논문 16-41-02-06 The Journal of Korean Institute of Communications and Information Sciences '16-02 Vol.41 No.02
http://dx.doi.org/10.7840/kics.2016.41.2.189

# DT-GPSR: 지연감내형 GPSR 라우팅 프로토콜

남 재 충◆, 조 유 제°

# DT-GPSR: Delay Tolerant-Greedy Perimeter Stateless Routing Protocol

Jae-Choong Nam◆, You-Ze Cho°

## 요 약

실제 이동 통신 환경은 불균일한 단말 분포와 이동성으로 인하여 링크 단절이 일어나는 경우가 빈번하다. 이러한 네트워크 환경에서 경로 수립 기반의 MANET 라우팅 프로토콜은 잦은 전송 실패를 야기하여 메시지 전달률을 감소시키고, 경로 재수립을 위한 제어 메시지를 많이 발생시켜 네트워크 효율성을 크게 저하시킨다. 반면 GPSR과 같은 위치 정보 기반 MANET 라우팅 프로토콜은 종단 간 경로 수립 절차 없이 hop-by-hop 라우팅을 수행하여 제어 메시지 발생을 최소화하지만, 중계 노드의 결손으로 인해 보이드(void)가 발생 할 경우 데이터 전달 실패 등 다양한 문제를 유발한다. 본 논문에서는 보이드로 인해 발생되는 라우팅 문제점들을 개선하기 위하여, GPSR 프로토콜에 확률 기반 Delay Tolerant Networking 기술이 결합된 DT-GPSR 프로토콜을 제안한다. NS-2 시뮬레이션을 통해 기존 GPSR 프로토콜 및 PRoPHET 프로토콜과의 성능을 비교하였으며, 제안 방안이 다양한 망의 변화에 대응하여 우수한 성능을 보임을 확인하였다.

**Key Words** : GPSR, PRoPHET, store-carry-forward, MANET, DTN

## ABSTRACT

Mobile ad-hoc networks (MANETs) experience frequent link disconnections due to non-uniform node distribution and mobility. Thus, end-to-end path establishment-based routing protocols cause frequent transmission failures in MANETs, resulting in heavy control messages for path reestablishment. While location-based MANET routing protocols, such as Greedy Perimeter Stateless Routing (GPSR), use location information to forward messages in a hop-by-hop routing fashion without an end-to-end path establishment procedure, such protocols encounter communication void problems when message forwarding to the next hop fails due to the absence of a relay node. Therefore, to solve this problem, this paper proposes a Delay Tolerant-GPSR (DT-GPSR) protocol, which combines Delay Tolerant Networking (DTN) technology with the GPSR protocol. The performance of DT-GPSR is compared with the performances of the original GPSR and PRoPHET routing protocols through simulation using NS-2. The simulation results confirm that DT-GPSR outperforms GPSR and PRoPHET in terms of the message delivery ratio and message delivery delay.

---

※ 본 연구는 2015년도 정부(미래창조과학부)의 재원으로 정보통신기술진흥센터[10041145, 자율군집을 지원하는 웰빙형 정보기기 내장 소프트웨어 플랫폼 개발]와 한국연구재단[NRF-2013R1A1A4A01012534]의 지원을 받아 수행되었습니다.

◆ First Author : Kyungpook National University, jch-nam@ee.knu.ac.kr, 학생회원
° Corresponding Author : Kyungpook National University, yzcho@ee.knu.ac.kr, 종신회원

논문번호 : KICS2015-12-379, Received December 1, 2015; Revised February 4, 2016; Accepted February 12, 2016

## Ⅰ. Introduction

Mobile ad-hoc networks (MANETs) are attracting a great deal of attention due to their significant advantages based on multihop and infrastructure-less transmission[1,2]. Notwithstanding, their non-uniform node distribution and dynamic node mobility mean that reliable message delivery remains a challenge in MANETs, especially in environments with high mobility. Traditional topology-based MANET routing protocols (e.g., DSDV, AODV, DSR, OLSR) are quite susceptible to node mobility[3-7], essentially due to their pre-establishment of an end-to-end route before a message transmission. Yet, with a frequently changing network topology, it is very difficult to maintain a deterministic route. The route discovery and recovery procedures are also time consuming. Once a route breaks, the messages get lost or delayed until the route is reconstructed, resulting in transmission interruptions[8].

