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CRARQ: 모바일 Ad-hoc 무선 센서 네트워크를 위한 ARQ 전송기반 협력도움 라우팅 프로토콜

(CRARQ: A Cooperative Routing using ARQ-based Transmission in Mobile Ad-hoc Wireless Sensor Networks)

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요 약

본 논문에서는 모바일 ad-hoc 무선 센서 네트워크에서 ARQ 기반 전송을 사용하는 협력도움 라우팅 프로토콜(CRARQ)을 제안한다. 제안된 CRARQ 의 주요한 목적은 데이터 전송의 효율과 신뢰성을 함께 향상시키기 위함이다. 제안된 CRARQ 의 주요한 특징 및 기여도는 다음과 같다. 첫째, CRARQ 는 어떤 요구기반 개념을 사용하여 소스와 목적지 사이에 경로를 설정한다. 둘째, CRARQ 는 설정된 경로를 따라서 엔트로피 기반 전략을 사용하여 안정된 릴레이를 선택한다. 셋째, 소스와 목적지 사이에 데이터 전송의 신뢰성을 향상시키기 위해서 ARQ 기술기반 협력전송 방법을 사용한다. 마지막으로, 제안된 CRARQ 의 이론적인 분석 모델을 제안 설명한다. 제안된 라우팅 프로토콜의 성능평가는 시뮬레이션과 이론적인 분석을 통하여 이루어 진다. 시뮬레이션과 이론적인 분석 결과는 패킷전송 효율(PDR) 및 Outage Probability 에 대한 CRARQ 의 향상된 성능을 보여준다.

Abstract

In this paper, we propose a Cooperative Routing using ARQ-based Transmission (CRARQ) in Mobile Ad-hoc Wireless Sensor Networks (MAWSN). The goals of the CRARQ are to improve both the efficiency of transmission and the reliability of transmission together. The main features and contributions of the proposed CRARQ for supporting these goals are as follows. First, CRARQ uses a reactive concept to construct a route from a source to a destination. Second, CRARQ chooses the most stable relay at each hop along the route by mobility-based strategy. Third, cooperative transmission using the ARQ technique which can improve reliability is used at each hop to send data packets from source to destination. Finally, we present a theoretical analysis model for the proposed CRARQ. The performance evaluation of our protocol is implemented via simulation using Optimized Network Engineering Tool (OPNET) and analysis. The results of both simulation and analysis show that CRARQ achieves the improved packet delivery ratio (PDR) and outage probability.

Keywords : Cooperative Communication, ARQ, Entropy, Mobility, Mobile Ad-hoc Wireless Sensor Networks

Ⅰ. Introduction

Due to the random movement of mobile sensor nodes, the bandwidth and power limitations, and the lack of fixed infrastructure, the development of efficient protocols to support the various networking operations in mobile ad-hoc wireless sensor networks(MAWSN) present many issues and

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challenges[1~3]. When users can not support multiple antennas, a cooperative diversity protocol[4] has been proposed to provide transmit diversity. Currently, various cooperative transmission protocols, implementation issues, performance and outage analysis have been studied in literature[4~7]. So far, the most of works related to cooperative communication has focused on just single-hop networks. However, significant research challenges for cooperative multi-hop network still exit. 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 focus on mainly fixed sensor nodes. We focus on routing issue in the view points of both efficiency and reliability in MAWSN[2, 8]. The proposed CRARQ can improve the efficiency of transmission by using cooperative transmission with advanced SNR while the reliability of transmission can be improved by ARQ-based technique during cooperative transmission[9~11]. The rest of this paper is organized as follows. The proposed CRARQ is described in section II and the theoretical analysis of the CRARQ is presented in section III. The performance evaluation of the CRARQ is presented in section IV and section V concludes this paper.

II. The proposed CRARQ

2.1 The basic concepts of CRARQ

As we can see in Fig. 1, the basic concepts of the proposed CRARQ to support both the efficiency of transmission and the reliability of transmission together are as follows. First, we use a cooperative aided transmission by the most stable relay which is selected by using mobility-based concepts to support the efficiency of transmission from a source to destination.

