논문 2008-4-3

A Cross-Layer Transmission Architecture to Support Power Saving High-Speed Multimedia Services in Mobile Ad-hoc Wireless Sensor Networks

모바일 Ad-hoc 무선 센서 네트워크에서 전력 절약 고속 멀티미디어 서비스를 지원하기 위한 Cross-Layer 전송구조

안병구[*], 최진규[**]

Beongku An[*], Ginkyu Choi[**]

요 약 본 논문은 모바일 ad-hoc 무선 센서 네트워크에서 전력 절약 고속의 멀티미디어 서비스를 지원하는 Cross-Layer 전송 구조(CLTA)를 제안한다. 본 논문의 주요한 목적은 모바일 ad-hoc 무선 센서 네트워크에서 경로들의 생존시간(lifetime)을 증가시키기 위해서 노드들의 이동성 기반위에서 경로의 안정성을 결정하는 방법과 전송전력을 절약하는 방법을 제안하고 보여주는 것이다. 이러한 목적을 달성하기 위해서 본 연구에서는 네트워크 계층 기술과 물리 계층 기술의 융합과 상호 유기적인 관계로 인해서 시너지 효과를 얻을 수 있는 Cross-Layer 구조 전략을 제안한다. 기존의 연구들은 주로 고정된 노드들로 구성된 센서 필드 환경에서 연구가 진행된 반면에, 본 논문은 센서 필드에서 고정된 노드들뿐만 아니라 이동 센서노드들도 함께 고려한 좀 더 실제적인 환경에서 연구가 진행된다. 제안된 구조(CLTA)의 성능평가는 시뮬레이션과 이론적인 분석을 통하여 이루어진다.

Abstract In this paper, we propose a Cross-Layer Transmission Architecture (CLTA) to support power saving high-speed multimedia services in mobile ad-hoc wireless sensor networks(MAWSN). The main goals of this paper are in showing and proposing how the routing routes are decided on route stability based on mobility of mobile nodes to increase the operational lifetime of routes as well as how the transmit power can be saved in mobile ad-hoc wireless sensor networks. To obtain these goals, we propose a cross-layer architecture strategy which combines network layer technology with physical layer technology to get synergy effects in the view of transmission power saving. We consider a realistic approach, in the points of view of the MAWSN, 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. The performance evaluation of the proposed CLTA is performed via simulation and analysis.

Keywords : Cross-Layer, Routing, Power Saving, Mobile Ad-hoc Wireless Sensor Networks, Multiresolution, Subband, Scaling Function.

Ⅰ. Introduction

A sensor networks [1][2][3] consists of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. There are wide range of application areas healthcare, military, and home. Realization of these and other sensor network applications require mobile ad-hoc wireless networking techniques. Due to the random movement

---

[*] 종신회원, 홍익대학교 컴퓨터정보통신공학과

[**] 정회원, 홍익대학교 전자전기공학과

접수일자: 2008.7.15, 수정완료일자: 2008.8.

of nodes, the bandwidth and power limitations, and the lack of fixed infrastructure, the development of efficient routing protocols to support the various networking operations in mobile ad-hoc wireless sensor networks presents many issues and challenges[1][2][3].

Recently, some research works [4][5] show that the need to cross-layer interactions between the network and lower layers to achieve QoS preservation and energy efficiency in wireless ad hoc networks is indispensable. This work[4] suggests that there is still more to energy-efficient, cross-layer network design than what has been revealed so far. In fact, battery capacity cannot be used as the sole means to satisfy our requirements for a power-efficient, reliable, and load-aware routing scheme.

Therefore, the basic motivations of the proposed CLTA stem from: Even if just one layer technology good for transmit power saving, we can not obtain the best transmit power saving. The proposed CLTA can select the most stable route[6] over the underlying clustering structure in the view points of mobility of nodes [1][2][3] as well as save transmit power by using cross-layer design architecture.

This paper consists of as follows. The background of the CLTA is presented in section 2. The operation of the proposed architecture, CLTA, is explained in section 3, and section 4 presents the theoretical analysis of the CLTA. The performance evaluation of the CLTA is presented in section 5 and section 6 concludes this paper.

