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MANET에서 이동성과 연결성을 고려한 다중 모드 라우팅 프로토콜 적용 기법

(Multi-Protocol Based Routing Selection Scheme for MANET Using Mobility and Connectivity)

허웅*, 만신*, 조일*, 유강수**, 최재호**

(Ung Heo, Yi Zhao, Xin Wan, Kang Soo You, and Jaeho Choi)

요 약

이동 애드 혹 네트워크는 인스턴트하고 자가 발견적인 특성과 함께 임시적이며 변화가 심한 연결성을 가진다. 토폴로지와 루트 변화가 빈번한 까닭에 일반 네트워크 용 라우팅 기법으로는 좋은 성능을 기대하기 어렵다. 노드의 증가에 따라, 또는 노드의 빠른 이동성에 따라 라우팅 프로토콜의 성능 저하가 발생한다. 본 논문에서는 MANET의 실시간 환경 변화에 적응적인 라우팅 프로토콜을 살펴본다. 먼저, 여러 다른 환경에서 두 가지 대표적 라우팅 프로토콜의 성능을 확인한다. 이어서, 성능 테스트로 얻어진 데이터를 분석하여 다중 모든 라우팅 프로토콜 선택 레퍼런스를 구축한다. 이 레퍼런스는 모든 노드에서 주기적으로 라우팅 환경을 체크할 때 사용된다. 다중 모드 라우팅 프로토콜 적용 방법을 사용함으로써 노드는 주기적으로 네트워크 환경을 체크하고 레퍼런스와 비교하여 성능저하를 최소화 할 수 있는 대체 라우팅 프로토콜을 결정하고 네트워크 전반에 걸쳐 적용한다. 제안한 기법은 OPNET 네트워크 모델링 시뮬레이션으로 그 성능을 확인하고 평가한다. 실험결과, 적응적으로 변화하는 다중 모드 라우팅 프로토콜 적용 기법이 네트워크 환경변화에 매우 효과적으로 사용될 수 있음을 확인하였으며 네트워크의 대역 이용비 측면에서도 우수한 것으로 나타났다.

Abstract

A mobile ad hoc network is instant and heuristic, and it is also vulnerable and volatile. Since topology and route changes are frequent, no single routing protocol designed for a conventional network performs well. Some protocols suffer from significant performance degradation when the number of nodes increases, or when nodes become highly mobile. In this paper we investigate a way to adaptively select a routing protocol that fits to the real-time network conditions. The first phase of our study is to analyze the performances of two classes of routing protocols under various network scenarios. The second phase consists of constructing a routing protocol selection reference. All nodes continue to monitor the status of neighbor nodes and control packets exchanged. Then, the aggregated information is periodically compared against the protocol selection reference. The selected routing protocol is maintained throughout the network until the network property changes substantially. The performance of the proposed algorithm is verified by a set of computer simulations using the OPNET modeler. The experimental results show that selectively changing routing protocol adaptive to the network conditions greatly improves the efficacy of bandwidth utilization.

Keywords : Mobile ad hoc networks, Adaptive routing protocol selection, Mobility, Connectivity

I. Introduction

Wireless networks are increasingly popular because they are relatively fast to deploy, provide a convenient access to Internet, and support various real-time services to mobile nodes. One of them drawing some attention recently is a mobile ad hoc network (MANET). It is formed when users communicate with each other through a wireless link

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* 학생회원, ** 정회원, 전북대학교, 영상정보신기술연구센터
(Chonbuk National University),
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without using infrastructures. This newly emerging network has applications from battlefields to rescue operations, and from accessing the Internet to controlling home appliances while users are mobile. For such a network, all nodes are equally responsible for maintaining network functions because they should act as both users and base stations, e.g. as intermediate nodes or routers.

Routing, the process of managing the route from source to destination, is a critical mechanism in MANET, because most of its applications involve multi-hop scenarios. Especially in a multi-hop network, the flow of transit traffic is very high, and the role of a router is becoming vital.

Due to the dynamic nature of MANET, the allocated resources are not matched a priori with the requirements or methods of communication among them. Additively, estimating and predicting the exact mobility model of the nodes consume much network resource. Because the communication environment undergoes frequent topology and connectivity changes, to come up with an efficient routing scheme that fits to every network scenario is a challenging problem.

Recently, the routing problem in MANET has drawn much attention in the communications network society, and volumes of literatures can be found. We introduce some of them that are related to our work. In [1], the multi-mode routing protocol is described using two algorithms, namely *Limited Link States and Self Organized.* This paper proposes a reference area concept: the closer to the destination a n ode is, the more information related to that destination it will have. It does not consider, however, what happens when the destinations move out of the target area. The packets may move unreliably if the routing protocol is not immediately updated accordingly.

On the other hand, the service discovery as a multi-protocol framework is presented in [2]. It is a common architecture for an individual discovery protocol to enhance network configurability and re-configurability. The paper shows a core framework, but does not discuss decision parameters.

The collaborative management of MANET, which calculates a capability function as an optimizing factor in a self-configuring strategy, is proposed in [3]. It presents a component-based service discovery framework for the development of an adaptive service discovery middleware which operates in diverse environments, e.g., both in fixed and ad-hoc networks.