Second, we use an ARQ-based technique to improve the reliability of the transmission from a source to a destination during cooperative transmission. In the Fig. 1, at each hop, if a node can not decode the received packet from its previous node correctly, it sends a negative acknowledgment message (NACK) to request the chosen relay to relay the packet.

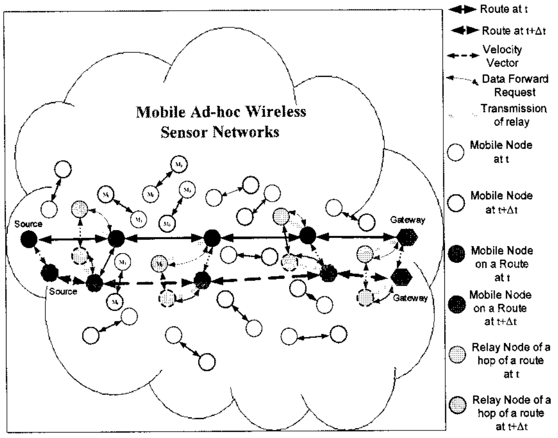

그림 1. CRARQ의 기본 개념

Fig. 1. The basic concepts of the CRARQ.

2.2 The relay selection strategy

In the Fig. 2, we consider the second hop of the established route in the Fig. 1. Let us denote by S_{R2} ($S_{R2} = \{M_1, M_2, M_3, M_4, M_5\}$ as in the Fig. 2), the set of nodes that exist in the neighborhood of both node N_2 and N_3 (or the set of the available relay nodes at this hop). In this paper, two nodes are called neighbors if they can reach each other in one hop (e.g., direct transmission). Thus, each node of the set S_{R2} can know the mobility information (including velocity and direction) of node N_2 and node N_3 from the operation of route construction. We use the relative mobility concept to choose the most stable

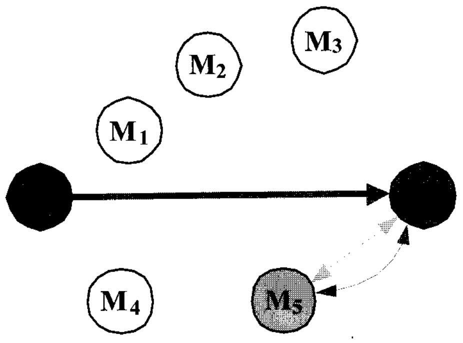

그림 2. 릴레이 선택 전략

Fig. 2. The relay selection strategy.

relay M_i as the following strategy:

$$M_i : \min_{M_i \in S_{R2}} (\max(a_{M_i,N_2}, a_{M_i,N_3})) \tag{1}$$

where a_{M_i,N_2} and a_{M_i,N_3} defined in [12], are the relative mobility between node M_1 and N_2 and between node M_1 and N_3, respectively.

2.3 The operation of CRARQ

The operations of CRARQ are as following steps:

Step 1: Source generates and advertises a RREQ packet to its neighbors using broadcast. The RREQ consists of the basic elements as source ID, source sequence number, broadcast ID, destination ID, destination sequence number, hop count and the various elements such as ID, position and mobility information of the node which sends the RREQ.

Step 2: When a node receives RREQ packet, it discards this packet if it has already received from a neighbor earlier. Then, it calculates the relative mobility and re-broadcasts the RREQ to its own neighbors. For example, node M_i in the Fig. 2 can calculate the relative mobility between itself and node N2 (a_{M_i,N_2}) when it receives RREQ from N_2 .

Step 3: When a destination receives RREQ, it sends a RREP along a route to source. The RREP consists of source ID, destination ID, ID of its previous node that sends RREQ to it first, destination sequence number, hop count, lifetime and ID, position and mobility information of the node which sends the RREP.

Step 4: When a node receives RREP, it checks if it is the target node of this packet by comparing its ID with ID of the previous node included in this packet. If it is the target node, it sends the RREP to its previous node. Otherwise, it discards this packet. For example, from step 2 and step 4, node M_i can calculate the value of $\max(a_{M_i,N_2}, a_{M_i,N_3})$ and it sends a message including this value to node N_2. Then, node N2 can choose the most stable relay from nodes in the set S_{R2} .