II. The Background

How to both save transmission power and increase packet delivery ratio in mobile ad-hoc wireless sensor networks ? This problem is one of the most important challenging issues in mobile ad-hoc wireless sensor networks. Currently, there are several works in these research areas.

Cooperative communication[7] is one of the solvable approaches of these issues. High energy utilization efficiency is a stringent design criterion for MAWSNs since the batteries can not usually be replaced because of operations in hostile or remote environments. In addition, reliable communications over wireless channels which is a difficult problem due to fading is another requirement. One of the feasible solutions is to take full advantage of idle SNs, namely relays, in the vicinity of the transmitting node to relay the original signal to its destination. This not only benefits from path-loss reduction but also enables nodes to use each other's antennas to obtain an effective form of spatial diversity without the need for physical antenna arrays. Additionally, a constraint on node size which requires each SN to be equipped with single-antenna makes such a solution very appropriate in MAWSNs scenario. The ways the idle SNs process the signals received from a desired node are known as cooperative protocols.

The cross-layer design [8]-[11] is one of the most effective techniques to improve the average throughput or to reduce the wireless resource consumption caused by overhead.

At the protocol design phase, the designer has two choices[12]. Protocols can be designed by respecting the rules of the original architecture. In the case of the layered OSI reference model, this would mean designing protocols such that they only make use of the services at the lower layers and not be concerned about the details of how the service is being provided. It also implies that the protocols would not need any interfaces that are not present in the reference architecture. Alternatively, protocols can be designed by violating the reference architecture. Since the reference architectures in communication and networking has traditionally been layered, its violation is generally termed as cross-layer design.

There are have been a large number of cross-layer design proposals in the literature recently. Generally speaking, cross-layer design refers to protocol design done by actively exploiting the dependence between protocol layers to obtain performance gains. The authors in [11] presents a survey of several cross-layer design proposals from the literature based on the layers that are coupled.

We need stable routing routes in view point of power and mobility to increase packet delivery ratio. There are several approaches [12] to support stable routing routes in view points of both power and mobility in mobile ad-hoc wireless networks.

In [5], two algorithms the objective of which is to enhance the operation of existing power-based multipath routing schemes via cross-layer design and optimal load assignments are proposed. Those two schemes employ probabilistic dynamic programming techniques and utilize cross-layer interactions between the network and MAC layers.

Several cross-layer designs require creation of new interfaces between the layers. The new interfaces are used for information sharing between the layers at runtime. The architecture violation here is obviously the creation of a new interface not available in the layered architecture. There are several open challenging issues for designers proposing cross-layer design ideas[11].

The goal of our proposed design architecture is to use the cross-layer method which combines both physical layer and network layer to both reduce the resource (power) consumption and increase route stability in mobility view points for supporting high packet delivery ratio.

Ⅲ. The Proposed CLTA

The proposed CLTA consists of two part structures as follows. The first part is the constructing structure of the stable routing route over the underlying clustering structure while the second part is the transmission structure for supporting power saving services. Figure 1 presents the basic concepts of the CLTA.

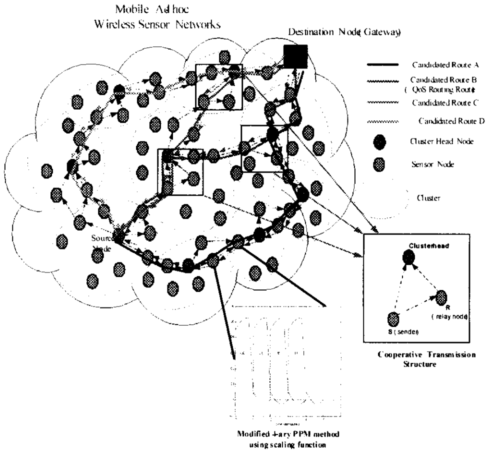

Figure 1. The basic concepts of the CLTA

The operations of the CLTA are as follows:

Step 1: The clustering is operated periodically. The operation for clustering is in detail explained in this paper [13].

Step 2: The source node generates and advertises a JOIN REQUEST to its neighbor nodes to cluster head using the broadcast. The JOIN REQUEST consists of the source node ID, mobility information of the node which sends the JOIN REQUEST, sequence number from the source node.

