논문 11-36-03-11 한국통신학회논문지 '11-03 Vol.36 No.3

지향성 안테나를 사용하는 Ad Hoc 네트워크에서 간섭완화를 위한 전력제어기반 접근제어프로토콜

정회원 푸칭시안*, 최 명 길**, 종신회원 황 원 주*°

Power Control based MAC Protocol for Interference Mitigation in an Ad Hoc Network with Directional Antennas

Pu Qingxian* , Myeonggil Choi** ***Regular Members***,
Won-Joo Hwang*° ***Lifelong Member***

요 약

지향성 안테나는 네트워크의 공간 재사용 기술이 발전함에 따라 Ad Hoc 네트워크에서 널리 사용되고 있다. 그러나 확장된 전송영역은 이웃하는 수신 노드 간에 충돌을 일으키고, 이것은 지향성 안테나의 전송능력을 충분히 사용하지 못하게 하는 원인이 된다. 본 논문에서는 지향성 안테나를 위한 새로운 전력제어 MAC프로토콜을 제안한다. 이 프로토콜을 지원하기 위하여 이웃하는 수신 노드들 중에서 간섭 노드의 집합을 찾아내기 위한 기법을 개발한다. 그리고 전력 제어 알고리즘을 이용하여 최소 전송 전력을 계산한 후, 데이터를 전송한다. 이 프로토콜의 시뮬레이션 결과, 네트워크 성능이 향상되었으며 전력 소비가 감소하였음을 알 수 있었다.

Key Words : MAC, interference detection, directional antenna, power control, Ad Hoc network

ABSTRACT

Directional antennas have been used in Ad Hoc networks, significantly improving the spatial reuse of the networks. However, the extended transmission range causes collisions at the receivers of neighbors, which prevents full exploitation of the potential of the directional antenna. In this paper, we propose a new power control MAC protocol for a directional antenna. For this protocol, we propose a method to detect a set of interference nodes in the neighbors of a receiver. We then use a power control algorithm to calculate the minimum transmission power and send data. Simulation results demonstrate that this protocol increases the network performance and reduces energy consumption.

Ⅰ. Introduction

Popular wireless networks, such as Ad Hoc networks[1], are dynamically formed amongst a group of wireless users and require no existing infrastructure or pre-configuration. Because of their infrastructure, Ad Hoc networks have garnered attention for their possible application in military battlefields, civilian disaster recovery operations, farm animal monitoring, etc.. Building such Ad Hoc networks poses a significant technical challenge, however, because of the many constraints imposed

---

※ 이 논문은 2009년도 정부(교육과학기술부)의 재원으로 한국연구재단의 기초연구사업 지원을 받아 수행된 것임(2010-0016905)

* 인제대학교 전자정보통신공학과 HSV-TRC (puqx_47@yahoo.com.cn, ichwang@inje.ac.kr), (° : 교신저자)
** 중앙대학교 경영학과(mgchoi@cau.ac.kr),

논문번호 : KICS2010-10-501, 접수일자 : 2010년 10월 2일, 최종논문접수일자 : 2011년 3월 2일

by the environment. Thus, the devices used in the field must be lightweight. Furthermore, since they are battery operated, they need to be energy conserving so that battery life is maximized. Therefore, one of the fundamental challenges in designing Ad Hoc networks is finding a method to increase the overall network throughput while maintaining low energy consumption for packet processing and communications.

Directional antennas offer clear advantages for improving the network capacity by increasing the potential for spatial reuse[2]. Allowing antennas to direct their transmissions in the direction of the intended receiver clearly reduces the level of contention with other nodes, thereby allowing for more simultaneous transmissions. Moreover, directional antennas can increase the signaling range without spending extra power (as opposed to omni-directional) and, accordingly, some receivers outside the omni-directional range may be reached in a one-hop transmission. Since a directional antenna has a higher gain, a transmitter using directional antenna requires a lower amount of power to transmit to the same distance as would be needed with an omni-directional antenna. Hence, transmitting nodes can conserve power by adequately reducing the power utilized for directional transmissions.