The *Terminode* Project[6] basically operates on a self-organized mobile ad hoc network and even explores interlayer interactions. Each *Terminode* has a permanent, unique node identifier, called the end system unique identifier, encoded in the hardware to be used as an IPv6 address. Another related work for developing a multi-routing strategy is discussed in [12]. The paper contains analysis of mobility, connectivity, and distribution of nodes in the network area; and their implications are described.

As a new approach to this problem, mobility and connectivity are considered in order to adapt to changes made during the lifetime of the network. Here, multiple routing protocols are analyzed; their behaviors are investigated; and the protocol selection reference is made in this paper.

Inherently, having an uncertainty in network topology due to node mobility, the MANET requires a better routing algorithm that counteracts the performance degradation. Here, we propose a routing protocol selection scheme that provides an appropriate routing protocol that fits to network conditions in real time. The basic concept given to our routing protocol selection scheme is to dynamically monitor the important network parameters, i.e., mobility and connectivity, and to periodically replace the current routing protocol with another one that better fits to the updated, current network condition.

The first phase of our investigation involves analyzing the performances of two major classes of routing protocols under various network scenarios. In this routing protocol performance analysis, we have chosen one typical routing protocol from the proactive class and another typical one from the reactive class. Based on the extensive performance measurements, the second phase of our study consists of constructing a multi-protocol routing selection reference.

Continuously, the effects of network parameters are monitored using the control packets exchanged among the neighboring nodes. Then, the performance such as throughput is periodically checked against the protocol selection reference. The selected routing protocol is maintained among the nodes in the network until the network condition changes substantially. The construction of the protocol selection reference is elucidated in the later sections.

In the following of the paper, Section II discusses an overview of various routing schemes designed for MANET. Two important network parameters are defined and analyzed in Section III; and in Section IV our proposed method for multi-protocol based routing selection scheme is presented. The behaviors of two well-known ad-hoc routing protocols in terms of two network parameters are investigated based on the computer simulations using the OPNET modeler; and the routing protocol selection reference is constructed in Section V. Finally, the conclusions are made in Section VI.

II. Routing in MANET

Routing describes a method of providing a path to send data from source to destination in multi-hop communications. In this section we briefly describe the conventional routing protocols that have been developed for the MANET.

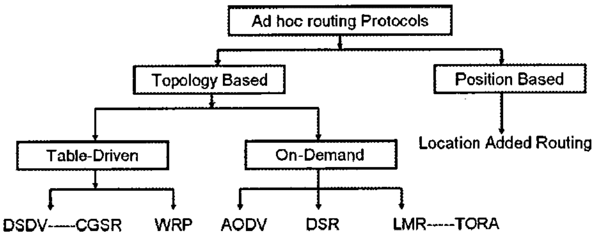


그림 1. MANET을 위한 라우팅 프로토콜 분류
Fig. 1. Classification of routing protocols for MANET

The routing protocols can be categorized into three different classes as shown in Fig. 1. Those include proactive routing protocols, reactive routing protocols, and hybrid routing protocols. The characteristic of each of them is summarized as follows:

- Proactive Routing : This is a table-driven routing protocol. A routing table is maintained by each node, and tables are periodically exchanged among nodes to share the network topology information. A node can refer to its table to determine a path to the destination. The optimized link state routing (OLSR) protocol [15] is a typical one.
- Reactive Routing : No periodic updates are performed on the routing table, but the route is made on-demand whenever a node needs to send a data. This is bandwidth-efficient in a sense that it can limit the periodic exchanges of topology information. A typical example is the ad-hoc on-demand distance vector (AODV) protocol [16].
- Hybrid Routing : The protocols in this class combine both proactive and reactive routing. Frequently, these protocols use position devices such as GPS.The zonal routing protocol is a typical one.

One can refer to [9] for more on the routing protocols. In fact, the proactive and the reactive routing protocols are main focus of our investigation in the proposed scheme.

III. Network Parameters

In this section a set of network parameters are considered. The investigation into these parameters is to jointly provide a set of reference points for our multi-protocol based routing selection scheme. We call them network parameters and they are classified into two groups, i.e., global parameters and local parameters. The global parameters provide perspectives at the network level while the local parameters provide perspectives at the node level. We first begin with the definition of global parameters followed by the local parameters.

3.1 Global Parameters

The first global parameter to consider is the network coverage ratio. Given a network of a certain size, this parameter gives some idea about how nodes are connected and distributed over the network area. We define the coverage ratio as follows [14]:

$$W = \frac{\hat{d} \cdot \sum_{n=1}^{N} \sum_{i \in \Delta_n} A_n \cap A_i}{|A_T - \bigcup_{j=1}^{N} A_j|} \quad (1)$$