Step 3: When a cluster head node which is i^{th} (sequence number) node from source node receives a JOIN REQUEST from the neighbor node, the node accepts the message except the one that received the request from and the node store node ID, sequence number, the mobility information of the upstream node(to source node) and itself node in REQUEST TABLE (REQT). The operation is repeated until the cluster head node(destination cluster head node), which exists in the cluster with destination node, receives JOIN REQUEST.

Step 4: When the destination cluster head node receives the JOIN REQUEST, the node sends JOIN REQUEST to the destination node.

Step 5: When a destination node receives a JOIN REQUEST, the node accepts themessage except the one that arrives at via the same routes comparing with previous arrival JOIN REQUESTs. The destination node generates and forwards a JOIN REPLY via the cluster head node to the upstream node (to source node). The JOIN REPLY consists of the destination node ID and route mobility information at the node.

Step 6: When a node receives a JOIN REPLY from the downstream node (to destination node), the node executes the operation as follows:

- Store node ID, sequence number, the mobility information of the downstream node ID(to destination node) in REPLY TABLE (REPT).
- If the sequence number of the current node (i^{th}) is greater than two (i.e., No. of downstream nodes ≥ 2), the route stability (RS) (i.e., γ^1 & γ^2) is calculated by using the proposed entropy-based route stability (RS)[6] method explained in equation (2) and (3).
- If the RS is greater than some threshold (i.e., RS $\geq TH_{RS}$), the node stores the route stability information up to previous node in the REPT for all candidate routes. The priority number based on the route stability information is assigned in the REPT if there are multiple routes for the node. The node advertises the JOIN REPLY to its previous nodes (to source node).
- If the RS is less than some threshold (i.e., RS $\leq TH_{RS}$), the node doesn't advertise the JOIN REPLY any more.
- These operations are executed until the JOIN REPLY arrives at the source node.

Step 7: When the source node receives the JOIN REPLY messages via each routes, the source node forwards the data messages to the destination node by cooperative transmission as follows:

- The source node forwards the data message to the next node over the stable routes depending on the priority number in REPT as well as the neighbor nodes (i.e., relay nodes) of the next node simultaneously.
- The relay nodes also forward the data message to the next node.
- The next node receives the messages from two nodes (i.e., source node and relay node) together.

Step 8: When a node over the routes receives the data messages, the node executes the same operation as step 7. This operation is executed until the destination node receives the data message.

Ⅳ. The theoretical analysis of the CLTA

In this section, we present just the basic concepts of theoretical analysis of the CLTA, the construction of the stable routing route and the construction of power saving transmission architecture. The paper [13] explains in detail the underlying clustering structure, mobility-based clustering (MBC), which is our proposed method in our previous works while the paper [6] explains in detail the entropy-based model for supporting and evaluating stability. In this paper, we explain just the basic concepts and result equation models of the entropy-based model.

Based on this, we can define the entropy $H_m(t,\Delta_t)$ at mobile m during time interval Δ_t. The entropy can be defined either within the whole neighboring range of node m (e.g. within set S_m), or for any subset of neighboring nodes of interest. In general, the entropy $H_m(t,\Delta_t)$ at mobile m is calculated as follows:

$$H_m(t,\Delta_t) = \frac{-\sum_{k\in F_m} P_k(t,\Delta_t)\log P_k(t,\Delta_t)}{\log C(F_m)} \qquad (1)$$

where $P_k(t,\Delta_t) = \dfrac{a_{m,k}}{\sum_{i\in F_m} a_{m,i}}$.