However, using a directional antenna[3] also presents new problems in the design of MAC protocols, such as new hidden terminal problems [4] and deafness problems[4] as well as potential interference due to the extended transmission range. For instance, in Figure 1, node A and node B are communicating. First, node A uses an omni-directional antenna to send data. The transmission signal cannot interfere with node C. Meanwhile, if node A uses a directional antenna to send data, the extended transmission range covers node C. Therefore, node C is interfered with by node A.

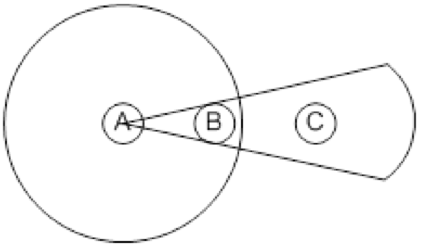

Fig. 1. Interference problem

In this paper, we present an interference aware power control MAC protocol for a directional antenna (IAPC).

First, we propose an interference detection method. The nodes that interfere in the receiver of the main transmission are the interference nodes. In the interference method, we compare the angle of transmission of neighbor nodes with half of the beam angle and decide whether the receiver is in the area of the transmission range of neighbor nodes. The receiver then gathers local interference information and computes the total potential interference.

Second, based on the total interference at the receiver of the main transmission and the SINR constraint requirements, the receiver calculates the minimum received power value. The receiver then computes the minimum transmission power and sends it to the transmitter.

Finally, we evaluate our protocol performance and compare it with other existing protocols. The results show that it provides higher performance than other protocols.

Ⅱ. System Model

2.1 Anthenna Model

Assume that each mobile node is equipped with an array of M non-overlapping sectorized antennas covering all angles. Each antenna has a conical radiation pattern, spanning an angle of $\theta = 2\pi/M$ radians. The transmitter gain of the main lobe is g and the antenna height is h. Let P_t be the transmission power and P_r be the receive power of a frame from a transmitter node at the receiver. The distance between the transmitter node i and the receiver node j is d_{ij}. If there are a transmitter node i and a receiver node j, using the two-ray propagation model with the exponential attenuation factor equal to 4, the transmitted power P_t of a frame can be written as:

$$P_r = \frac{g_i g_j h_i^2 h_j^2}{d_{ij}^4} P_t \tag{1}$$

where g_i, g_j, h_i and h_j are constants; hence we can rewrite equation (1) as follows:

$$P_r = \frac{\sigma}{d_{ij}^4} P_t \tag{2}$$

where $\sigma = g_i g_j h_i^2 h_j^2$ is a constant.

2.2 Network Model

The channel loss gain between a pair of nodes can be determined and is stationary for the duration of the control and ensuring data and control packets. The channel loss gain between node i and node j can be measured as follows:

$$G_{ij} = \frac{P_r}{P_t} \tag{3}$$

According to equations (2) and (3), we can obtain

$$G_{ij} = \frac{\sigma}{d_{ij}^4} \tag{4}$$

Let $P_{t\_\max}$ and $P_{t\_\min}$ denote the maximum and minimum transmission powers for a transmitter, respectively. Let P_{rcv_th} denote the minimum received signal power threshold for receiving a valid packet. Let $SINR_{th}$ denote the "capture threshold", i.e. the minimum signal to noise and interference ratio for which the receiver can successfully receive a packet.

Given the transmitter and receiver power parameters and the channel propagation characteristics, a transmitter i must transmit a packet to a receiver j at the minimum transmission power P_{t_i} that satisfies the following power constraints.

1) The transmission power of i must be within its parameter range, $P_{t_{\max}} \le P_{t_i} \le P_{t_{\max}}$

2) The received power at j must at least be equal to the minimum received power threshold, $G_{ij} P_{t_i} \ge P_{rcv\_th}$

3) The observed signal to noise and interference ratio for the transmission at j must at least be equal to the minimum $SINR_{th}$

$$SINR_j = \frac{G_{ij} P_{t_i}}{I_{j\_tal}} \ge SINR_{th} \tag{5}$$

I_{i_tal} is the total noise and interference at node j.