Step 5: When a source receives RREP, it starts to send the data packets to a destination by using cooperative transmission based on ARQ technique at each hop. For example, at the second hop in the Fig. 2, N_2 sends data packet to node N_3 and at the same time node M_5 (the chosen relay of this hop) also receives data packet from node N_2 . Both node N_3 and M_5 decode the received data packet. If node N3 decodes correctly, it sends this packet to next hop. Otherwise, it sends a negative acknowledgment message (NACK) to node M_5 . If node M_5 decoded correctly, it transmits the received data packet to node N_3. Otherwise, M_5 remains silent and this means the data packet drops at this hop. This process continues hop by hop until the destination receives data packet.

III. The analysis of CRARQ

3.1 System Model

We consider a m-hop wireless network that has a selected route consisting of nodes $N_1, N_2, N_3, \ldots, N_m, N_{m+1}$ as shown in Fig. 3. Where N_1 is a source node and N_{m+1} is a destination node. In each hop, there is a relay that assists the transmitting node to forward the information towards the next hop. Therefore, we exploit a cooperative diversity hop by hop.

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. Each node has a single half duplex radio and a single antenna. The baseband equivalent received signal at node j due to the transmission of node i for symbol n is given by,

$$r_{i,j}(n) = \sqrt{P d_{i,j}^{-\alpha}}\, h_{i,j} s(n) + \eta_j(n) \tag{2}$$

where P is the transmitted power, $d_{i,j}$ is the distance between node i and j, α is path loss exponent that varies from 2 to 6 on the basis of

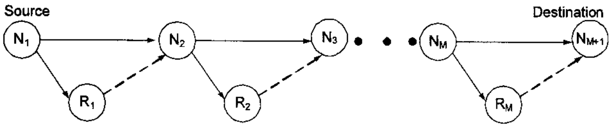

그림 3. CRARQ의 시스템 모델

Fig. 3. The system model of the CRARQ.

channel environment, $h_{i,j}$ is fading coefficient between node i and j, $s(n)$is the signal transmitted by node i with normalized unit power and $\eta_j(n)$is AWGN noise sample with variance $N_o/2$.

3.2 Outage Analysis

In this paper, we focus on the end-to-end (source to destination) 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 as,

$$P_{out}(i) = pr\left[I_{N_i, N_{i+1}} < R\right] \tag{3}$$

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

$$\begin{aligned} P_{out}^{DT}(i) &= \Pr\left[I_{N_i, N_{i+1}} < R\right] = \Pr\left[\log(1+\frac{Pd_{N_i, N_{i+1}}^{-\alpha}\left|h_{N_i, N_{i-1}}\right|^2}{N_0}) < \mathrm{R}\right] \\ &= \Pr\left[\left|h_{N_i, N_{i-1}}\right|^2 < \frac{(2^R-1)N_0 \cdot d_{N_i, N_{i+1}}^{\alpha}}{P}\right] \end{aligned} \tag{4}$$

Now, we consider $h_{N_i, N_{i+1}}$ has Rayleigh distribution, so $\left|h_{N_i, N_{i+1}}\right|^2$ has exponential distribution. Using the CDF of $\left|h_{N_i, N_{i+1}}\right|^2$ we can easily calculate the outage probability of direct transmission as follows

$$P_{out}^{DT} = 1 - \exp(-\frac{(2^R - 1)N_o d_{N_i, N_{i+1}}^{\alpha}}{P}) \tag{5}$$

3.2.2 ARQ-based Transmission

In general, some combining techniques such as Maximal Ratio Combining (MRC), Equal Gain Combining (EGC) or Selection Combining (SC) are used at the receiver to combine the signal. For more simplicity, we use ARQ-based cooperative transmission. With this technique, we derive the outage probability at hop i as follows:

$$\begin{aligned} P_{out}{}^{ARQ}(i) &= \Pr[I_{N_i,N_{i+1}} < R].P[I_{N_i,R_i} < R] + \Pr[I_{N_i,N_{i+1}} < R] \\ &(1 - \Pr[I_{N_i,R_i} < R])\ \Pr[I_{R_i,N_{i+1}} < R] \end{aligned} \tag{6}$$