In this relation, by F_m we denote the set (or any subset) of the neighboring nodes of node m, and by

$C(F_m)$ the cardinality (degree) of set F_m. If we want to calculate the local network stability (with reference to node m), then F_m refers to the set that includes all the neighboring nodes of mobile node m, while if we are interested in the stability of a part of a specific route then F_m represents the two neighboring nodes of mobile node m over that route. As can be observed from the previous relation, the entropy $H_m(t,\Delta_t)$ is normalized so that $0 \le H_m(t,\Delta_t) \le 1$. It should be noted that the entropy, as defined here, is small when the change of the variable values in the given region is severe and large when the change of the values is small. The local route (or the part of the route that represents the links of the path associated with an intermediate node), is stable if $H_m(t,\Delta_t)$ is large while the local route is unstable if $H_m(t,\Delta_t)$ is small. However, in general in MAWSN the route between a source and a destination may traverse multiple intermediate nodes (hops). Let us present the entropy-based Route Stability (RS) between two nodes S and G during some interval Δ_t as $\gamma = RS_{s,g}(t,\Delta_t)$. We also define and evaluate two different measures to estimate and quantify end to end route stability, denoted by $\gamma^1 = RS^1{}_{s,g}(t,\Delta_t)$ and $\gamma^2 = RS^2{}_{s,g}(t,\Delta_t)$ and defined as follows respectively:

$$\gamma^1 = RS^1{}_{s,g}(t,\Delta_t) = \prod_{i=1}^{N_r}[H_i(t,\Delta_t)] \qquad (2)$$

and

$$\gamma^2 = RS^2{}_{s,g}(t,\Delta_t) = \min_{i=[1,2,3,\ldots,N_r]} H_i(t,\Delta_t) \qquad (3)$$

where Nr denotes the number of intermediate mobile nodes over a route between the two end nodes (S,G).

The power saving strategy is the most important thing for the transmission from the source node to the destination node (i.e., gateway via multiple sensor nodes). Reduction of transmission data interval time between two wireless sensor nodes is a good candidate of the power saving in not only network layer but also physical layer structure. Especially this section describes power saving in physical layer structure. The 4-ary PPM method using scaling function was proposed in [14]. For obtaining the scaling function by 4-ary PPM, the dyadic subband tree[15][16] structure was introduced. The dyadic subband tree structure in figure 2 provide multiresolution decomposition and is the one of the hierarchical subband filter banks.

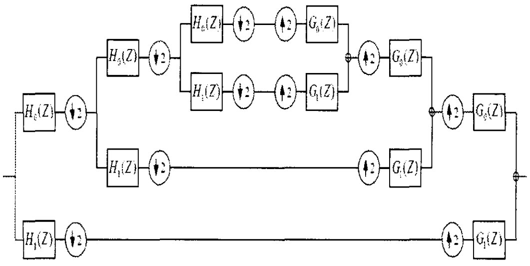

Figure 2. Dyadic subband structure

The dyadic subband structure is the useful one for the signal decomposition so that the incomingsignal is divided into two kinds of characteristics which are lowpass and highpass. The analysis part in next level is performed as the same way before. That is, the bypassed signal through lowpass filter is divided into another lowpass and highpass. Through these steps infinitely, we can get the finite scaling functions[17]. The scaling function, $\phi(t)$, is defined as

$$\phi(t) = \sqrt{2}\sum_{k=0}^{N-1} h_0[k]\phi(2t-k) \qquad (4)$$

where $h_0[k]$ is a lowpass filter in figure 2.

As we see, $\phi(t)$ is the recursive function with dilation and translation embedded by lowpass filter coefficient. The normalized starting point and ending point of $\phi(t)$ is restricted by the number of lowpass filter, i.e. N. Notice that any scaling function has a non-zero DC gain as

$$\int \phi(t)dt \neq 0 . \tag{5}$$

The Fourier transform, $H_0(\Omega)$ of $h_0[k]$ is defined as

$$H_0(\Omega) = \sum_k h_0[k]\, e^{-jk\Omega} . \tag{6}$$

Then Fourier transform , $\Phi(\Omega)$ of $\phi(t)$ is obtained recursively

$$\Phi(\Omega) = \Phi(0)\prod_{k=1}^{\infty} \frac{1}{\sqrt{2}} H_0(\frac{\Omega}{2^k}) . \tag{7}$$

