ISSN : 0974 - 7435 Volume 8 Issue 10

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 8(10), 2013 [1376-1383]

The mac protocol optimization based on physical layer's information feedback

Wang Jun[1]*, Wang Jian[2], Pang.Yujun[2]

[1]Dept. of Computer Science & Technology, Shenyang University of Chemical Technology, Shenyang, (CHINA)

[2]Dept. of Information Engineering, Shenyang University of Chemical Technology, Shenyang, (CHINA)

E-mail : Wj_software@hotmail.com

ABSTRACT

In this paper, we present a cross-layer optimization scheme to improve the fairness and quality of service (QoS) of wireless ad-hoc network. As for the physical layer's information feedback, it is mainly the physical link quality. We adopt multi-access technique such as TDMA and a fusion of technologies, such as Multiple -Input and Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). Using multi-user detection to physical link quality, to achieve the joint cross-layer optimization design of PHY-MAC, we propose the MAC protocol with RTS/CTS reservation mechanism based on a distribution of slots (RD-TDMA). The objective is to improve energy utilization, reduce bit error rate (BER) and alleviate network congestion effectively. The experimental results show that the cross-layer optimization can effectively improve the overall performance of wireless ad-hoc network, significantly in energy saving and throughput.

KEYWORDS

Microbial breakdown;
Crude oil;
Polluted soil;
Amended.

INTRODUCTION

It is widely acknowledged that wireless ad-hoc network has become the main method of wireless communication. As a result, the problems of energy saving and QoS in wireless ad-hoc network are becoming the focus area for scholars in recent years. In order to improve the overall performance of wireless ad-hoc further, many MAC protocol optimization strategies have been proposed by scholars. For example, the authors in[1] adopt the non-contention mechanism to reduce the possibility of collision and idle detection to channel state to save energy, so the traffic adaptive MAC protocol is proposed. What's more, the authors in[2] take advantage of the distributed power control algorithm and an integration of back-off mechanism to improve energy saving and throughput. Therefore, the rate adaptive MAC protocol is presented to alleviate network congestion, and reduce packet loss rate and energy consumption.

However, the conventional rigid layer architecture can't meet the demand of the network performance. So a lot of scholars pay attention to this cross-layer optimization design. At the same time, the cross-layer optimization can achieve the improvement of the overall performance of wireless ad-hoc network by configuring network resource reasonably. To this end, according to the network optimization index, a lot of cross-layer optimization design schemes are put forward. They utilize a variety of techniques such as CDMA, TDMA, MIMO and OFDM to optimize MAC protocol respectively rather than jointly. Moreover, they don't take the physical link quality into consideration. For instance, the authors have discussed the cross-layer optimization to challenge for saving energy, reducing network congestion and collision. So the cross-layer optimization scheme of PHY-MAC-Transport layer is proposed to improve the QoS of application layer[3]. In addition, a joint optimal design scheme of PHY-MAC is adopted to reduce channel interference, packet retransmission, and improve network throughput[4]. To find a solution for the hidden terminal and exposed terminal problems, the authors in[5] take advantage of cross-layer optimization design of PHY-MAC to achieve it. Besides, some scholars make use of the means of PSK/QSK modulation to optimize PHY-MAC for the purpose of enhancing network throughput[6]. Moreover, a technical integration of CDMA and MIMO is discussed to improve network throughput and save energy for end-to-end QoS[7]. Last but not least, a cross-layer optimization algorithm of PHY-MAC is proposed by using OFDM[8]. At the same time, to improve the overall performance of wireless ad-hoc network, many researchers have put up with their MAC optimization schemes and cross-layer optimization design[8-17].

To the best of our knowledge, a cross-layer optimization design scheme is very few based on the physical link quality. So we should make full use of the physical layer's information feedback to optimize MAC protocol. Different from the previous cross-layer optimization, according to the physical link quality, such as path loss, bit error rate (BER) and signal to noise rate (SNR), we utilize a technical integration of MIMO and OFDM, optimize MAC protocol, and propose RD-TDMA to realize the joint cross-layer optimization design, with targets at improving the reliability of transmission in physical link.

In view of all these, this paper is organized as follows. Section II presents the system model of a joint cross-layer optimization design. Section III discusses the proposed cross-layer design architecture in detail. Section IV displays a technical integration model of MIMO and OFDM. Section V states the proposed RD-TDMA. Section VI describes the simulation results, and the paper concluded in Section VII.

SYSTEM MODEL

In this section, we will display our system model to realize the joint cross-layer optimization design of PHY-MAC. In order to improve the overall performance of wireless ad-hoc network, a joint cross-layer optimization of PHY-MAC is proposed based on information feedback about the physical link quality. The system model is a model across three levels, i.e. the physical link, the physical layer and the MAC layer. At physical layer, we incorporate a technical integration of MIMO and TDMA, and multi-user detection mechanism into our proposed system model to optimize link quality. Meanwhile, we adopt a new time slotted MAC protocol with RTS/CTS reservation mechanism, so as to achieve the goals of reducing co-channel inference, alleviating network congestion and ensure QoS provisioning.