The Greedy Perimeter Stateless Routing (GPSR) protocol exploits geographic information instead of topological connectivity information and forwards messages with a gradual approach[9]. By using location information to forward messages in a hop-by-hop routing fashion, the GPSR protocol does not require the establishment or maintenance of a complete route from source to destination. As a result, the localized operation and stateless feature of the GPSR protocol make it simple and scalable in dynamic mobile ad-hoc networks. However, location-based MANET routing protocols have a communication void problem, as message forwarding to the next hop fails due to the absence of a relay node[10]. Recently, this communication void problem has become an important issue for location-based MANET routing in dynamic mobile ad-hoc networks[11-17]. In communication void regions of a network where there is no node close to the destination node, the GPSR protocol recovers using perimeter forwarding based on routing to a node on a perimeter close to the destination[9]. Yet, in a sparse network region, perimeter routing can cause message dropping due to the absence of perimeter nodes. The characteristics of the GPSR routing operation that delivers messages through hop-by-hop routing without an end-to-end path establishment procedure is very similar to the message delivery approach used in Delay Tolerant Networks (DTNs)[19,20].

Accordingly, this paper proposes a Delay Tolerant-GPSR (DT-GPSR) protocol that combines DTN technology with the GPSR protocol. DT-GPSR is a hybrid scheme for enhancing the message delivery ratio when a network disconnection occurs during a GPSR routing operation in a MANET. Basically, DT-GPSR operates in the GPSR routing mode when neighbor nodes exist, in which case it delivers messages quickly to the node closest to the destination. However, if a message cannot be delivered further due to a perimeter routing failure, DT-GPSR operates in the DTN routing mode. This study uses the Probabilistic Routing Protocol using History of Encounter and Transitivity (PRoPHET) protocol[21] for the DTN routing to enhance the message delivery ratio. The performance of DT-GPSR is compared to the performances of the original GPSR and PRoPHET routing protocols using an Network Simulator-2 (NS-2)[22] in terms of the message delivery ratio and message delivery delay.

The remainder of this paper is organized as follows. Section 2 outlines related work. Section 3 explains the proposed DT-GPSR scheme. Section 4 describes the simulation environment and compares the performance of the DT-GPSR scheme with those of existing schemes. Section 5 gives some final conclusions.

## Ⅱ. Related Work

This section briefly describes the GPSR routing protocol and PRoPHET routing protocol used in the proposed scheme.

### 2.1 GPSR

GPSR is a representative location-based routing protocol[9] which assumes that each node is equipped with a location information measuring device, such as a global positioning system (GPS), to confirm its location information needed for routing.

In GPSR, each node broadcasts a beacon periodically, which contains its identifier (ID) and location information. By periodic exchanges of beacons, all nodes maintain a neighbor table which stores the identifiers and locations of their single-hop neighbors.

As shown in Fig. 1, a source or an intermediate node with a message delivers a message to the node closest to the destination node based on greedy forwarding using location information on the neighbor table. If no neighbor is closer, the node enters perimeter forwarding mode. In the perimeter forwarding mode, a node with a message delivers a message using the right-hand rule. A node delivered a message by perimeter forwarding compares the location entered perimeter mode with oneself location. If the message reaches a location closer than where greedy forwarding previously failed, the message can continue greedy progress toward the destination. Also, if no neighbor nodes exist within the transmission range in the GPSR routing, the node with the message discards the message.

GPSR repeatedly performs the two modes explained above, greedy forwarding and perimeter forwarding, in order to deliver messages to their destination. The overall operation of GPSR is shown in Fig. 2.