In equation (6), the cooperative transmission is outage when both N_i-N_{i+1} and N_i-R_i are in outage or when N_i-N_{i+1} and R_i-N_{i+1} are in outage but Ni-R_i is not in outage. The mutual information of N_i-N_{i+1}, N_i-R_i, R_i-N_{i+1} are respectively

$$I_{N_i,N_{i+1}} = \frac{1}{2}\log(1+\frac{Pd_{N_i,N_{i+1}}^{-\alpha}\,|h_{N_i,N_{i+1}}|^2}{N_0}) \tag{7}$$

$$I_{N_i,R_i} = \frac{1}{2}\log(1+\frac{Pd_{N_i,R_i}^{-\alpha}\,|h_{N_i,R_i}|^2}{N_0}) \tag{8}$$

$$I_{R_i,N_{i+1}} = \frac{1}{2}\log(1+\frac{Pd_{R_i,N_{i+1}}^{-\alpha}\,|h_{R_i,N_{i+1}}|^2}{N_0}) \tag{9}$$

Similar to equation (4) and (5), we have:

$$\Pr[I_{N_i,N_{i+1}} < R] = 1 - \exp(-\frac{(2^{2R}-1)N_0 d_{N_i,N_{i+1}}^{\alpha}}{P}) \tag{10}$$

$$\Pr[I_{N_i,R_i} < R] = 1 - \exp(-\frac{(2^{2R}-1)N_0 d_{N_i,R_i}^{\alpha}}{P}) \tag{11}$$

$$\Pr[I_{R_i,N_{i+1}} < R] = 1 - \exp(-\frac{(2^{2R}-1)N_0 d_{R_i,N_{i+1}}^{\alpha}}{P}) \tag{12}$$

Now, replacing the values of equation (10), (11), (12) into the equation (6) we can calculate the cooperative outage probability of hop i for the ARQ-based transmission.

3.2.3 End-to-End outage probability

In this subsection, we will derive the end-to-end (source to destination) outage probability of our proposed CRARQ in the given mobile ad-hoc wireless sensor networks (MAWSN). Assume S is a subset of M that has successfully selected a relay and consider all the hopes are independent. So, the end-to-end outage probability for an M-hop cooperative routing route is simple multiplication of outage probability of each hop and can be given as

$$P^{Total}_{out}(i) = 1 - \prod_{i\in S}^{M}\left(1-P^{ARQ}_{out}(i)\right)\prod_{j\notin S}^{M}\left(1-P^{DT}_{out}(j)\right) \qquad (13)$$

Ⅳ. Performance Evaluation

4.1 Simulation Scenario and Frameworks

The performance evaluation of our protocol is accomplished via simulation using the Optimized Network Engineering Tool (OPNET)and analysis. A mobile ad-hoc wireless sensor network consisting of 50 nodes that are placed randomly within a rectangular region of 1 km x 1 km is modeled in the simulation. Each node is modeled as an infinite-buffer, store-and-forward queuing station, and 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 constant radio range of Z= 250m. The radio range is used to construct a route and find the most stable relay, but it is not used in the 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, 2π] 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 into network.

4.2 Performance Metrics

The performance metrics for simulation and analysis are as follow:

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

4.3 Numerical Results

In this section, we present some simulation results of CRARQ under Rayleigh Fading channel. We choose the target rate of the system R = 1 b/s/Hz, the path loss exponent α=3, 200 seconds for the simulation time, 1pkts/sec for the rate of sending packets and 5 seconds for recontructing a new route from a source and a destination.