To the end for the fairness of channel access, TDMA as a non-contention mechanism is used to improve the overall performance of wireless ad-hoc network. In contention access period, CSMA/CA can almost afford the requirement of the fairness of channel access. Because there exists to be some problems about collision and retransmission as a consequence of competition to access channel. A system model of cross-layer optimization is taken to illustrate the implementation of technical means for objectives in TABLE 1.

At the same time, we should take the characters of

TABLE 1 : CROSS-LAYER OPTIMIZATION OF TECHNIQUES AND OBJECTIVES

Layer	Techniques	Objective
MAC Layer	RD-TDMA	Fairness & QoS Throughput & Energy Saving Congestion & Error Control
PHY Layer	MIMO OFDM	
Link	Path Loss BER SNR	

FULL PAPER

wireless ad-hoc network into consideration as a cross-layer optimization design for wireless ad-hoc network. Wireless ad-hoc network which is composed of many peer to peer nodes with independence forms a multi-hop network. Aiming at enhancing the overall performance of wireless ad-hoc network, we take advantage of RD-TDMA to reduce the probability of collision due to competition between slots. Moreover, a variety of techniques and multi-user mechanism are applied to optimize PHY- MAC, eventually to realize to save energy and improve throughput.

CROSS-LAYER OPTIMIZATION FRAMEWORK

As is known to us, the physical parameter settings are reasonable configured, based on the physical link quality. A lot of information can be estimated at physical layer, such as path loss, BER and SNR, etc. At MAC layer, a joint cross-layer optimization of PHY-MAC is carried out, based on the characters of wireless ad-hoc network and the physical layer's information feedback. The key innovation is to adopt the technical integration of MIMO and OFDM, and the proposed RD-TDMA to save energy and enhance throughput. First of all, we should pay attention to the optimization design of physical link quality to change physical link conditions. It is beneficial to increase the robustness and improve the performance of wireless ad-hoc network for cross-layer optimization framework.

Path loss

As each node's energy is limited in wireless ad-hoc network, it is necessary to study and analyze path loss. Meanwhile, path loss is an important indicator of physical link quality and it plays an important role in prolonging node's life. The equation of path loss is shown in (2), [3].

$$\mathbf{T_R = T_s\left(\frac{\alpha}{4\pi d}\right)^2 S_T S_R} \quad (1)$$

The relational expression between transmitting power $\mathbf{T_R}$ and receiving power $\mathbf{T_S}$ is given above. Where $\mathbf{S_T}$ and S_R represent transmitting node and receiving node of omni-direction antenna gain respectively, $\boldsymbol{\alpha}$ is given as the carrier wavelength, and $\mathbf{d}$ is the distance from transmitter to receiver.

$$\mathbf{path\_loss = T_R - T_S} \quad (2)$$

As shown above, path loss is equal to D-value between $\mathbf{T_R}$ and $\mathbf{T_S}$.

From other aspects to take account of wireless ad-hoc network, there are a lot of relays which amplify signal to transmit further. Path loss is related to reflection coefficient, while the reflection coefficient is connected with the propagation environment. The expression of path loss is given as following (3), [10].

$$\mathbf{path\_loss = \left(\frac{\lambda a^{t_i}}{4\pi d_i}\right)^2} \quad (3)$$

Of which $\mathbf{t_i}$ is the reflected number among relays, $\mathbf{d_i}$ is the distance between transmitter and receiver, $\boldsymbol{\lambda}$ is the carrier wavelength.

From what has been discussed above, we draw the following conclusion: there exists to be many factors accounting for the phenomenon of path loss, such as propagation environment, multi-path fading, co-channel interference and collision, etc. Concretely speaking, path loss is closely related to the carrier wavelength, the distance between transmitter and receiver, transmitting and receiving gain, and reflection coefficients. As a result, to the end for reduction of path loss, we should get down to doing this. We take advantage of a technical integration of MIMO and OFDM to accelerate the transmission rate and reduce the co-channel inference, eventually to achieve the goals of improve the physical link quality.

Adaptive BER scheme

Although the digital modulation is applied at physical layer to improve retransmission due to collision conditions, the effect isn't obvious. BER is an accuracy index of data transmission in limited time. As a consequence, we analyze and optimize the physical layer's information feedback, with aims at improving the reliability of transmission. Reducing BER is beneficial to retransmission, thus saving slots and energy. The definition of BER is expressed as (4).

$$\mathbf{BER = \frac{E_{bit}}{S_{bit}}} \quad (4)$$

Of which $\mathbf{E_{bit}}$ is the number of error bits, $\mathbf{S_{bit}}$ is the total number of transmitted bits. We can only know that BER is connected with transmitted bits from the definition. Non-coherent FSK MODEM scheme about BER as an algorithm formula is given by (5), [16].

$$\mathbf{BER} = \frac{1}{2}(e^{\frac{SNR}{2}*\frac{B_N}{R}}) \quad (5)$$

As shown above, $\mathbf{SNR}$ is the signal to noise rate, $\mathbf{B_N}$ is the noise bandwidth, $\mathbf{R}$ is the transmission rate. As can be seen from the expression, BER is related to SNR.