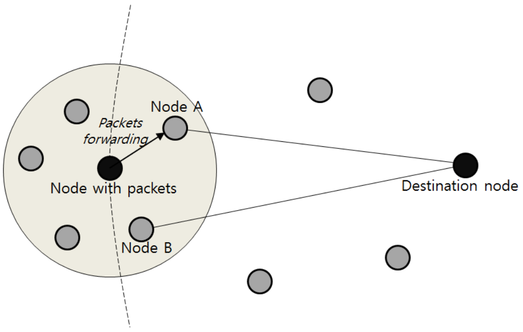

Fig. 1. Greedy forwarding in GPSR.

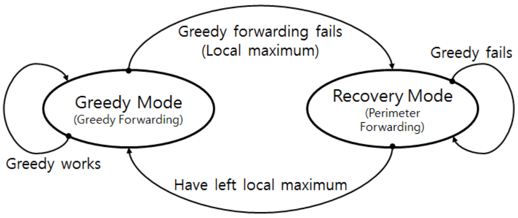

Fig. 2. Process of GPSR routing protocol.

## 2.2 PRoPHET

PRoPHET is a probabilistic DTN routing protocol, which was proposed to improve the delivery predictability and reduce the wastage of network resources in DTN[21].

PRoPHET initially estimates the probabilistic metric, called the delivery predictability $(A,B)\in[0,1]$ at every node A for each known destination B. Whenever a node encounters other nodes in the network, they exchange summary vectors, as in Epidemic routing. This summary vector contains messages list in buffer and the delivery predictabilities for destinations known by each node. The operation of the PRoPHET protocol is then determined based on the delivery predictabilities plus forwarding strategies.

Calculating the delivery predictabilities of the nodes involves three parts. The nodes update their delivery predictability metrics whenever they meet each other. Thus, contacting a node more times results in a higher delivery predictability value. This calculation is shown below the equation (1), where $P_{enc}\in[0,1]$ is the initialization constant and $\delta$ is a small positive number that effectively sets an upper bound for $P(A,B)$.

$$P(A,B)=P(A,B)_{old}+(1-\delta-P(A,B)_{old})*P_{enc} \quad (1)$$

The delivery predictabilities for all other destinations $C$ known by the encountering nodes are also updated based on the values in the table sent to node $A$ from node $B$ due to transitivity of delivery predictability. For the all other destinations $C$, node $A$ updates its delivery predictability using (2) where $\beta$ is a constant.

$$P(A,C)=MAX[P(A,C)_{old},P(A,C)*P(A,C)_{recv})*\beta] \quad (2)$$

In order to eliminate stale information from the network, the delivery table is periodically aged according to (3) for all destinations $B$, where is a constant and is the number of time units since the last time the delivery predictability aging.

$$P(A,B)=P(A,B)_{old}*\gamma^{k} \quad (3)$$

In the PRoPHET routing, if node *A* with a message to a destination node *D* encounters with node *B*, node *A* compares *P(A,D)* and *P(B,D)*. If *P(A,D)* < *P(B,D)*, the message to destination node *D* is copied to node *B*. Otherwise, the message is not copied to node *B*.

## Ⅲ. Design of Delay Tolerant-GPSR

This paper proposes DT-GPSR to enhance message delivery ratio in an intermittently connected MANET environment. DT-GPSR is a hybrid routing scheme which combines GPSR with PRoPHET. In this section, we describe the basic operation of DT-GPSR and design it with a state transition diagram and a flow chart.

### 3.1 Basic Operation of DT-GPSR

In DT-GPSR, each node broadcasts a beacon periodically, which contains its ID and location information the same as GPSR. But, DT-GPSR expands the beacon by including the delivery predictabilities for destinations known by each node, which are used in PRoPHET. By periodic exchanges of beacons, each node maintains one-hop neighbors and their locations in a neighbor table, and updates the delivery predictabilities for each destination.