If the above constraints can be met, then node i can successfully transmit to j. The critical issues are therefore (a) determining the total noise and interference; and (b) determining the minimum transmission power that satisfies constraints 2 and 3.

Ⅲ. The IAPC protocol

We present in this section an IAPC protocol for reducing the energy consumption and achieving high network capacity. In this protocol, there are two components: (a) interference detection and computation; and (b) minimum transmission power calculation. Interference detection is carried out to estimate the potential interference at the receiver and compute the total noise and interference. Minimum transmission power entails calculation of the minimum data transmission power based on the total noise and interference.

3.1 Interference Detection

We consider a two-hop interference model[7]. If the hop distance between two links is less than 2, then the transmissions over both links will interfere with each other. The two-hop interference model can reduce the complexity in comparison with the conventional model. Because the conventional model considers all the distance between the links, the network state that must be exchanged is huge. If one pair of nodes starts communicating, other neighbor nodes cannot realize this pair's transmission because they send RTS/CTS packets directionally. However, when their neighbor nodes initiate a new pair transmission, it may interfere with their transmission. In Figure 2, if node i and node j start to communicate, node m_1 cannot detect their communication. While node m_1 and node k_1 initiate a new transmission, node k_1's signal will interfere with the transmission between node i and node j due to the extended directional antenna gain, which points to node j (shaded area ①). However, node k_2's signal will not interfere with the transmission node i and node j , because node k_2's antenna beam does not point to node j (shaded area ②). Here, node k_1 is an interference node but k_2 is not an interference node. Thus, to determine the interference nodes, the receiver needs to check whether it is inside its neighbors' transmission range. If the receiver is within the range of its neighbors, the neighbors are interference nodes. However, if the receiver is not in the range of neighbor nodes, the neighbor nodes are not interference nodes.

The method to determine whether a receiver is in the range of neighbor nodes entails calculation of the transmission angle of neighbor nodes β. This angle is then compared with the angle of half of the transmission beam Θ/2. If $\beta<\Theta/2$, the neighbor nodes are interference nodes of the receiver. If $\beta>\Theta/2$, the neighbor nodes are not interference nodes of the receiver. For example, in Figure 3, node i and node j start to communicate. At the same time, node k_1 and node k_2 initiate new transmissions to node m_1 and node m_2, respectively. The distances of each are d_{ij}, $d_{k_1m_1}$, $d_{k_2m_2}$, d_{im_1} and d_{jm_2} , respectively. Node m_2 uses beam 2 to communicate with node j and uses beam 6 to communicate with node k_1. Here, we assume that the transmitter uses the central direction of a beam to send data. To decide whether node k_1 is an interference node, we need to compare angle β with Θ/2. If $\beta<\Theta/2$, node j is within the transmission range of node k_1. Hence, node k_1 is an interference node of node j. If $\beta>\Theta/2$, node j is outside the transmission range of node k_1. Therefore, node k_1 is not an interference node of node j.

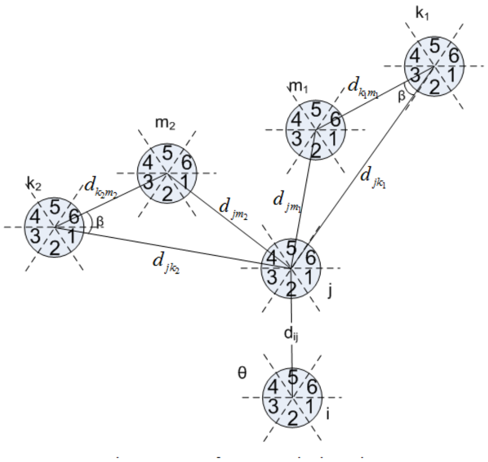

Fig. 3. Interference node detection

To calculate β and determine interference nodes, the following steps are taken:

```
Algorithms
Step 1: Node j calculates $d_{jk_1}$ :
    A)  Calculate the $\alpha_{m_1}(j,k_1)$ from (6)
    B)  Calculate the $d_{jk_1}$ from (7)
Step 2: Node j calculates β from (8)
Step 3: Compare β with Θ/2 and determine interference nodes:
    If $\beta<\Theta/2$, node $k_1$ is an interference node of node j.
    If $\beta>\Theta/2$, node $k_1$ is not an interference node of node j.
```