Here, A_T is the area of a network and it is typically less than one square kilometers in our study; A_k is the average transmission area in square meters covered by a node k, $N$is the number of nodes in the network; Δn is the set of neighboring nodes in the transmission range of a node n; and $\hat{d}$ is the average distance between any two nodes in the network and it defined as follows:

$$\hat{d} = \frac{N(N-1)}{2} \breve{d}$$
$$\because \breve{d} = \begin{cases} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} |\overline{n_i} - \overline{n_j}| & \text{for } |\overline{n_i} - \overline{n_j}| \le \tilde{r} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Here, $|\overrightarrow{n_i} - \overrightarrow{n_j}|$ is the distance between nodes i and j; $\tilde{r}$ is the average transmission range of a node and it is typically around 150 meters in our study. The average distance $\hat{d}$ gets smaller as the node dispersion gets larger and the distance between the nodes gets farther apart. Furthermore, in Eq. (1), the union operations on the transmission areas are defined as follows:

$$\bigcup_{i=1}^{N} A_i = A_1 \cup A_2 \cdots \cup A_N \quad (3)$$

On the other hand, the intersection operations on the transmission areas of nodes are defined as follows:

$$\sum_{n=1}^{N} \sum_{i \in \Delta_n} A_n \bigcap A_i = \{A_1 \cap A_{\Delta_1} + A_2 \cap A_{\Delta_2} + \cdots + A_N \cap A_{\Delta_N}\}$$
$$\text{where } A_{\Delta_i} = \bigcup_{i \in \Delta} A_i \quad (4)$$

From the literature, the intersection area between two nodes is a non-linear function of the distance between them. When the distance is less than the transmission range, the two nodes are assumed to communicate without any degradation in performance. This intersection area is defined as follows [12]:

$$A_i \cap A_j = 2\tilde{r}^2[\cos^{-1}(x) - x\sqrt{(1-x^2)}] \text{ for } x = \frac{|\vec{n}_i - \vec{n}_j|}{2\tilde{r}} \quad (5)$$

From above equations we can observe that the coverage ratio W is a basically multi-dimensional function that it depends on the average distance $\hat{d}$ defined in Eq. (2), the intersection of the transmission areas defined in Eq. (3), and the union of the transmission areas defined in Eq. (4).

When the network is coordinated by a central station, there is no difficulty of gathering related information to estimate W. However, in an ad-hoc network situation, there is no coordinator to provide such information and it is normally unthinkable to estimate it exactly. In any case it is an important global parameter that we have developed and it shall be taken into our investigation.

Now, another global parameter considered is the connectivity. Given the networking field, the connectivity describes how well the nodes are connected, i.e. the number of neighboring nodes with good connection [17]. The connectivity along with the coverage ratio is another major factor that critically determines the reference points for the multi-protocol based routing selection scheme. It is determined as follows:

$$C = \frac{\frac{1}{\hat{d}}\sum_{n=1}^{N}\sum_{i\in\Delta_n} A_n \cap A_i}{A_T} \tag{6}$$

The connectivity C indicates whether communication is possible among the nodes and helps determine a particular instance of choosing a better-fitting routing protocol. For a network with a higher connectivity value C, the nodes tend to cluster one another and create densely populated spots. At the extreme situation, most of nodes gather within the transmission range of one anther so that the connectivity increases rapidly while the coverage ratio decreases fast. Similarly to the estimation of the coverage ratio, for being a global parameter, the exact measurement of the connectivity value C also requires centralized network coordination.

3.2 Local Parameter

In this section we consider a parameter that can be estimated locally around a node. The basic concept that we try to obtain is to collect critical information locally, analyze them, and use them for a routing purpose aimed by our routing protocol selection scheme.

The first local parameter we consider is the mobility. Now, consider a node that moves from one point to another point in the network, and assume that its velocity is uniformly distributed as $\vec{V}(t) = \{\overrightarrow{V_{\min}}, \overrightarrow{V_{\max}}\}$. The pausing time and moving time are assumed to have an exponential distribution. So, the node is in either moving phase or pausing phase, i.e., $P_h = \{move, pause\}$; and the node location at time t is $X(t) \in \{(x_{\min}, y_{\min}), (x_{\max}, y_{\max})\}$. Then, the node velocity with its phase can be defined as follows:

$$V(t) = \begin{cases} v_i & \text{iff } p_h = \{\text{move}\} \\ 0 & \text{iff } p_h = \{\text{pause}\} \end{cases} \tag{7}$$

In the time interval from t to $(t+\Delta t)$, the node may cover some distance and can reach a position as far as $X(t) + \vec{V}(t)\Delta t$. Depending on the routing protocol, when a node moves in or moves out of the transmission range of its neighborhood, it sends out its identity so that its neighboring nodes can update their routing tables. When the mobility of a node increases, the chance of moving out the current neighborhood and moving into another neighborhood escalates. Here, we are not using any kind of global positioning system to manage the velocity of each node. Instead, we monitor the control messages exchanged in the neighborhood of nodes and analyze the collected information to indirectly assess the mobility of nodes locally.

On the other hand, another resort for the mobility measurement can be obtained from the probabilistic model proposed in [13]. In this model, at time t,let $P[X(t), \vec{V}(t), t]$ be the probability that the node is passing by the location $X(t)$ at the velocity $\vec{V}(t)$. The slope of this function over a small time interval Δt around the position $X(t)$ provides a mobility indicator M for a node as follows:

$$M = \begin{cases} stationary & \text{iff } \frac{\partial P[X(t),\vec{V}(t),t]}{\partial t} = 0 \\ low & \text{iff } 0 < \frac{\partial P[X(t),\vec{V}(t),t]}{\partial t} < T_h \\ high & \text{iff } \frac{\partial P[X(t),\vec{V}(t),t]}{\partial t} > T_h \end{cases} \tag{8}$$

As $P[X(t), \vec{V}(t), t]$ monotonically increases over time and the velocity of a node is relatively continuous, if there is a certain location transition due to velocity $\vec{V}(t)$, a node chooses the pause time and moving time to reach to the destination. With the first condition $\partial P[X(t), \vec{V}(t), t]/\partial t = 0$ met in Eq. (8), the mobile node is in the pausing phase and its mobility is zero. When the second or the third condition is met, the nodes should have higher speeds. With a higher threshold T_h the mobility range gets wider. The determination of the threshold value however does depend on network scenarios.