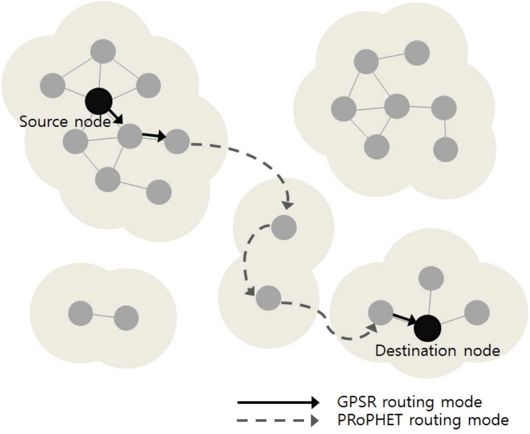

Fig. 3. Scenario of DT-GPSR.

When a node receives a beacon from its neighbor node, it first searches the neighbor node ID in the neighbor table. If the neighbor node is new one, the node adds the new neighbor node ID in the table and maintains it during a lifetime. Also, the node updates the delivery predictabilities for destinations using the same algorithm as PRoPHET with the equations (1)~(3).

When a source or an intermediate node with a message has neighbor nodes, DT-GPSR basically operates in the GPSR routing mode. Otherwise, it operates in the PRoPHET routing mode. Therefore, to deliver a message to its destination, DT-GPSR operates either in the GPSR routing mode or the

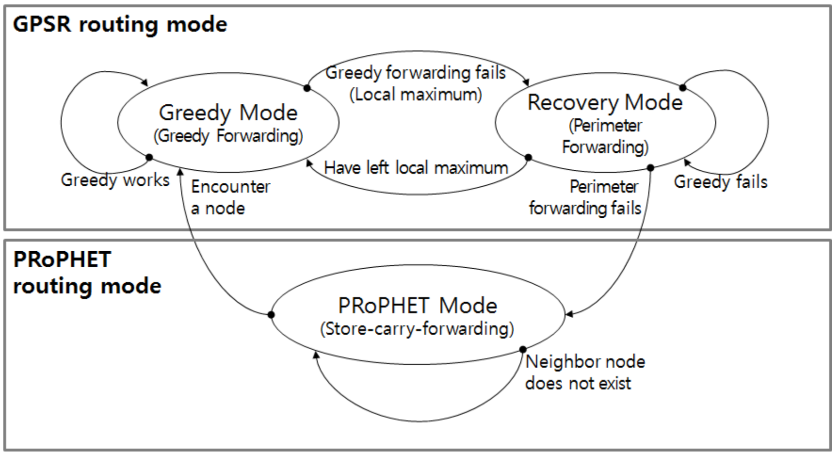

Fig. 4. State transition diagram of DT-GPSR.

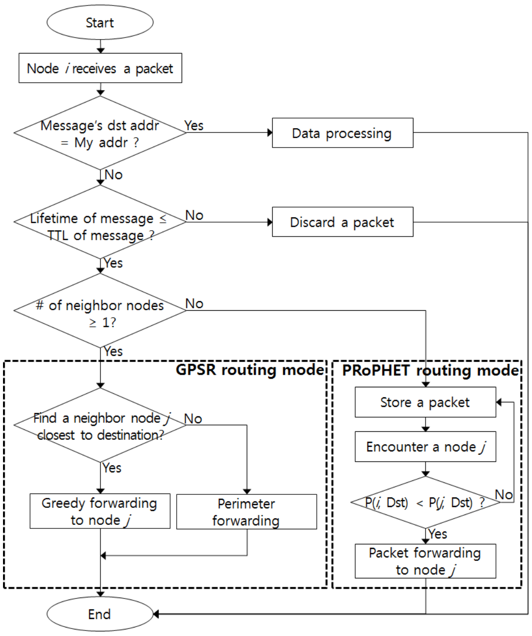

Fig. 5. Flow chart of DT-GPSR.

PRoPHET routing mode.

