}x) \exp(-\sigma^{-2}x); & \text{for } \sigma_{N_i, N_{i+1}}^{-2} = \sigma_{R_i, N_{i+1}}^{-2} = \sigma^{-2} \\ 1 - \left[\frac{\sigma_{R_i, N_{i+1}}^{-2}}{\sigma_{R_i, N_{i+1}}^{-2} - \sigma_{N_i, N_{i+1}}^{-2}} \exp(-\sigma_{N_i, N_{i+1}}^{-2}x) + \frac{\sigma_{N_i, N_{i+1}}^{-2}}{\sigma_{N_i, N_{i+1}}^{-2} - \sigma_{R_i, N_{i+1}}^{-2}} \exp(-\sigma_{R_i, N_{i+1}}^{-2}x) \right]; & \text{for } \sigma_{N_i, N_{i+1}}^{-2} \neq \sigma_{R_i, N_{i+1}}^{-2} \end{cases} \quad (11)$$

We can rewrite equation (10) using the CDF of (11) as

$$P_{2,i}(\rho) = \begin{cases} 1 - (1 + \sigma^{-2} \rho) \exp(-\sigma^{-2} \rho); & \text{for } \sigma_{N_i, N_{i+1}}^{-2} = \sigma_{R_i, N_{i+1}}^{-2} = \sigma^{-2} \\ 1 - \left[\frac{\sigma_{R_i, N_{i+1}}^{-2}}{\sigma_{R_i, N_{i+1}}^{-2} - \sigma_{N_i, N_{i+1}}^{-2}} \exp(-\sigma_{N_i, N_{i+1}}^{-2} \rho) + \right. \\ \left. \frac{\sigma_{N_i, N_{i+1}}^{-2}}{\sigma_{N_i, N_{i+1}}^{-2} - \sigma_{R_i, N_{i+1}}^{-2}} \exp(-\sigma_{R_i, N_{i+1}}^{-2} \rho) \right]; & \text{for } \sigma_{N_i, N_{i+1}}^{-2} \neq \sigma_{R_i, N_{i+1}}^{-2} \end{cases} \quad (12)$$

where $\rho = (2^{2R} - 1) / \gamma$.

Similar to equation (5) and (6), we can write the outage probability between N_i and R_i as

$$\Pr[I(N_i, R_i) < R] = 1 - \exp(-\sigma_{N_i, R_i}^{-2} \rho) \quad (13)$$

Therefore, we can obtain the probability of success between N_i and R_i as

$$\Pr[I(N_i, R_i) \geq R] = \exp(-\sigma_{N_i, R_i}^{-2} \rho) \quad (14)$$

Replacing the values of equation (6), (12), (13) and (14) in equation (9) we can calculate the cooperative outage probability of hop i .

3.2.3 End-to-End Outage Probability

In this subsection, we derive the end-to-end (source node to destination node) outage probability of our proposed cooperative transmission in the given MAWSN. We consider M -hops cooperative routing route, whilst all hops are independent. We assume L is the number of hops that has successfully selected a relay, where L is a subset of M (i.e. $L \subset M$). Therefore, the end-to-end outage probability for the M -hops cooperative routing is a simple multiplication of the outage probability of each hop and can be given as

$$P_{out} = 1 - \prod_{i \in L} (1 - P_{out}^{CT}(i)) \prod_{j \notin L} (1 - P_{out}^{DT}(j)) \quad (15)$$

4. Performance Evaluation

4.1 Simulation Scenario and Frameworks

The performance of our protocol is evaluated by means of analysis and simulation using the Optimized Network Engineering Tool (OPNET). The simulation models a MAWSN consisting of 50 nodes placed randomly within a rectangular region of 1 km x 1 km. Each node is modeled as an infinite-buffer, store-and-forward queuing station. It is assumed to be aware of its position with the aid of a reliable position location system (i.e., GPS). The mobile nodes are assumed to have a constant radio range of $Z = 250$ m. The radio range is used to construct a route and find the most stable relay at each hop of this route, but it is not used in data transmission over Rayleigh fading channel. We use the random mobility scenario, in which the speed and the direction of each move are uniformly distributed with speed range $[0, v_{max}]$ km/h and direction range $[0, 2\pi]$ respectively. During the simulation, a node moves

around the network and if a mobile arrives at the boundary of the given network coverage area, the node reenters the network.