Ⅳ. Proposed Method

The large number of routing protocols designed for MANET indicates that each routing protocol works well when a particular condition is fulfilled. In a typical application, however, network conditions vary, and no single routing protocol performs robustly all the times. For example, the exact position, speed of nodes, and connectivity can not be predicted. It naturally leads to a fact that the initial routing protocol may not be matched to the working conditions of the network that undergoes continuous topology changes.

If we have a scheme that chooses a routing protocol that reflects the changes in the network conditions, the network performance degradation can be minimized. So, the adaptive routing selection scheme that we try to adopt is fruitful for optimization of the existing routing protocol. In our proposed method, therefore, the routing protocol is selected in real-time, as the selection scheme can be dynamically started up and closed down in a periodic interval. In other words, the multi-protocols based routing selection scheme is designed to adapt itself to network conditions set by various node mobility and connectivity.

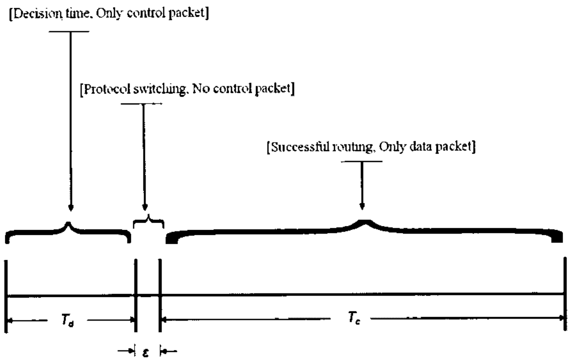


그림 2. 제안된 기법의 3가지 양상
Fig. 2. Three phases in the proposed scheme.

```
•  Start;
•  For (Decision period)
•
•    a) for (t = t1)
•           L1 = get_location;
•         for (t = t2)
•           L2 = get_location;
•         if (d = (L2-L1) > dth)
•           Send UPDATE packet;

•    b) if (Update_received = TRUE)
•           if (Node_ID = NEW)
•                  Neighbor++;
•             Density=Neighbor/Coverage_area;

         Del_time = current_time - starting_time;

•         for (Del_time)
•           if (packet_rx = TRUE)
•              Var = link_change++;
•              Link_breakage_rate = Var/del_time;

•        Decision procedure follows ....
```

그림 3. 결정단계의 프로시저
Fig. 3. Procedures performed during the decision phase.

4.1 Overview of Our Algorithm

In the proposed algorithm two network parameters are analyzed so that a node can assess the current network conditions. Every node is equally responsible for the efficient implementation of this algorithm. As illustrated in Fig. 2, there are three phases in our multi-protocol based routing selection scheme and those phases repeat periodically. The first time interval is called a decision phase. The decision phase includes the times for initialization, estimation, and decision. The second interval is called a protocol switching phase. The third and final interval is called a communications phase. The communications phase is used for data packet transmission and reception. These three time intervals make a periodic cycle and they are defined as follows:

$$T_p = T_d + \varepsilon + T_c \tag{9}$$

where T_d is the time for the decision phase, ε for the protocol switching phase, and T_c for the communications phase. Our focus is on the decision phase, and in this phase, the nodes calculate the mobility and connectivity of their neighbors. Rather than coming up with a high accuracy in velocity estimation, the more important issue is to assess the degree of mobility in the neighboring nodes. The degree of mobility can be distinguished into three states, namely, low, medium, and high. For the mobility estimation, in the decision phase, the nodes exchanges UPDATE control packets that carry essential information of nodes in the neighborhood.

The proposed method is founded upon the investigation on the behaviors of reactive and proactive routing protocols with respect to node mobility and connectivity. AODV is taken from the reactive routing category and OLSR from the proactive category. The procedures performed to analyze the effects of mobility and connectivity on each routing protocol is shown in Fig. 3.

4.2 Mobility in the Neighborhood

Mobility refers to the movement patterns of nodes; and it includes the speed and direction. In practice, mobile nodes not only move but also slow down to pause; and in order to describe the real-life moving patterns of mobile nodes, several mobility models had been proposed.

In our study, however, the node is assumed to take a straight path with a constant velocity over a certain amount of time before it comes to a rest. Along with that node movement assumption, in our multi-protocol based routing selection scheme, the mobility of neighboring nodes is assessed by monitoring the exchanges of UPDATE control packets among the nodes in the neighborhood.

The UPDATE packet is one type of hello messages; and it has a distinctive feature adopted for our algorithm. It is sent by a node whenever the node traverses a fixed length of distance through the field as shown in Fig. 4. In our study we fixed the length of distance at 20 meters. In other words, the higher the velocity the more UPDATE packets the node sends out in a unit amount time. By keeping track of unique UPDATE packet sequences from the neighboring nodes, any node can effectively assess the degree of node mobility in its neighborhood.