In the simulation, we compare the simulation results of CRARQ with the analytical results. In order to present the theoretical results in MAWSN, we calculate the average outage probability as follows. First, we calculate the average distance between node N_i and N_{i+1} ($\overline{d}$), between node N_i and R_i ($\overline{d_1}$), between node R_i and N_{i+1} ($\overline{d_2}$). Second, the average number of hop per a route ($\overline{m}$) and the average number of hop per a hop ($\overline{n}$) that selects successfully a relay for cooperation are also calculated. Thus, from equation (10), (11) and (12), we have the average outage probabilities as follows

$$\Pr[I_{N_i,N_{i+1}} < R] = 1-\exp\left(-\frac{(2^{2R}-1)N_0\overline{d}^{\alpha}}{P}\right) \qquad (14)$$

$$\Pr[I_{N_i,R_i} < R] = 1-\exp\left(-\frac{(2^{2R}-1)N_0\overline{d_1}^{\alpha}}{P}\right) \qquad (15)$$

$$\Pr[I_{R_i,N_{i+1}} < R] = 1-\exp\left(-\frac{(2^{2R}-1)N_0\overline{d_2}^{\alpha}}{P}\right) \qquad (16)$$

Then, the average cooperative outage probability of each hop ($\overline{P^{ARQ}_{out}}$) can be calculated as the equation (6) from the equation (14), (15) and (16).

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

$$\overline{P_{out}^{Total}} = 1-(1-P_{out}^{DT})^{\bar{m}-\bar{n}}(1-P_{out}^{ARQ})^{\bar{n}} \tag{17}$$

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

$$PDR \approx 1-\overline{P_{out}^{Total}} = (1-P_{out}^{DT})^{\bar{m}-\bar{n}}(1-P_{out}^{ARQ})^{\bar{n}} \tag{18}$$

Fig. 4, Fig. 5 and Fig. 6 present the packet delivery ratio (PDR) as a function of SNR when the value of V_max is fixed. Otherwise, in the Fig. 7, Fig. 8, Fig. 9, we fix the SNR and draw the PDR as

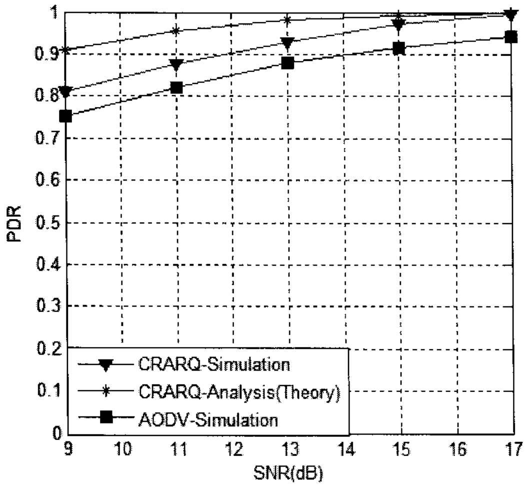

그림 4. v_max = 20 km/h 일때 페킷전달효율
Fig. 4. Packet delivery ratio (PDR) when the v_max = 20 km/h.

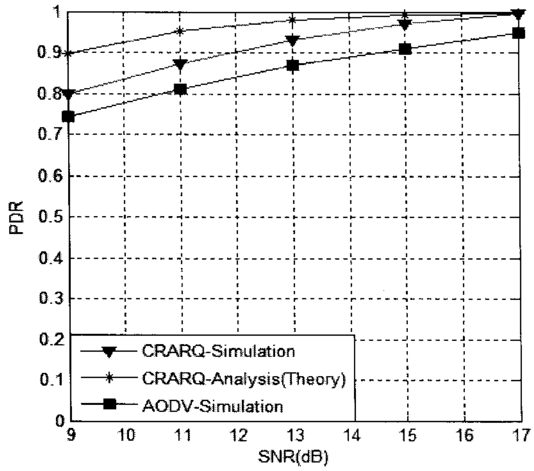

그림 5. v_max = 40 km/h 일때 페킷전달효율
Fig. 5. Packet delivery ratio (PDR) when the v_max = 40 km/h.