Fig. 3 shows a scenario of DT-GPSR for forwarding a message from the source to the destination. In a cluster with connected nodes, a node forwards a message to a next hop using the GPSR routing mode. However, a relay node at the edge of a cluster will store-carry-and-forward the message in the PRoPHET routing mode, because the relay node does not have other neighbor nodes except the node which forwarded the message to itself. Fig. 4 shows a state transition diagram of DT-GPSR and Fig. 5 illustrates its flow chart.

### 3.2 GPSR Routing Mode

When a source or an intermediate node with a message has more than one neighbor node, it basically forward the message in the GPSR routing mode. The GPSR routing mode delivers a message to the node closest to the destination node based on greedy forwarding using location information on the neighbor nodes. Greedy forwarding is continuously performed until the message is delivered to a node located at the edge of a cluster.

During greedy forwarding, if a local maximum problem occurs, meaning no neighbor node located closest to the destination node, perimeter forwarding is performed the same as in the original GPSR routing.

### 3.3 PRoPHET Routing Mode

When a source or an intermediate node with a message has no neighbors, it delivers the message using a store-carry-forwarding mechanism in the PRoPHET routing mode. When a node carrying the message encounters a new neighbor node during movement, they exchange summary vectors. The summary vector in DT-GPSR contains only messages list in buffer. New neighbors will be discovered by periodic exchanges of beacons. As illustrated in the section 3.1, the beacon contains the delivery predictabilities for destinations known by each node.

Whenever a node encounters a new neighbor, the node updates the delivery predictabilities for destinations. If the node with a message has a lower delivery predictability for a destination node than that of its new neighbor node, it hands over the message to its neighbor node. Otherwise, the message is not handed over. If the TTL (Time-to-Live) of the message expires, the message will be dropped before forwarding.

## Ⅳ. Performance Evaluation

### 4.1 Simulation Environment

In order to evaluate the performance of DT-GPSR, we have simulated DT-GPSR, GPSR, and PRoPHET in the NS-2 and measured their performance in terms of message delivery ratio and end-to-end delay in mobile network topologies.

Our simulations are for networks of 50~300 nodes, which are initially placed uniformly at random in 2,000m X 2,000m area. A node chooses a destination at random in the simulated area. All nodes move with speed of 5 to 10 m/sec according to the Levy Walk mobility model, which statistically measures and implements the moving patterns used in daily life[23]. Also, we assumed the IEEE 802.11g with a nominal 100m tranmission range. Table. 1 summarizes simulation parameters.

Table 1. Simulation parameters.

| Parameters | Values |
|---|---|
| Simulation tool | Network Simulator (NS)-2 |
| Map size | 2,000m X 2,000m |
| Mobility model | Levy walk |
| Transmission range | 100 m |
| MAC protocol | IEEE 802.11g |
| Transmission rate | 2 Mbps |
| Message size | 250 Kbytes |
| Simulation time | 40,000 sec |
| TTL of message | 3,600 sec |
| Node speed | 5~10 m/sec |
| Message generation interval | 25~35 sec |
| Beacon interval | 1 sec |
| Number of nodes | 50, 100, 150, 200, 250, 300 |

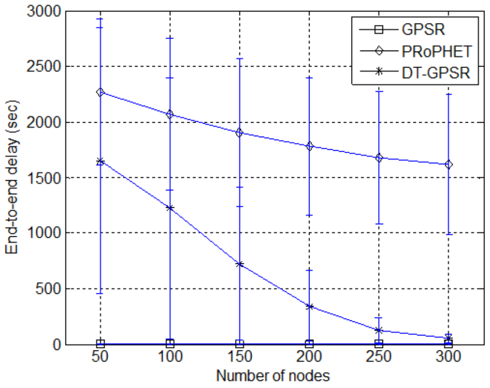

Fig. 6. End-to-end delivery delay according to number of nodes.

### 4.2 Performance Metrics

The following metrics were used for the performance comparison.