4.3 Connectivity in the Neighborhood

The connectivity is closely related to the distribution of nodes in the network area. Since the size of network area may vary depending on various conditions, rather than the mere count of node population, we use the density of nodes, which is defined as the number of nodes in a unit of transmission area.

In order to estimate the degree of connectivity in terms of the node density, we observe the UPDATE control packets; and a brief procedural description is provided in the pseudo-codes given in Fig. 3. When a node moves faster, it is likely to get across the transmission areas of its neighboring nodes in a relatively shorter duration of time; and the frequency of its UPDATE control packet observation goes higher compared to those nodes stationary or slowly moving.

In our study on the connectivity in the neighborhood, we are concerned with the number of unique node IDs collected from the UPDATE control

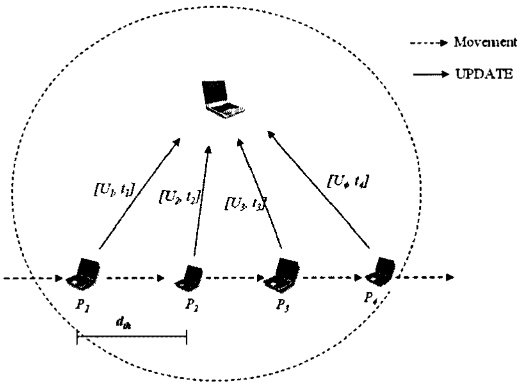


그림 4. 이웃노드에서 이동성에 대한 평가
Fig. 4. Assessment of mobility in the neighborhood.

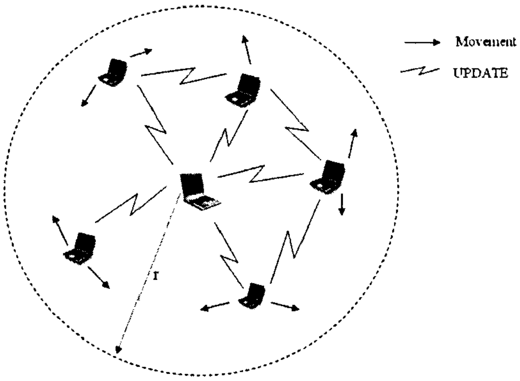


그림 5. 이웃노드에서 연결성에 대한 평가
Fig. 5. Assessment of connectivity in the neighborhood.

packets received. An illustration is shown in Fig. 5 where the node in the middle is receiving the UPDATE control packets from its neighboring nodes. The UPDATE control packet also is equipped with joining and disjoining indications so that nodes coming into and going out of its connection area can be traced and the node list can be managed. Hence, by maintaining accounts on neighboring nodes as listening to the UPDATE control packets, an efficient assessment on the degree of connectivity can be obtained.

V. Protocol Selection Reference

In this section, we have performed a set of computer simulations using the OPNET modeler to construct a protocol selection reference for our multi-protocol based routing selection scheme. The two routing protocols, i.e., proactive and reactive, are investigated in various network scenarios set by the mobility and connectivity. Using the simulation results, the protocol selection reference is constructed and the best-fitting routing protocol can be applied to the network on the fly.

The simulation parameters are shown in Table 1, and a few parameters are fixed according to the requirements. Each simulation time runs up to 300 seconds; and for the mobility model of the nodes the random waypoint mobility model is used. The size of the network area varies from (1kmx1km)to(250m x 250m); and this size variation can be used to control the network scalability.

표 1. 실험 파라미터
Table 1. Simulation Parameters.

Simulation Time	300 sec
MAC Protocol	IEEE802.11 DCF
Transmission Power	25 mw
Number of Nodes (N)	20 ~ 50
Speed of Nodes	1 ~ 15 m/s
Traffic Source	1 Kbps
Routing Protocols	AODV & OLSR

5.1 Reference in Mobility

In this simulation, the performances of two routing protocols are observed with respect to node velocity. As shown in Figures 6, 7, and 8, the overall throughput degrades as the node velocity increases for both protocols. The symbol in the legend is the routing protocol name followed by the number of nodes N. For example, $AODV_i$ indicates the usage of $AODV$ for $N=i$ nodes. The interesting observation comes from the fact that there is a short

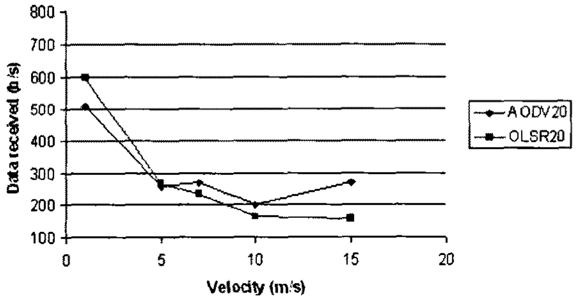


그림 6. 평균 수신 데이터 vs. 가속도 (N=20)
Fig. 6. Average received data vs. velocity (N=20).