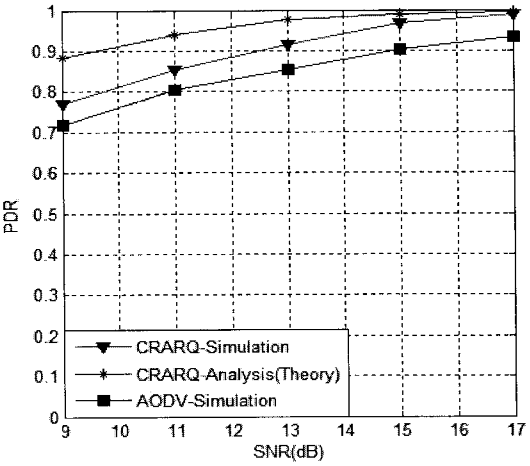

그림 6. v_max = 60 km/h 일때 페킷전달효율
Fig. 6. Packet delivery ratio (PDR) when the v_max = 60 km/h.

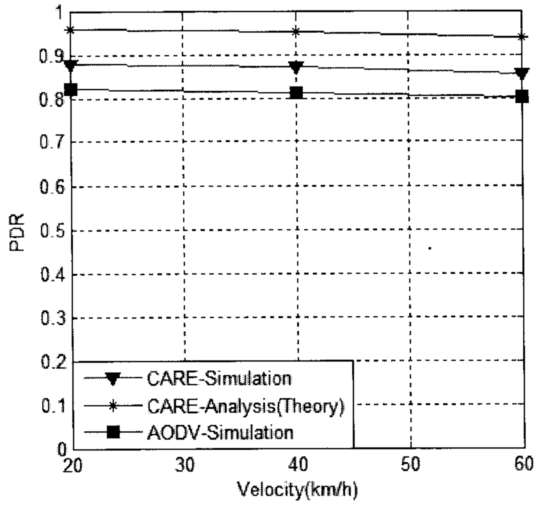

그림 7. SNR = 11dB 일때 페킷전달효율
Fig. 7. Packet delivery ratio (PDR) when the SNR = 11dB.

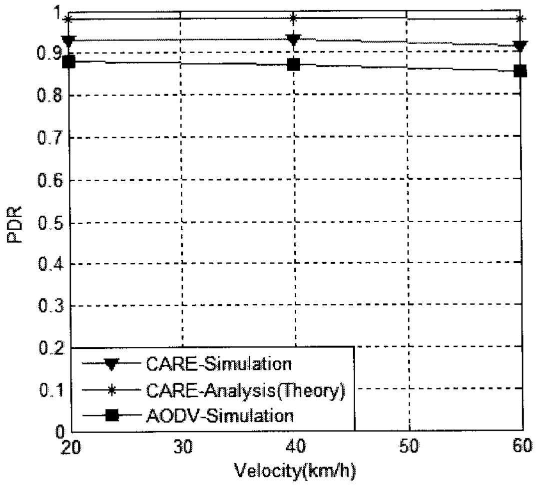

그림 8. SNR = 13dB 일때 페킷전달효율
Fig. 8. Packet delivery ratio (PDR) when the SNR = 13dB.

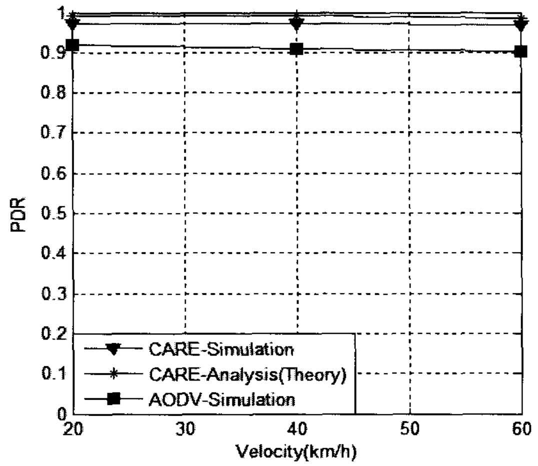

그림 9. SNR = 15dB 일때 패킷전달효율
Fig. 9. Packet delivery ratio (PDR) when the SNR = 15dB.

the function of velocity. As we see, the PDR of CRARQ and AODV[13] increases when the SNR increases but the PDR of CRARQ is larger than that of AODV[13]. The reason is because CRARQ uses the cooperative communication that it improves the reliability of data transmission.