Now we see that the frequency characteristic of $\phi(t)$ is the smallest lowpass signal of the incoming signal. This implies that lowpass signal can be evaluatedin more detail other than general Fourier transform does. Also $\phi(t)$ satisfies the orthogonality condition to its integer shifts as

$$\int \phi(t)\phi(t-n)dt = \delta(n) \tag{8}$$

when the following condition is true:

$$\sum_k h_0[k]h_0[k+2n] = \delta[n] \tag{9}$$

Therefore the selection process for the filter coefficient value should be made very thoroughly. Those are searched for the entire communication system to be stable and get the best performance. The resulting orthogonality condition is applied to physical layer from the source node to the destination node. Usually the one bit, or symbol is transmitted through one transmission time interval in the communication system. While our system is capable of transmitting four bits in one transmission time interval because of the orthogonality of scaling function. In receiver side, the recovery process is performed using the correlation and orthogonality criterion. Based on these properties, we utilize a time-hopping, pulse position modulation, ultra-wideband (TH-PPM UWB) system. The transmitted signal for the k^{th} user[18] is defined as

$$s^{(k)}(t) = \sum_{j=-\infty}^{\infty} A_{d^{(k)}_{\lfloor j/N_s \rfloor}}\, q(t - jT_f - c_j^{(k)}T_c - \delta_{d^{(k)}_{\lfloor j/N_s \rfloor}}) \tag{10}$$

where $q(t)$ represents the transmitted impulse waveform, the quantities with superscript k indicate k^{th} user, T_f is the uniform pulse train spacing, which is often called the frame time or pulse repetition time, $c_j^{(k)}$ is called a TH sequence, d is N-ary data stream generated by the k^{th} source after channel coding, $\delta_{d^{(k)}_{\lfloor j/N_s \rfloor}}$ describes modulation time shift utilized for PPM determined by the input data d, and $A_{d^{(k)}_{\lfloor j/N_s \rfloor}}$ is the signal amplitude which depends on d. The monopulse of TH-PPM UWB is generally a differentiated pulses with a Gaussian. The Gaussian pulse does not satisfy the orthogonality condition and four bits can not be transmitted in the one transmission time interval, one time frame or one time slot

V. Performance Evaluation

The performance evaluation of our protocol is accomplished via simulation using the Optimized Network Engineering Tool (OPNET) and theoretical analysis. A mobile ad-hocwireless 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. In this simulation, Random Waypoint mobility model is used. A mobile node picks a position within the simulation area randomly in each movement epoch, then move towards it with a speed in the range [0, $V_{\max}$] km and direction range [0, 2π] respectively. The pause at the end of each epoch is zero second. If a mobile arrives at the boundary of the given network coverage area, the node reenters into network.

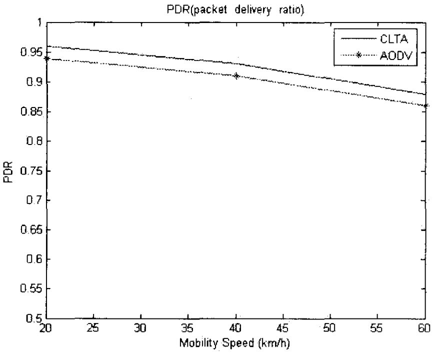

Figure 3. Packet delivery ratio

Figure 3 shows the results of the packet delivery ratio (PDR) via simulation. As we can see in figure 3, the performance is good while the PDR is slightly decreased according to the increasing of the node mobility speed. The reason is that CLTA uses the node mobility information for route setup, then in this network environments the route setup is much more unstable. Therefore, the PDR is secreased according to the increasing of the node mobility speed. In this simulation, In our simulation of this paper, we just used the first model in equation (2) to find the routing route and measure the route stability.

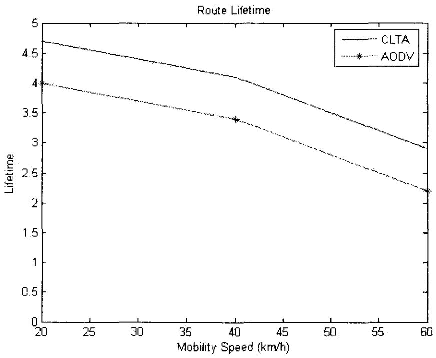

Figure 4. Route lifetime

Figure 4 presents the result of the route lifetime. As we can see in figure 4, the route lifetime is slightly decreased according to the increasing of the node mobility speed. In this simulation, In our simulation of this paper, we just used the first model in equation (4) to find the routing route and measure the route stability. The reason is that CLTA uses the node mobility information for route setup, then in this network environments the route setup is much more unstable. Therefore, the route lifetime is decreased according to the increasing of the node mobility speed.