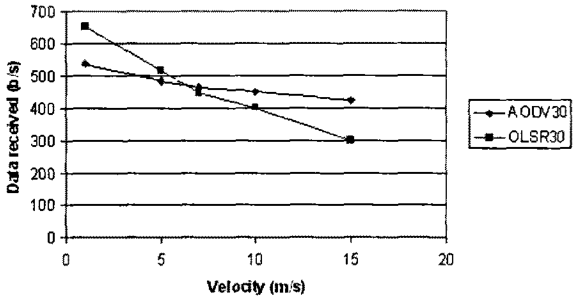


그림 7. 평균 수신 데이터 vs. 가속도 (N=30)
Fig. 7. Average received data vs. velocity (N=30).

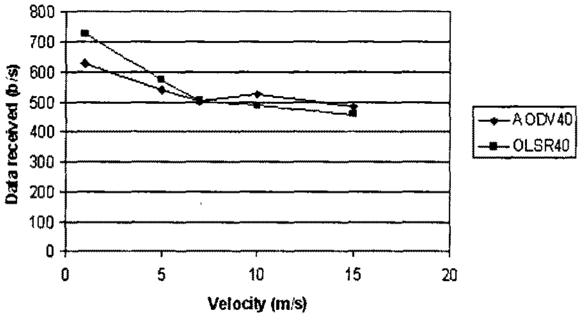


그림 8. 평균 수신 데이터 vs. 가속도 (N=40)
Fig. 8. Average received data vs. velocity (N=40).

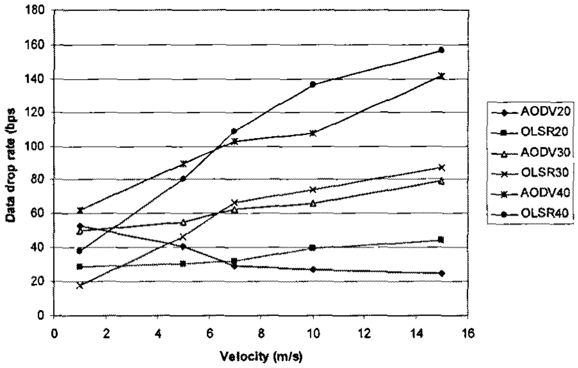


그림 9. 감소 율 vs. 다양한 N을 가진 가속도
Fig. 9. Drop rate vs. velocity with different N.

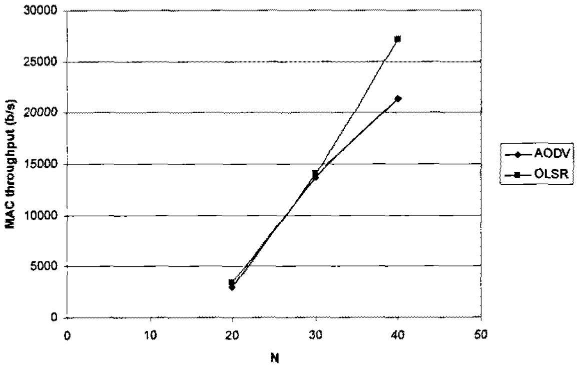


그림 10. 처리량 vs. 노드 N의 수
Fig. 10. Throughput vs. number of nodes N.

range of points that performance curves for *AODV* and *OLSR* cross each other. In some cases, a few points fluctuate because of the unpredictable nature of mobile networks, however, the performance of *AODV* and *OLSR* just change at these points. This behavior indicates that one protocol performs better than the other one in different network conditions.

Furthermore, with variation in the velocity and number of nodes, the data drop rates for two routing protocols are observed and compared. The combined results are shown in Fig. 9. As expected, the data drop increases as the node velocity escalates. Fascinatingly, for each value of N, the performance curves intersect each other and performances just reverse around there. The crossing points observed in performance curves for data receiving rate and those for data drop rate are in the proximate range. As shown in the figures, the crossing points are in the range of 6 to 8 m/s; and this range has a significant meaning as far as defining the mobility reference. Moreover, it is interesting to note that the throughput performance increases for both protocols with increasing numbers of nodes, as it can be observed in Fig. 10. One reason for this is that the data rate of the IEEE 802.11 interface now is set to $11Mbps$, and a sufficient amount of data can be sent without too much competition. Up to the network capacity, the more node traffic can be accommodated, however, the competition for transmission will increase and the chance for packet collision will also escalate. Eventually, the throughput will decrease. For more convincing results with respect to node population growth, we go on with more simulations to understand the behavior of *AODV* and *OLSR* in terms of the node connectivity.

5.2 Reference in Connectivity

In this simulation, the performances of two routing protocols are observed with respect to node connectivity. The node connectivity is expressed in terms of node density. The node connectivity can be changed in two ways. One is by changing the node density while the network area is fixed; and the other is by changing the scale of network area with a fixed number of nodes. For example, with the fixed number of nodes, when the size of the network gets reduced by four times, $A' = A/4$, the connectivity increases by four times.

The simulation results for three different connectivity scenarios are shown in Figures 11, 12, and 13. It can be easily observed that the throughputs for both routing protocols decrease as the velocity increases. The more interesting observation is that the throughput also decreases as the node density increases. Moreover, the performance curves for *AODV* and *OLSR* cross each other; and the crossing points also occur in the proximity of 6 to 8 m/s.