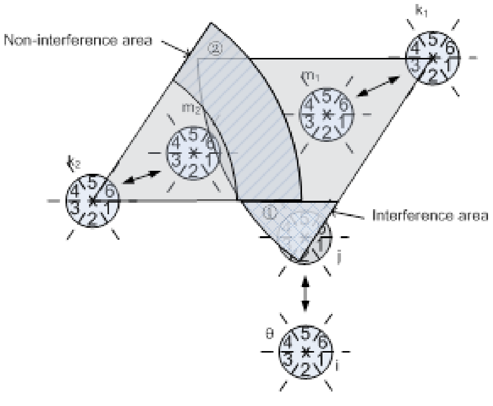

Fig. 2. Two-hop interference model

Step 1: Node j requires the distance d_{jk_1} between node j and node k_1. Node j knows the distance d_{jm_1} and $d_{k_1m_1}$ from the two-hop interference model and the antenna beam that is used to transmit data at node m_1 from the AOA (Angle of Arrival)[8] and past transmissions. The beam that node m_1 uses to send data to node j is B_{jm_1} and the beam that node m_1 uses to send data to node k_1 is $B_{k_1m_1}$

A) To calculate d_{jk_1} we need to know the angle of $\alpha_{m_1}(j,k_1)$ which is the angle between link (j,m_1) and link (m_1,k_1). $\alpha_{m_1}(j,k_1)$ A) can be determined by the antenna beam. Thus,

$$\alpha_{m_1}(j,k_1)=\begin{cases}\left(|B_{k_1m_1}-B_{jm_1}|+1\right)\theta & |B_{k_1m_1}-B_{jm_1}|<\dfrac{M}{2}\\ 180^0 & |B_{k_1m_1}-B_{jm_1}|=\dfrac{M}{2}\\ 360^0-\left(|B_{k_1m_1}-B_{jm_1}|-1\right)\theta & |B_{k_1m_1}-B_{jm_1}|>\dfrac{M}{2}\end{cases}\quad(6)$$

In this case $B_{k_1m_1}=6$, $B_{jm_1}=2$ and M=6 and therefore $|B_{k_1m_1}-B_{jm_1}|>\frac{M}{2}$. We can obtain $\alpha_{m_1}(j,k_1)=360-\left(|B_{k_1m_1}-B_{jm_1}|-1\right)\theta$. In (6), we find that as M becomes larger, the angle of $\alpha_{m_1}(j,k_1)$ becomes more precise.

B) We can then calculate d_{jk_1}

$$d_{jk_1}=(d_{k_1m_1}^2+d_{jm_1}^2-2d_{k_1m_1}d_{jm_1}\cos(\alpha_{m_1}(j,k_1)))^{1/2}\quad(7)$$

Step 2: Thus, the angle of β, that is $\alpha_{m_1}(j,k_1)$, is

$$\beta=\operatorname{arcos}\frac{d_{k_1m_1}^2+d_{jk_1}^2-d_{jm_1}^2}{2d_{k_1m_1}d_{jk_1}}\quad(8)$$

As we know, the angle of β, that is $\alpha_{k_1}(j,m_1)$, is smaller than $\theta/2$, and therefore node k_1 is an interference node of node *j*.

Step 3: We compare angle β with $\Theta/2$. If $\beta<\Theta/2$, node j is within the transmission range of node . Hence, node k_1 is an interference node of node j. If $\beta>\Theta/2$, node j is outside the transmission range of node k_1 . Hence, node k_1 is not an interference node of node j. Here, we can see β<Θ/2. Therefore, node k_1 is an interference node of node j.

In the same manner, for node k_2 and node m_2, because β>Θ/2, node k_2 is not an interference node of node j.

3.2 Local Power Control

We now present an overview of the operation of IAPC, explaining how interference detection is implemented and how the protocol protects ongoing receptions from experiencing interfering transmissions. As Figure 3 shows, there is a link between node i and node j; node i is a transmitter and node j is a receiver. If node i tends to communicate with node j, then the local power control method works as delineated in Figure 4.