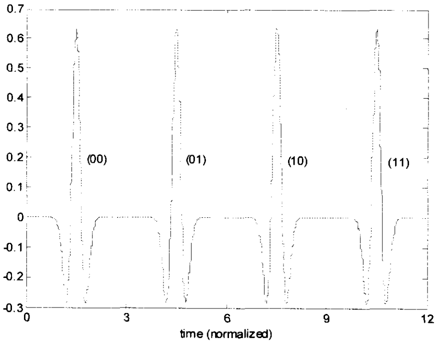

Figure 5. General 4-ary PPM method using Gaussian function

Figure 5 shows the general 4-ary PPM methodusing Gaussian function. The four symbols are transmitted using the general 4-ary PPM method,where a 2-bit symbol is assigned to each impulse waveform comprising of 2nd derivative Gaussian shape.On the other hand, figure 6 describes a modified 4-ary PPM method using scaling function. The main difference between the two figures is the reduction of transmission time interval since the scaling function has the property of orthogonality if some conditions are met. The general 4-ary PPM method using Gaussian function needs 12 normalized time for transmitting 4 symbols while the modified 4-ary PPM method using scaling functiondoes only 6 normalized time for accomplishing the same purpose. This results in shorting the transmission time interval twice than general system and leads to data rates two times in the modified system. Notice that lots of scaling functions with orthogonality condition can be made but the best scaling function in some given application should be chosen appropriately.

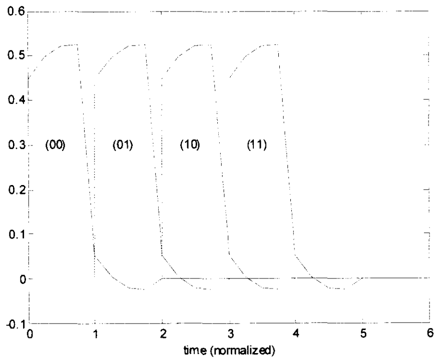

Figure 6. Modified 4-ary PPM method using scaling function

VI. Conclusion and Next Works

One of the most important challenging issues in mobile ad-hoc wireless sensor networks is how to both save transmission power and increase packet delivery ratio together. To solve these problems, in this paper we propose a Cross-Layer Transmission Architecture (CLTA) to support power saving high-speed multimedia services in mobile ad-hoc wireless sensor networks (MAWSN). The CLTA combines network layer technology with physical layer technology. We consider a realistic approach, in the points of view of the MAWSN, 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. The results of both simulation and analysis are very closed and good. For the transmission in physical layer from the source node to the destination node, the reduction of transmission data interval time between two wireless sensor nodes is a good candidate of the power saving strategy both in network layer and physical layer structure. For the given system, we showed the advantage of the 4-ary PPM method using scaling function made by the dyadic subband structure compared to the general 4-ary PPM method using 2nd derivative Gaussian function. The half period of transmission time interval due to the orthogonality condition of scaling function results in data rate increase and better performance two times than the general system. But the appropriate scaling function among lots of choice should be selected more thoroughly. In this works, the proposed CLTA just combines two technologies to save transmission power and increase packet delivery ratio together. Currently, we are focusing on the development of the combined modeling architecture of two technologies to get high improvement.

Reference

[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 MobileAd-hoc WirelessNetworks: Issues, Challenges and Current Protocols," Wireless Communications and MobileComputing (WCMC), vol. 2, issue 2, pp.115-130, March 2002.

[4] A. Safwat, H. Hassanein., and H. Mouftah, "A MAC-based Performance Study of Energy-Aware Routing Schemes in Wireless Ad hoc Networks," *Proc. of IEEE Globecom 2002.*

[5] A. Safwat, H. Hassanein, and H. Mouftah, "ECPS and E2LA: New Paradigms for Energy Efficiency in Wireless Ad hoc and Sensor Networks," *Proc. of IEEE Globecom 2003.*

[6] Beongku An, Symeon Pappavassiliou, "An Entropy-Based Model for Supportingand Evaluating Stability in Mobile Ad-hoc Wireless Networks," IEEE Communications Letters, 2002.