1) Delivery ratio: defined as the ratio of the total number of delivered messages to the total number of originated messages.

$$Deliveryratio = \frac{NmberOfMessageDelivered}{NmberOfMessageCreated}$$

2) End-to-end delay: defined as the delay between the time the message originated at the source node and the time it reached the destination node.

$$EndToEndDelay = MessageReceiveTime - MessageGenerationTime$$

### 4.3 Simulation Results

In our simulations, nodes from 50 to 300 nodes are initially placed at random in 2,000m x 2,000m area. Also, we assumed a nominal 100m transmission range. Therefore, not all nodes are connected together even in a dense network with 300 nodes. Also, all nodes are not separate each other even in a sparse network with 50 nodes. Nodes are partially connected each other and form several clusters. In our simulations, the TTL of a message was assumed as 3,600 sec. If the TTL expires, the message was dropped at a node. We measured the end-to-end delay for only messages delivered to their destinations within the TTL.

Fig. 6 compares the end-to-end delivery delay according to the node density. GPSR exhibited the lowest end-to-end average delay of the delivered messages among the three routing protocols, because a message was only delivered when the end-to-end connectivity was ensured. But, in a sparse network scenario, more than half of messages in GPSR could not be delivered to destinations. PRoPHET showed the highest end-to-end message delay in all node densities, because the store-carry-and-forward approach in PRoPHET causes an additional delay overhead even though the end-to-end path exists between source and destination node pairs. Meanwhile, DT-GPSR exhibited a moderate end-to-end message delay between those of GPSR and PRoPHET. As the node density increased, the end-to-end message delay of DT-GPSR approached gradually to that of GPSR.

Figs. 7 and 8 compare the histograms of end-to-end delay for DT-GPSR, GPSR, and PRoPHET. The bar charts of histograms show the fraction of messages that had been delivered to their destinations within the life time.

Fig. 7 shows the end-to-end delay histograms in a sparse network (number of nodes = 100). All the delivered messages in GPSR arrived within the first 10 sec, while more than 85% of the delivered messages in PRoPHET were concentrated after 1500 sec. However, in DT-GPSR about 15% of the delivered messages arrived within 10 sec and others were distributed at diverse delay sections. This reason was that DT-GPSR adapts its routing

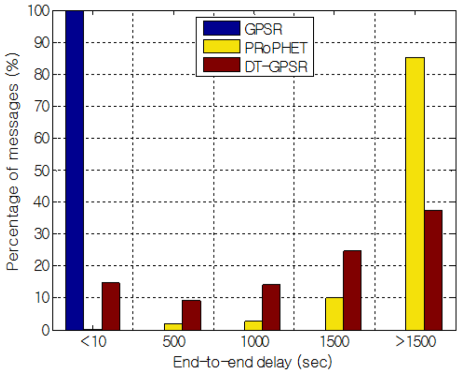

Fig. 7. End-to-end delay histograms in sparse network.

approach among GPSR and PRoPHET according to the network environment.

Fig. 8 shows the end-to-end delay histograms in a dense network (number of nodes = 300). While GPSR completed the messages delivery within the first 10 sec, as with a sparse network, PRoPHET completed most of the message deliveries in the last two sections (> 1000 sec). Plus, similarly to GPSR, DT-GPSR delivered most of the messages over 93% within 10 sec. This reason was that DT-GPSR could forward messages usually with the GPSR routing mode in a dense network.

Fig. 9 shows the end-to-end message delivery ratio according to the node density. In a sparse network (number of nodes = 50), GPSR exhibited a message delivery ratio of only 8%. This is because the end-to-end connectivity is not guaranteed between source and destination node pairs in most of case. But, PRoPHET could deliver 71% of messages to their destinations using a delay-tolerant

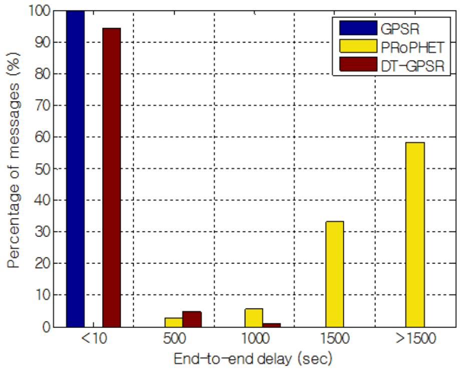

Fig. 8. End-to-end delay histograms in dense network.