Step 1: Node i sends RTS directionally at the maximum power to node j. The maximum power level guarantees that node j can receive the RTS.

Step 2: When node j receives the RTS, it calculates the channel loss gain G_{ij} using (4). Owing to the assumption that the wireless link between two nodes is bidirectional, the gain is the same for both directions ($G_{ij}=G_{ji}$).

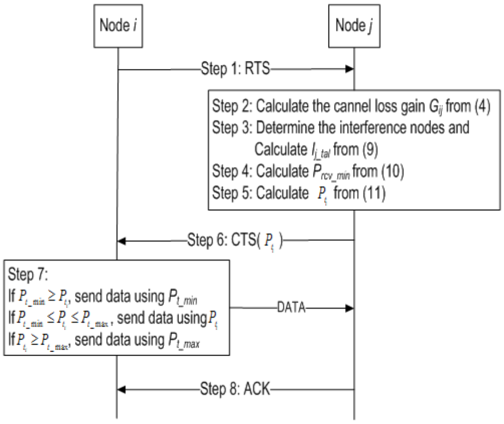

Fig. 4. Diagram of the relative timing of various actions in IAPC

Step 3: Then node j decides the set of potential interference nodes S_j using the interference detection method and calculates the total noise and interference I_{j_tal} using

$$I_{j-tal} = N_j + \sum G_{kj} P_{t_k} \tag{9}$$

where N_j is the power of the thermal noise at node j, S_j is the set of potential interference nodes, P_{t_k} is the transmission power of potential interference nodes, and G_{jk} is computed by (4)

Step 4: Node j then calculates $P_{rcv\_\min}$; according to constraint 3 (equation (5)), the minimum received power for an incoming data packet to be correctly decoded from its current noise environment is given by

$$P_{rcv\_\min} = \max\left(P_{rcv\_th}, SINR_{th} \cdot I_{j\_tal}\right) \tag{10}$$

Step 5: Node j then calculates the required minimum transmission power P_{t_i} as:

$$P_{t_i} = G_{ij} \cdot P_{rcv\_\min} \tag{11}$$

Step 6: After that, node j includes the value P_{t_i} in the DCTS packet and sends it to node I.

Step 7: When node i receives the DCTS, it checks whether P_{t_i} meets the first constraint, that is, $P_{t\_\min} \le P_{t_i} \le P_{t\_\max}$. Therefore, node i compares P_{t_i} with $P_{t\_\max}$ and $P_{t\_\min}$. If $P_{t\_\min} \le P_{t_i} \le P_{t\_\max}$, node i uses P_{t_i} to send data. If $P_{t_i} > P_{t\_\max}$, it means that the transmitter needs to enlarge the power such that it is larger than $P_{t\_\max}$. However, $P_{t\_\max}$ is already the maximum transmission power. Thus, in this situation, node i will use $P_{t\_\max}$ to send DATA. If $P_{t_i} < P_{t\_\min}$, node i will use $P_{t\_\min}$ to send DATA.

Step 8: After the data packet is successfully received, node j sends an ACK to node I.

Ⅳ. Performance Evolution

In this section we evaluate the performance of the IAPC protocol and contrast it with the DMAC and IEEE 802.11b protocols. Our simulation programs are written in Opnet[9]. In our simulations, we investigate both the network throughput and the energy consumption. The energy consumption is calculated by considering the power used for transmission only. The power consumed for receiving is not calculated. For our simulations, 20 nodes are arranged at random in a square area with dimensions of 500m. The destination nodes are chosen at random from one of the neighbors of the source node. We set the SINR threshold at 10dB[10]. The minimum received signal power is -64dB[11]. The maximum transmit power is 40dB[11]. Date pack size is 1024 bytes. Typical values are used for the antenna gains of a standard six-element circular array directional antenna.