V. Conclusion

In this paper, we propose a Cooperative Routing using ARQ-based Transmission (CRARQ) in Mobile Ad-hoc Wireless Sensor Networks (MAWSN). The main features and contributions of the CRARQ are the most stable relay selection at each hop and ARQ-based cooperative transmission. The performance evaluation of the proposed CRARQ is performed via simulation using OPNET (optimized network engineering tool) and numerical analysis. The CRARQ increases the packet delivery ratio and outage probability when compared to AODV protocol.

References

[1] R. Ramanathan and M. Steenstrup, “Hierarchically -Organized, Multihop Mobile Wireless Networks for Quality-of Services Support,” ACM/Baltzer Mobile Networks and Applications, vol.3, no.1, pp.101-119, 1998.

[2] Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramanian, and Erdal Cayici, “A Survey on Sensor Networks,” IEEE Communications magazine, pp.102-114, August 2002.

[3] Beongku An, Symeon Papavassiliou, “Supporting Multicasting in Mobile Ad-hoc Wireless Networks: Issues, Challenges and Current Protocols,” Wireless Communications and Mobile Computing (WCMC), vol. 2, issue 2, pp. 115-130, March 2002.

[4] J. N Laneman, D.N.C Tse, G.W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” Information Theory, IEEE Transactions on, vol. 50 ,12, pp. 3062 - 3080. December 2004.

[5] T. E. Hunter and A. Nosratinia, “Diversity through Coded Cooperation,” IEEE transactions on wireless communications, vol. 5, no.2, pp. 283, February 2006.

[6] A. Stefanov and E. Erkip, “Cooperative Coding for Wireless Networks,” IEEE transactions on communication, vol. 52, no. 9, September 2004.

[7] A. Bletsas, A Khisti, D. P. Reed, A Lippman, “A simple Cooperative Diversity Method Based on Network Path Selection,” IEEE Journal on Selected Areas in Communications, vol. 24, no. 3, pp. 659-672, March 2006.

[8] Sachin Abhyankar and Dharma P. Agrawal, “Distributed Mobility-Aware Route Selection for Wireless Ad Hoc Networks,” Performance, Computing, and Communications Conference, April 2002.

[9] P. Herhold, E. Zimmermann, and G. Fettweis, “A Simple Cooperative Extension to Wireless Relaying,” 2004 Int. Zurich Seminar on Communications, Zurich, Switzerland, February 2004.

[10] E. Zimmermann, P. Herhold and G. Fettweis, “On the Performance of Cooperative Relaying protocols in Wireless Networks,” European Trans. on Telecommunications, vol. 16, no. 1, January -February 2005.

[11] A. Sendonaris, E. Erkip, and B. Aazhang, “User cooperation diversity. Part I-II,” IEEE Trans on Communications, issue 11, pp. 1927-1948, 2003.

[12] Beongku An, Symeon Pappavassiliou, “An Entropy-Based Model for Supporting and Evaluating Stability in Mobile Ad-hoc Wireless Networks,” IEEE Communications Letters, vol. 6, issue 8, pp.328-330, August 2002.

[13] C.E Perkins and E.M. Royer, "Ad-Hoc on demand distance Vector Routing," Proc. of WMCSA '99, pp 90-100, February 1999.

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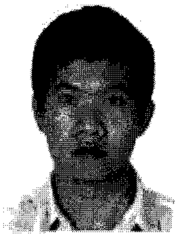

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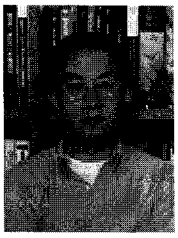
<주관심분야 : Mobile Ad-hoc networks, wireless sensor networks, cooperative communications, combining techniques>



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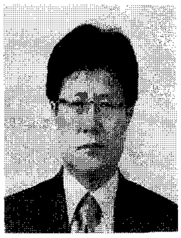

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