4.2 Performance Metrics

The performance metrics for analysis and simulation follow:

- **PDR:** the ratio of the number of packets received at the destination to the number of packets transmitted at the source.
- **Outage Probability:** the probability that the system model is in outage.

4.3 Numerical Results

In this section, we present simulation results of the cooperative transmission (**CooPTR**) over the Rayleigh Fading channel. We choose the system target rate $R = 1$ packet/s/Hz, the path loss exponent $\beta = 3$, simulation time of 200 seconds, packet sending rate 1pkts/sec and 5 seconds to reconstruct a new route from a source to a destination.

We compare the simulation results of the cooperative transmission (**CooPTR**) with the analytical results. We calculate the average outage probability, to present the theoretical results in MAWSN, as follows. First, we calculate the average distance between node N_i and N_{i+1} (\bar{d}), between node N_i and R_i (\bar{d}_1), and between node R_i and N_{i+1} (\bar{d}_2). Second, the average number of hops per route (\bar{m}) and the average number of hops per hop (\bar{n}) that selects successfully a relay for cooperation are calculated. Thus, from equation (6), (12), (13) and (14), we can calculate the average outage probabilities substituting $\rho = (2^{2R} - 1) / \gamma$, $\sigma_{N_i, N_{i+1}}^{-2} = \bar{d}^\beta$, $\sigma_{N_i, R_i}^{-2} = \bar{d}_1^\beta$ and $\sigma_{R_i, N_{i+1}}^{-2} = \bar{d}_2^\beta$.

Next, the average outage probability of a route can be given

$$P_{out} = 1 - (1 - P_{out}^{DT})^{\bar{m}-\bar{n}} (1 - P_{out}^{CT})^{\bar{n}} \quad (16)$$

Finally, the PDR of a route in the analysis can be approximated by

$$\text{PDR} \approx 1 - P_{out} = (1 - P_{out}^{DT})^{\bar{m}-\bar{n}} (1 - P_{out}^{CT})^{\bar{n}} \quad (17)$$

Fig. 4, 5 and 6 draw the packet delivery ratio (PDR) as a function of SNR when the value of v_{max} is fixed. The theoretical results and the simulation differ. In this paper, there is a deviation compared to the real distance and the real number of hops in the simulation, because the average distance and the average number of hops are used to calculate the theoretical results. However, the simulation results can approach the theoretical results and the difference is acceptable in the high SNR region. In these figures, the PDR of the cooperative transmission (**CooPTR**) and AODV increases when the SNR increases, but the PDR of cooperative transmission (**CooPTR**) is larger than that of AODV in the high SNR range. This is due to the cooperative transmission (**CooPTR**) using cooperative communication that can improve data transmission reliability.

In **Fig. 7, 8 and 9**, we fix SNR and draw PDR as a function of velocity. For all values of v_{max} , the PDR of cooperative transmission (**CooPTR**) is still larger than that of AODV at the high SNR values. When mobile nodes move at high velocity, the established routes between the source and destination are easily broken. Therefore, the PDR of AODV, as well as

of cooperative transmission (**CooPTR**), decreases when v_{max} increases.