We start by first analyzing the throughput performance as we vary the offered data rate. Figure 5 gives the average throughput of the 802.11b, DMAC, and IAPC protocols. The IAPC protocol has the highest throughput among the three protocols. This is due to the fact that IAPC can detect the interference nodes and, based on this estimation, it can assign consecutive powers to frames, thus differentiating it from DMAC in terms of achieving better throughput. However, in the DMAC protocol, there is no detected activity, and interference at the receiver due to the extended transmission range

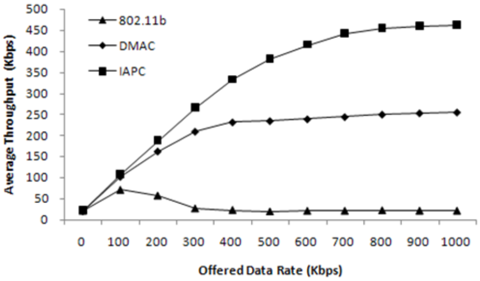

Fig. 5. Throughput performance with protocols using directional antenna

plays a major role in decreasing the throughput. Furthermore, there is no power control activity in DMAC and data is transmitted with the maximum power. This wastes energy and causes more interference and a high packet drop rate. For the 802.11b protocol, an omni-directional antenna is used to send data. When the offered data rate is low, the throughput is increased. In contrast, when the offered data rate is increased, the throughput becomes lower. This is attributed to the occurrence of more collisions when the offered data rate increases.

Figure 6 depicts the average power consumption in the transmitter. Energy consumption includes the energy of successful transmission of a packet and the lost energy in retransmitting a packet. The significant power savings is attributed to the gain of the directional antennas and to the correct assignment of power values for the IAPC protocol. We can see that the DMAC and IAPC protocols using a directional antenna provide significant savings in the average power consumption compared with the 802.11b MAC protocol. This is due to the fact that the 802.11b MAC protocol uses an omni-directional antenna, causing more collisions. In comparison with the IAPC protocol, DMAC does not use a power control algorithm, and thus the transmitter always uses maximum power to send data. Accordingly, the power consumption of DMAC is greater than that of IAPC. In the IAPC protocol, a power control algorithm is employed, thereby reducing the surplus power and lowering power consumption.

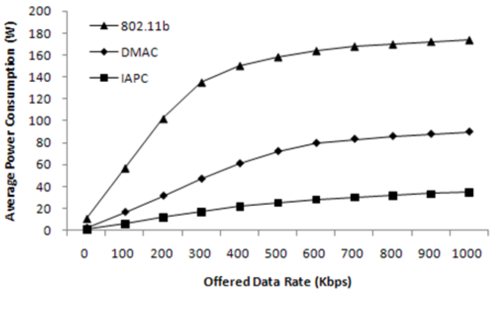

Fig. 6. Average Power Consumption Performance

V. Related Word

Power control with the use of directional antennas for packet radio networks was first proposed in[5], where a slotted ALOHA packet radio network was considered. The authors derived an equation model to calculate the performance improvement that can be obtained in a slotted ALOHA channel by the use of directional antennas and multiple receivers.

Performance evaluation of directional antennas with power control was also studied in[12]. Here, the RTS message is sent at a predetermined power – the maximum power. The receiver finds the difference between the received power of the RTS message and its threshold power[12]. The value of the difference is sent with the CTS packet. The source node will use a power that is equal to the maximum power minus the difference value.

In DMAC (Directional MAC)[13], a communication pair exchanges RTS/CTS/DATA/ ACK, and all frames are transmitted with the directional beam. The receiver receives packets with the directional beam, except RTS. The neighboring nodes receive the RTS or CTS set DNAV (Directional NAV), and postpone communication to the direction of the node that transmitted the RTS or the CTS. At this time, communication in the direction where DNAV is not set is possible. In DMAC, the position information acquisition method required for directional control is not shown.

Ⅵ. Conclusion

In order to effectively support the application of directional antennas in Ad Hoc networks, a new interference aware power control MAC protocol for a directional antenna (IAPC) is proposed. For this protocol, we first proposed the set of interference nodes and a method to detect interference nodes. Based on this set of interference nodes, we compute the total noise and interference. We then use power control to set the transmission power. This protocol reduces energy consumption and increases the network performance

References

〔1〕 R. Jurdak, C. Lopes and P. Baldi, "A Survey, Classification and Comparative Analysis of Medium Access Control Protocols for Ad Hoc Networks," *IEEE Communications Surveys and Tutorials*, 6(1), pp.2-16, 2004.