Furthermore, the channel utilization with respect to node density in Fig. 14 shows that the performance curves for *AODV* and *OLSR* also cross each other; and those crossing point occur in the range of 16 to 23 $nodes/km^2$. The proactive routing protocol *OLSR* performs lower than the *AODV* in the higher node density region; and the reasoning can be found from the fact that the *OLSR* must update the routing table periodically by sending a control packet at regular intervals to the neighbors. The occurrence of this performance change around some node density points has a meaningful significance in defining a connectivity reference.

5.3 Protocol Selection Reference Boundaries

From the simulation results obtained using various network scenarios set by different node mobility and connectivity, the boundaries for the routing protocol selection reference are determined; and the nodes can adaptively select the best-fitting routing protocol in a real-time basis.

From the simulation results shown in Figures 6, 7, 8, and 9, we have observed that the throughput performance curves for *AODV* and *OLSR* with respect to node velocity cross each other over the range around 6 to 8 m/s. As far as the mobility reference in terms of the velocity is concerned, three different degrees of mobility can be defined as follows:

- Low mobility : node velocities below 5 m/s
- Medium mobility : node velocities in <5~9>
- High mobility : node velocities above 9 m/s

In the low mobility region, e.g., node velocities below 5 m/s, the proactive routing protocol *OLSR* performs better while in the high mobility region the reactive routing *AODV* works better.

Moreover, the behavior of these two distinctive types of routing protocols with respect to node connectivity expressed in terms of node density has been found. As shown in Figures 11, 12, and 13, the throughput performance curves have close similarities

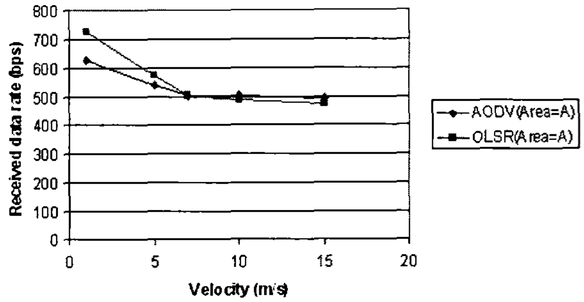


그림 11. 처리량 vs. 가속도 (A'=A)
Fig. 11. Throughput vs. velocity (A'=A).

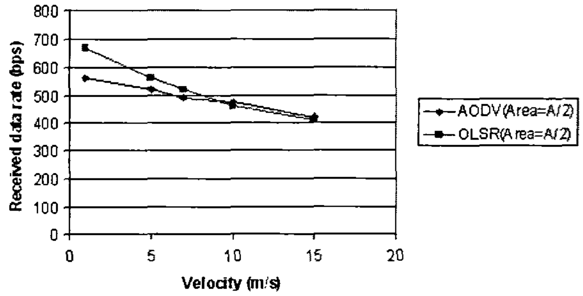


그림 12. 처리량 vs. 가속도 (A'=A/2)
Fig. 12. Throughput vs. velocity (A'=A/2).

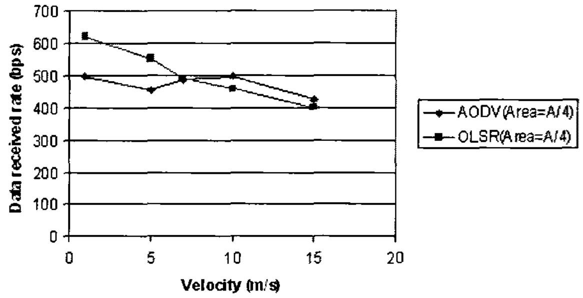


그림 13. 처리량 vs. 가속도 (A'=A/4)
Fig. 13. Throughput vs. velocity (A'=A/4).

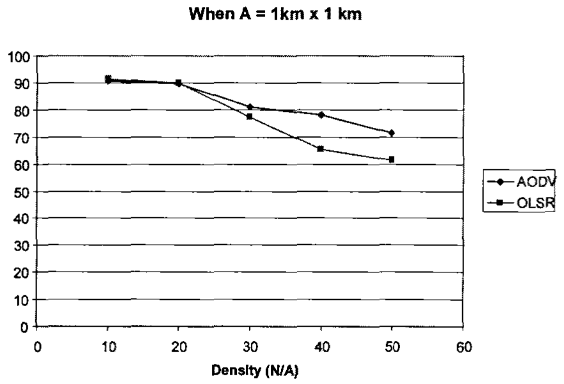


그림 14. 채널이용도(%) vs. 노드 밀집도
Fig. 14. Channel utilization (%) vs. node density.

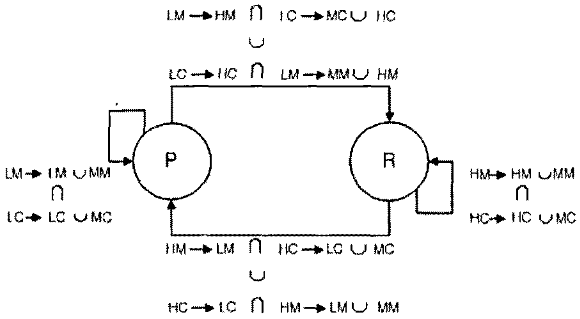
to the ones in Figures 6, 7, and 8; for both set of results the performance crossing points occur around the range of 6 to 8 m/s. Further more, as shown in Fig .14, as far as the connectivity reference in terms of the node density is concerned, the three different degrees of connectivity can be defined as follows:

- Low connectivity: density below 15/km2
- Medium connectivity: densities in <15~25>
- High connectivity: density above 25/km2

In the high connectivity region, e.g. the node density above 25, the reactive routing protocol *AODV* performs better while in the low connectivity region the proactive routing protocol *OLSR* performs better.