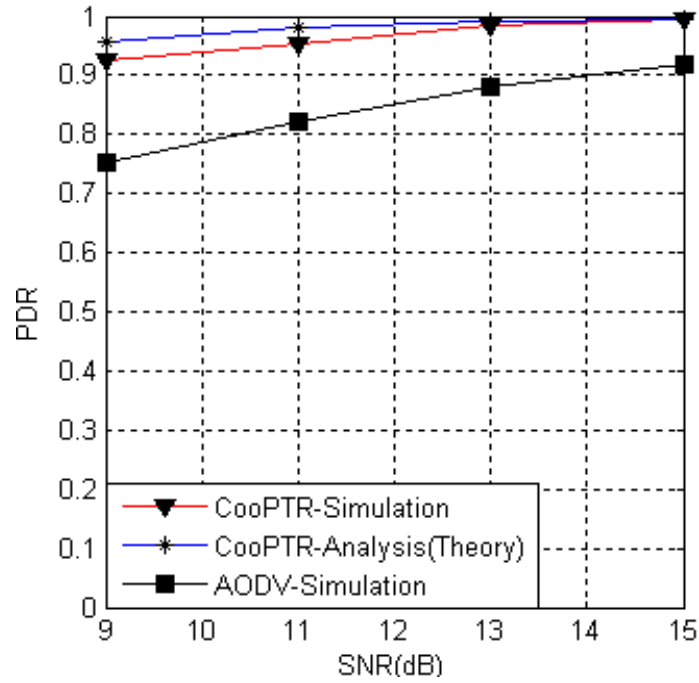


Fig. 4. Packet delivery ratio (PDR), $v_{max} = 20$ km/h

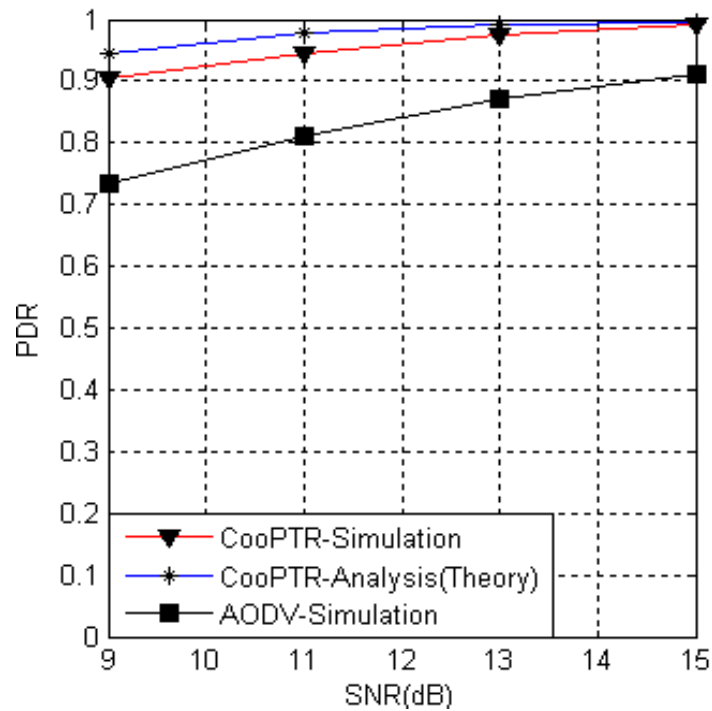


Fig. 5. Packet delivery ratio (PDR), $v_{max} = 40$ km/h

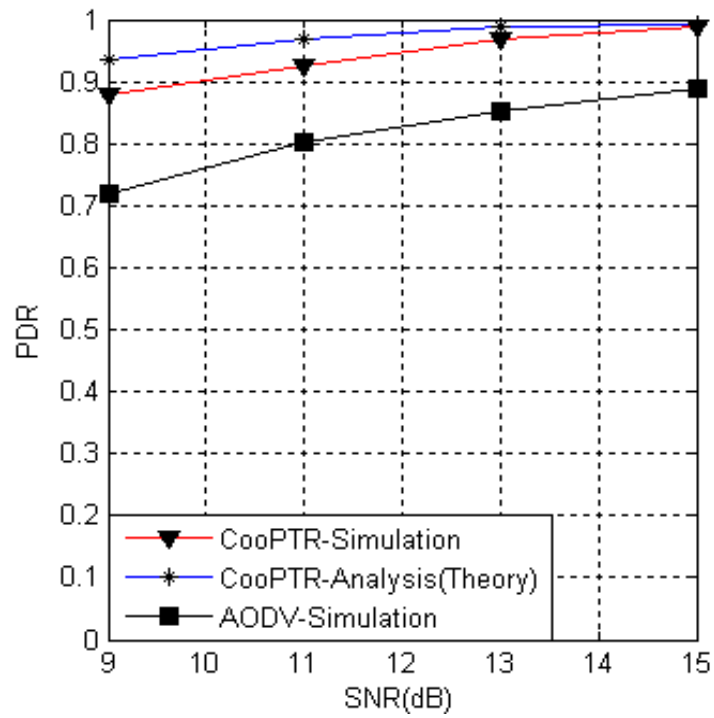


Fig. 6. Packet delivery ratio (PDR), $v_{max} = 60$ km/h

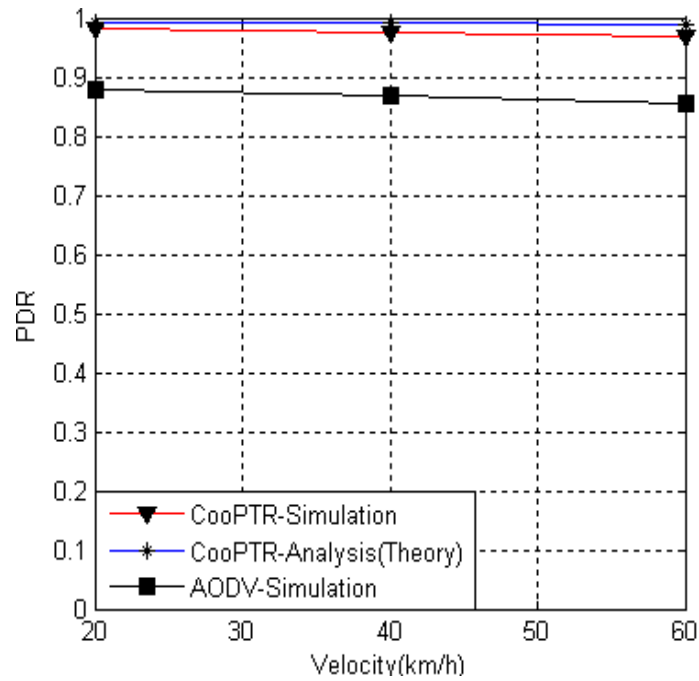


Fig. 7. Packet delivery ratio (PDR), SNR = 13dB

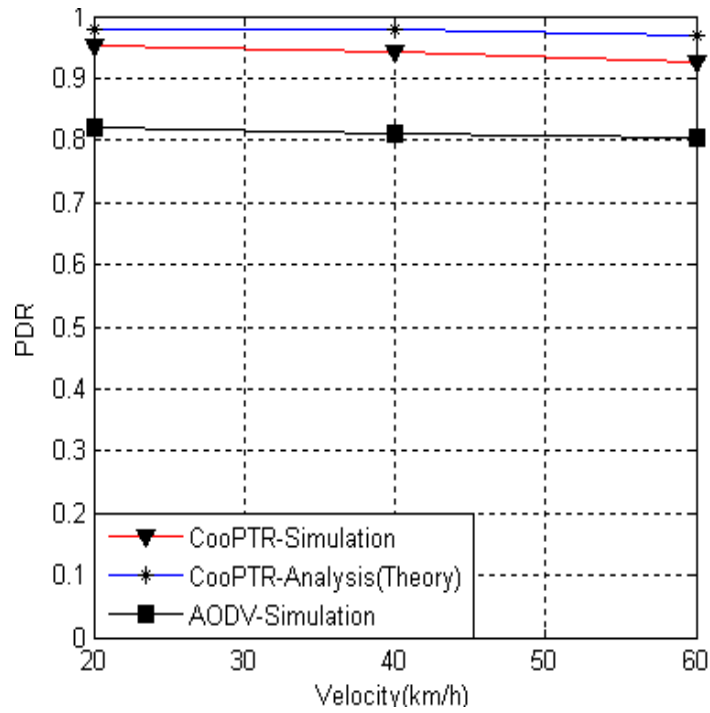


Fig. 8. Packet delivery ratio (PDR), SNR = 11dB

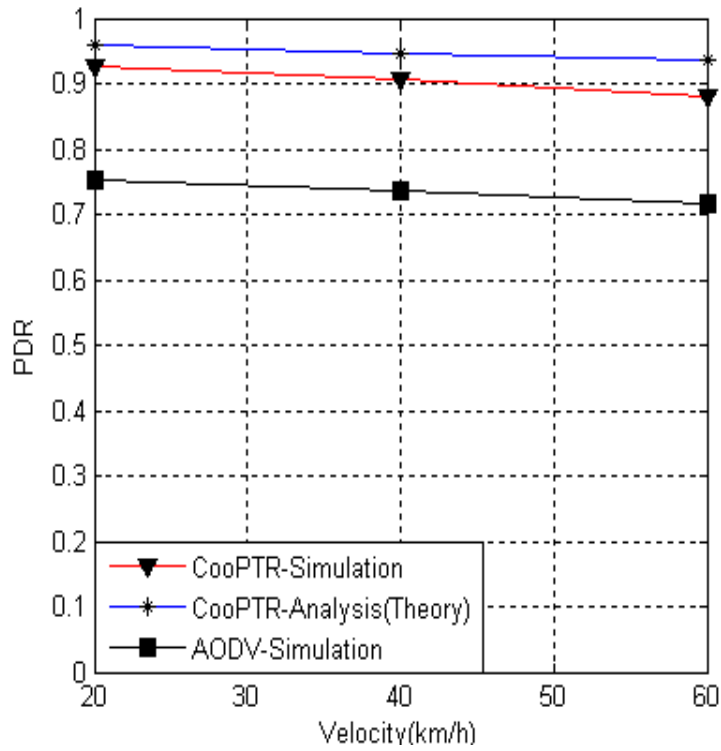


Fig. 9. Packet delivery ratio (PDR), SNR = 9dB

5. Conclusion

In this paper, we propose a cooperative transmission strategy using entropy-based relay selection in Mobile Ad-hoc Wireless Sensor Networks (MAWSN) with Rayleigh fading environments. The main features and contributions of the cooperative transmission are as follows: (i) stable relay selection, using entropy-based concepts, supports the reliability of cooperative data transmission, and (ii) a theoretical analysis model for cooperative transmission to calculate the average outage probability. Performance of the proposed cooperative transmission is evaluated by theoretical analysis and via simulation using OPNET. We compare the results of theoretical