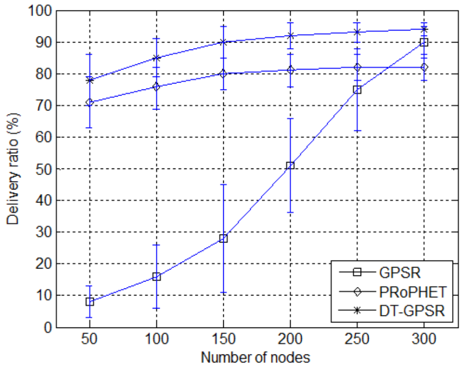

Fig. 9. Delivery ratio according to number of nodes.

routing approach. DT-GPSR was able to deliver more than 78% of the messages on average. When increasing the node density (number of nodes = 300), the message delivery ratios for GPSR and PRoPHET increased to 90% and 83%, respectively. Meanwhile, DT-GPSR was able to deliver more than 95% of the messages on average.

This figure shows that DT-GPSR can support a higher message delivery ratio than GPSR and PRoPHET by combining both advantages of two routing protocols regardless of node density in the simulation scenarios. The reason why the message delivery ratio of PRoPHET is less than DT-GPSR is that more messages were dropped due to their TTL expiry by a long end-to-end delay in PRoPHET. We can expect this result from the end-to-end delay histograms in Figs. 7 and 8.

## Ⅴ. Conclusion

This paper proposed a DT-GPSR routing protocol for mobile ad hoc networks, which combines DTN technology with the GPSR protocol. The DT-GPSR adapts its routing mode between GPSR and PRoPHET according to the network environment. The performance of DT-GPSR was compared with the performances of the original GPSR and PRoPHET routing protocols in terms of the delivery delay and end-to-end delivery ratio using NS-2. The simulation results confirmed that DT-GPSR inherited both advantages from GPSR and PRoPHET in performance.

## References

[1] M. Kumar and R. Mishra, "An overview of MANET: History, challenges and applications," *Indian J. Comput. Sci. Eng. (IJCSE)*, vol. 3, no. 1, Mar. 2012.

[2] H. Suh and H. Hwang, "Rerouting method for MANET using local path modification," *J. KICS*, vol. 39, no. 9, pp. 620-628, Sept. 2014.

[3] C. E. Perkins, and P. Bhagwat, "Highly dynamic Destination-Sequenced Distance - Vector routing (DSDV) for mobile computers," in *Proc. Commun. Architectures, Protocols and Appl.*, pp. 234-244, Aug. 1994.

[4] D. Johnson, *The Dynamic Source Routing Protocol (DSR)*, in IETF RFC 4728, Feb. 2007.

[5] C. Perkins, E. Belding-Royer, and S. Das, *Ad hoc On-Demand Distance Vector (AODV) Routing*, in RFC 3561, Jul. 2003.

[6] T. Clausen and P. Jacquet, *Optimized Link State Routing Protocol (OLSR)*, in RFC 3626, Oct. 2003.

[7] S. Alarmelu V., R. Poonkuzhali, and M. Y. Sanavullah, "An efficient void handling technique for geographic routing in MANET: A survey," *IJARCSSE*, vol. 2, No. 12, pp. 164-170, Dec. 2012.

[8] S. Lee and D. Choi, "A node status control algorithm in mobile ad-hoc networks," *J. KICS*, vol. 39, no. 3, pp. 188-190, Mar. 2014.

[9] B. Karp and H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," in *Proc. Annu. Int. Conf. Mob. Comput. and Netw.*, pp. 243-254, Aug. 2000.