5.4 Routing Protocol State Transition

Now, the selection reference boundaries for the multi-protocol based routing selection scheme have been decided; and using these boundaries, the state diagram for routing protocol transition can be constructed as follows:



In the state transition diagram, *P* denotes the proactive routing protocol *OLSR*, and *R* denotes the reactive routing protocol AODV. For the low, medium, and high mobility degrees, *LM*, *MM*, and *HM* are used, respectively; and for the low, medium, and high connectivity degrees, *LC*, *MC*, and *HC* are used, respectively. The intersection and union operators are used to denote 'and' and 'or' logical operations. According to the state diagram, for example, the routing protocol transition from the proactive protocol *P* to the reactive protocol *R*occurs when the protocol selection reference conditions take transitions as follows:

$$<(LM \rightarrow HM) \ \cap \ (LC \rightarrow MC \cup HC)>$$

and

$$<(LC \rightarrow HC) \ \cap \ (LM \rightarrow MM \cup HM)>$$

VI. Conclusions

In this paper we have investigated the behavior of two major routing protocols in terms of node mobility and connectivity and constructed a protocol selection reference for our multi-protocol based routing selection scheme.

Concerned with providing a best-fitting routing protocol among a stack of various proactive and reactive routing protocols for MANETs, we have first chosen two important parameters and studied their effects on the behavior of each routing protocol. Those two determining parameters are node mobility and connectivity. The abstraction of node mobility has been defined; and in practice it is expressed in terms of node velocity. Also, the abstraction of node connectivity is defined; and in practice it is expressed in terms of node density.

Another major part of the work is given to the construction of a protocol selection reference. In order to determine the selection reference boundaries, several sets of computer simulations using the OPNET modeler have been performed. Two well-known ad-hoc routing protocols, i.e., *AODV* and *OLSR*, are used and their performances are observed over various mobility and connectivity conditions. Using the simulation results collected, the protocol selection reference is constructed and the protocol transition diagram has been implemented. Based on the transition rules, the nodes in the network can determine which routing protocol fits better; and in real-time they can adaptively take a routing protocol transition from the current one to the other best-fitting one.

Now, as our on-going work, a routing protocol translation mechanism is under study. The protocol translator is needed to bridge two different routing protocols in a case where a mixture of different protocols coexists in the network.

In sum, our investigation on the multi-protocol based routing selection scheme has been successful in providing a meaningful multi-protocol based routing model that can not only increase the utilization of the network resources but also prepare a novel routing method for next-generation ad-hoc mobile ad-hoc networks to come.

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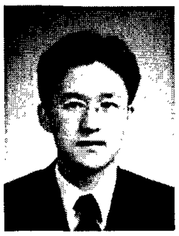
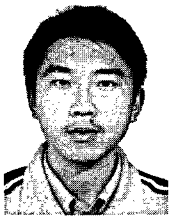
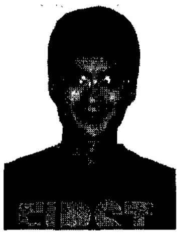
저자소개



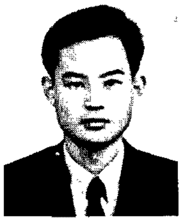
허 웅(학생회원)
2002년 전북대학교 컴퓨터공학과 학사 졸업.
2004년 전북대학교 컴퓨터공학과 석사 졸업.
2006년 전북대학교 컴퓨터공학과 박사 수료.
<주관심분야 : 무선통신, 센서 네트워크, 프로토콜 모델링>



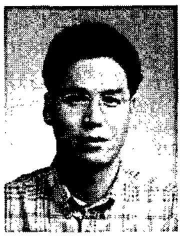
조 일(학생회원)
2008년 South Central University for Nationality (B.S.C.S).
2010년 현재 전북대학교 전자공학과 석사
<주관심분야 : 무선통신, 센서네트워크>



만 신(학생회원)
2008년 South Central University for Nationality (B.S.C.S).
2010년 현재 전북대학교 전자공학과 석사
<주관심분야 : 무선통신, 애드 혹 네트워크, 센서네트워크>



유 강 수(정회원)
1991년 전북대학교 컴퓨터공학과 학사 졸업.
1994년 전북대학교 컴퓨터공학과 석사 졸업.
2005년 전북대학교 영상공학과 박사 졸업.
<주관심분야 : 영상처리, 컴퓨터비전, 멀티미디어 시스템, 네트워크>



최 재 호(정회원)
1985년 NC State University (BSEE).
1988년 NC State University (MSEE).
1993년 NC State University (Ph.D. in Computer Eng.).
1994년~현재 전북대학교 전자공학과 교수
<주관심분야 : 멀티미디어 통신, 무선/센서 네트워크, 이종 네트워크 연결, 에드 혹 네트워크>