[7] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity. Part I-II," IEEE Trans on Communications, 51, Issue 11, pp.1927-1948, 2003.

[8] Q. Du and X. Zhang, "Cross-layer resource-consumption optimization for mobile multicast in wireless networks," Proc. of IEEE WoWMoM 2006, pp.368-376, June 2006.

[9] L. Lazos and R. Poovendran, "Cross-layer design for energy-efficient secure multicast communications in ad-hoc networks," in Proc. IEEE ICC 2004, pp.47-54, June 2004.

[10] A. Mohamed and H. Alnuweiri, "Cross-layer optimization framework for rate allocation in wireless multicast," in Proc. IEEE MASS 2006, pp.1-10, October 2006.

[11] Vineet Srivastava, Mehul Motani, "Cross-Layer Design: A Survey and the Road Ahead," IEEE Communications Magazine , pp.112-119, December 2005.

[12] C.-K. Toh, "Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad-hoc Networks," IEEE Communications Magazine, June 2001.

[13] Beongku An and Symeon Papavassiliou, "A Mobility-Based Clustering Approach to Support Mobility Management and Multicast Routing in Mobile Ad-hoc Wireless Networks," International Journal of Network Management (JNM), vol. 11, no. 6, pp.387-395, December 2001.

[14] Gin-Kyu Choi, Beongku An, Joong-Hoo Park, "A Modeling Architecture to Support Power Saving High-Speed Multimedia Services in Ubiquitous Wireless Sensor Networks," IWIT, vol. 7, no. 3, pp.15-22, June 2007

[15] G. Choi and R. A. Haddad, "Theory and Design of Dyadic Subband Tree Structures with Embedded PDF-Optimized Quantizers," IEEE Trans. Signal Processing, vol. 46, pp. 1260 - 1274, May. 1998.

[16] A. N. Akansu and R. A. Haddad, "Multiresolution Signal Decomposition: Transforms Subbands Wavelets," New York: Academic, 1992.

[17] P. P. Vaidyanathan, Multirate Systems and Filter Banks. Englewood Cliffs, NJ: Prentice-Hall, 1993.

[18] M.-G. Di Benedetto and G. Giancola, Understanding ultra wide band: radio fundamentals, Prentice-Hall, 2004.

Acknowledgement : This work was supported by the Hongik University new faculty research support fund

저자 소개

안 병 구(종신회원)

- 1988년 : 경북대학교전자공학(BS),
- 1996년 : (미)Polytechnic Univ. Dept. of Electrical & Computer Eng. (MS),
- 2002년 : (미)New Jersey Institute of Technology(NJIT), Dept. of Electrical & Computer Eng. (Ph.D),
- 1990년 ~ 1994년 : 포항산업과학기술연구(RIST), 선임 연구원,
- 1998년 ~ 2002년 : Lecturer, New Jersey Institute of Technology(NJIT). USA,
- 2003년 ~ 현재 : 홍익대학교 컴퓨터정보통신공학과 교수,
- 2005년 ~ 2008년 : Marquis Who's Who in Science and Engineering (세계과학기술 인명사전) 등재,
- 2006년 ~ 2008년 : Marquis Who's Who in the World (세계인명사전) 등재

<주관심분야:Wireless Networks, Ad-hoc & Sensor Networks, QoS & Multicast Routing,Cooperative Communications, Mobility Management, Location-Based Technology>

최 진 규(정회원)

- 1983년 : 성균관대학교 전자공학과 (BS),
- 1990년 : (미)Polytechnic Univ. 전자전기공학과(MS),
- 1994년 : (미)Polytechnic Univ. 전산과학과(MS),
- 1996년 : (미)Polytechnic Univ. 전자전기공학(Ph.D),
- 1983년 ~ 1986년 : LG 전자, Motolora Korea 연구원,
- 1996년 ~ 2004년 : 삼성전자 통신연구소 수석연구원,
- 2004년 ~ 현재 : 홍익대학교 과학기술대 전자전기공학과 조교수

<주관심분야: 차세대이동통신, 초광대역 통신, 통신신호처리>