[10] C. Tzu-Chiang, C. Jia-Lin, T. Yue-Fu, and L. Sha-Pai, "Greedy geographical void routing for wireless sensor networks," *World Academy of Sci., Eng. Technol.*, vol. 7, pp. 1269-1277, 2013.

[11] Q. Fang, J. Gao, and L. J. Guibas, "Locating and bypassing holes in sensor networks," *Mob. Netw. and Appl.*, vol. 11, no. 2, pp. 187-200, Apr. 2006.

[12] M. Aissani, A. Mellouk, N. Badache, and M. Djebbar, "A new approach of announcement and avoiding routing voids in wireless sensor networks," in *Proc. IEEE Global Telecommun. Conf.*, pp. 1-5, Nov. 2008.

[13] W-J. Liu and K-T. Feng, "Greedy routing with anti-void traversal for wireless sensor networks," *IEEE Trans. Mob. Comput.*, vol. 8, no. 7, pp. 910-922, Jul. 2009.

[14] M. Aissani, A. Mellouk, N. Badache, and M. Djebbar, "A preventive rerouting scheme for avoiding voids in wireless sensor networks," in *Proc. IEEE Global Telecommun. Conf.*, pp. 1-5, Dec. 2009.

[15] H. Wang, X. Zhang, and A. Khokhar, "Efficient void handling in contention-based geographic routing for wireless sensor networks," in *Proc. IEEE Global Telecommun. Conf.*, pp. 663-667, Nov. 2007.

[16] W. Jia, T. Wang, G. Wang, and M. Guo, "Hole avoiding in advance routing in wireless sensor networks," in *Proc. IEEE WCNC 2007*, pp. 3519-3523, Mar. 2007.

[17] M. Aissani, A. Mellouk, N. Badache, and B. Saidani, "Oriented void avoidance scheme for real-time routing protocols in wireless sensor networks," in *Proc. IEEE Global Commun. Conf.*, pp. 1-5, Nov. 2008.

[18] H. Cho, S. Kim, C. Kim, S. Kim, and C. Hwang, "Energy-Efficient face routing protocol considering radio range in wireless sensor networks," *J. KIC*S, vol. 40, no. 6, pp. 1058-1069, Jun. 2015.

[19] *Delay tolerant networking research group*, http://www.dtnrg.org

[20] L. Pelusi, A. Passarella, and M. Conti, "Opportunistic networking: data forwarding in disconnected mobile ad hoc networks," *IEEE Commun. Mag.*, vol. 44, no. 11, Nov. 2006.

[21] A. Lindgren, A. Doria, E. Davies, and S. Grasic, *Probabilistic routing protocol for intermittently connected networks*, in IETF RFC 6693, 2012.

[22] The Network Simulator - ns-2. http://www.isi.edu/nsnam/ns/

[23] K. Lee, S. Hong, S. Kim, I. Rhee, and S.

Chong, “SLAW: A mobility model for human walks,” in *Proc. IEEE INFOCOM*, pp. 855-863, Rio de Janeiro, Apr. 2009.

**남 재 충** (Jae-Choong Nam)

2010년 2월 : 경북대학교 전자전기컴퓨터학부 졸업

2013년 2월 : 경북대학교 전자공학과 석사

2013년 3월~현재 : 경북대학교 전자공학과 박사과정

<관심분야> 차세대 이동 네트워크, 무선 애드혹 네트워크

**조 유 제** (You-Ze Cho)

1982년 : 서울대학교 전자공학과 졸업

1983년 : 한국과학기술원 전기전자공학 석사

1988년 : 한국과학기술원 전기전자공학 박사

1989년~현재 : 경북대학교 전자공학부 교수

1992년~1994년 : Univ. of Toronto, 방문교수

2002년~2003년 : 미국 국립표준연구소(NIST), 객원연구원

<관심분야> 차세대 이동 네트워크, 무선 애드혹 네트워크, 이동성 관리 기술, Future Internet