analysis, simulation, and AODV for the packet delivery ratio (PDR). The theoretical analysis and simulation results for cooperative transmission are similar at high SNR. Cooperative transmission performs better than AODV.

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Beongku An received the M.S. degree in electrical engineering from the Polytechnic University, NY, USA, in 1996 and Ph.D. degree from New Jersey Institute of Technology (NJIT), NJ, USA, in 2002, respectively. After graduation, he joined the Faculty of the Department of Computer and Information Communications Engineering, Hongik University in Korea, where he is currently a Professor. From 1990 to 1994, he was a senior researcher in RIST, Pohang, Korea. He also was lecturer and RA in NJIT from 1997 to 2002. His current research interests include mobile wireless networks, such as ad-hoc networks, sensor networks, wireless internet, ubiquitous networks, and cellular networks. In particular, he is interested in cooperative routing, multicast routing, cross-layer technologies in mobile wireless sensor networks. Dr. An was listed in Marquis Who's Who in Science and Engineering in 2005-2008, and Marquis Who's Who in the World in 2006-2008, respectively.



Tran Trung Duy received the B.E. degree in Electronics and Telecommunications Engineering from Ho Chi Minh City University of Technology, Vietnam, in 2007. He is currently working toward the Master degree in the Department of Electrical Engineering, University of Ulsan, Korea. His major research interests are mobile ad-hoc networks, wireless sensor networks, cooperative communication, cooperative routing, cognitive radio, combining techniques.



Hyung Yun Kong received the ME and PhD degrees in electrical engineering from Polytechnic University, Brooklyn, New York, USA, in 1991 and 1996. He received the BE in electrical engineering from New York Institute of Technology, New York in 1989. In 1996, he was with LG electronics Co., Ltd., in the multimedia research lab developing PCS mobile phone systems, and from 1997 the LG chairman's office planning future satellite communication systems. Currently he is Professor in electrical engineering at University of Ulsan, Korea. He works in several government projects supported by ITRC, Korean Science and Engineering Foundation (KOSEF), etc. His research area includes high data rate modulation, channel coding, detection and estimation, cooperative communications, and sensor networks. He is a member of IEEK, KICS, KIPS, IEEE and IEICE.