〔2〕 R. Ramanathan, "Antenna Beam forming and Power Control," *Mobile Ad Hoc Networking, IEEE Press/Wiley*, 2004.

〔3〕 H. Dai, K. Ng and M. Wu, "An Overview of MAC Protocols with Directional Antennas in Wireless Ad hoc Networks," *Proceeding on Wireless and Mobile Communications 2006 (ICWMC2006)*, 2006.

〔4〕 R. Choudhury and N. Vaidya, "Impact of Directional Antennas on Ad Hoc Routing," *Proceeding on Personal and Wireless Communication 2003 (PWC2003)*, 2003.

〔5〕 J. Zander, "Slotted Aloha Multihop Packet Radio Networks with Directional Antenna," *Electronics Letters*, 26(25), pp.2098-2100, 1990.

〔6〕 A. Arora, M. Krunz and A. Muqattash, "Directional Medium Access Protocol DMAP with Power Control for Wireless Ad Hoc Networks," *Proceeding on Global Telecommunications Conference 2004 (GLOBECOM2004)*, pp.2797-2801, 2004.

〔7〕 Z. Zhang, "On the Application of Directional Antenna to Two Hop Relay System," *Proceeding on Vehicular Technology Conference 2007 Spring (VTC2007-Spring)*, pp. 3130-3134, 2007.

〔8〕 M. Takai, J. Martin, A. Ren, and R. agrodia, "Directional Virtual Carrier Sensing for Directional Antennas in Mobile Ad Hoc Networks," *Proceeding on Mobile Ad Hoc Networking and Computing 2002 (MobiHoc2002)*, pp.183-193, 2002.

〔9〕 OPNET Simulator, www.opnet.com.

〔10〕 B. Alawieh, C. Assi and H. Mouftah, "Power-aware Ad Hoc Networks with Directional Antennas: Models and Analysis," *Ad Hoc Networks*, 7(3), pp.486-499, 2008. .

〔11〕 J. Monks, V. Bharghavan and W. Hwu, "A Power Controlled Multiple Access Protocol for Wireless Packet Networks," *Proceeding on INFOCOM*, pp.219-228, 2001.

〔12〕 R. Ramanathan, "On the performance of ad hoc networks with beamforming antennas," *Proceeding on Mobile Ad Hoc Networking and Computing 2001 (MobiHoc2001)*, 2001.

〔13〕 R. Choudhury, S. Yang, N. Ramanathan and N. Vaidya, "Using Directional Antennas for Medium Access Control in Ad Hoc Networks," *Proceeding on Mobile Computing and Networking 2002 (MobiCom2001)*, pp. 59-70, 2002.

푸칭시안 (QuingXian Pu) 정회원

2007년 6월 중국소주대학 전자정보공학과 학사

2009년 8월 인제대학교 전자정보통신공학과 석사

<관심분야> 지향성 안테나, Ad hoc 네트워크

최 명 길 (Myeonggil Choi) 정회원

1993년 2월 부산대학교 경영학과 학사

1995년 2월 부산대학교 경영정보학과 석사

2004년 7월 한국과학기술원 정보보호 공학박사

2005년 9월~2008년 2월 인제대학교 시스템경영공학과 조교수

2008년 3월~현재 중앙대학교 정보시스템전공, 경영학과 조교수

<관심분야> 정보보안 정책 및 관리, 거버넌스, 기술창업, 보안성 평가

황 원 주 (Won-Joo Hwang) 종신회원

1998년 2월 부산대학교 컴퓨터공학과 학사

2000년 2월 부산대학교 컴퓨터공학과 석사

2002년 9월 일본오사카대학 정보시스템공학과 박사

2002년 9월~현재 인제대학교 정보통신공학과 부교수

<관심분야> 네트워크 최적화 이론, 미래인터넷 아키텍처 설계