For the sake of simplicity, we simplify BER by the equation of $\mathbf{Pe = lg(BER)}$. In contrast to various modulation algorithms, we draw the relation between SNR and BER, as Figure 1 shown.

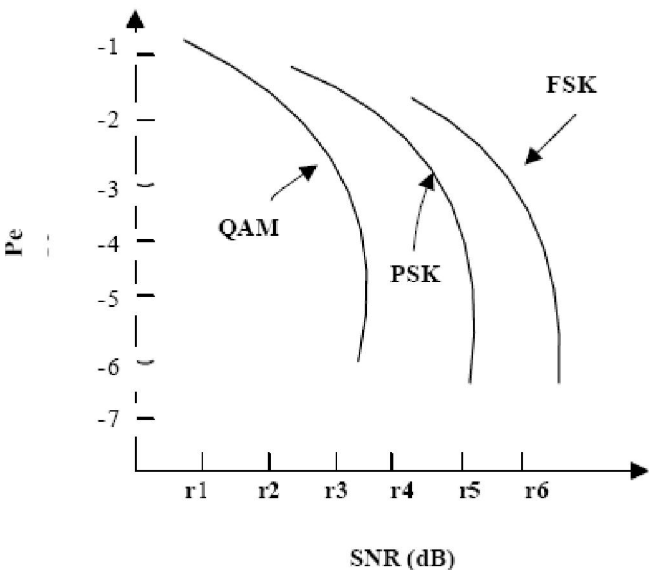

Figure 1 : The relation between SNR and BER

As can been seen from the above Figure 1, by comparison with other modulation algorithms, QSK has a good performance over PSK and FSK. We can address the BER problem without effects on SNR by using QSK. In reality, each channel utilizes QSK modulation technique in OFDM system. Therefore, we adopt OFDM to make BER adaptive to changing conditions, which makes for the stability and reliability of wireless ad-hoc network.

Next, the relation between the number of modulated bits $\mathbf{b_i}$ in each channel and SNR is given as following (6), where r_i in each channel is the number of internal SNR.

$$\mathbf{b_i = \log_2(1 + \frac{SNR}{r_i})} \quad (6)$$

To sum up, in order to improve the overall performance of wireless ad-hoc network, we optimize MAC protocol by optimize the physical link quality. Using OFDM is beneficial to reduce BER for improving transmission reliability.

c. Channel capacity and bandwidth utilization

Channel capacity and bandwidth play an important part in improving the physical link quality, which are important information of physical layer's information feedback. Meanwhile, they are vital index of measuring channel utilization. As for MAC layer, the MAC protocol is mainly responsible for channel access and resource allocation. However, the enhancement of channel capacity and bandwidth utilization is good for having an increase in throughput. Network throughput in wireless ad-hoc network is an important indicator to assess the network performance. To the end, it is essential for us to study channel capacity and bandwidth utilization.

To put it simply, Channel capacity refers to the largest average rate of channel as it can. As Shannon said, the definition of channel capacity is given by (7).

$$\mathbf{C = B_W \log_2(1 + SNR)} \quad (7)$$

Of which $\mathbf{SNR} = S/N$, $\mathbf{B_W}$ is channel bandwidth.

At the same time, in terms of wireless ad-hoc network, it is a multi-hop network. So channel capacity isn't simply to describe. We take advantage of MIMO to improve channel conditions. The authors in[10] have studied the equation of channel capacity of a multi-hop network, which is given by (8).

$$\mathbf{C = \log_2\left[\det\left[I_M + \frac{HH^H}{\sigma^2 \sum_{i=0}^{m} \frac{1}{l_i p_i}}\right]\right]} \quad (8)$$

Where the channel matrix of system is $\mathbf{H}$, $\mathbf{p_i}$ is a transmission power of relay antenna, and $\mathbf{l_i}$ is the meaning of path loss.

In addition, band utilization is to measure the effectiveness of the digital communication system. Band utilization is to describe a relationship between data transmission rate and bandwidth. The expression is given by (9).

FULL PAPER

$$N_b = \frac{R_b}{B_w} \quad (9)$$

Where channel transmission rate is R_b.

According to the expressions of (7-9), we know that channel capacity and bandwidth utilization are related to bandwidth. Channel capacity is proportional to bandwidth, while bandwidth utilization is inversely proportional to bandwidth. Therefore, we can't blindly improve the network performance. On the contrary, we should take several aspects into consideration to design MAC protocol. Only in this way can effectively enhance and improve the overall performance of wireless ad-hoc network.

As introduced above, as the physical layer's information feedback is critical to design cross-layer optimization scheme, we have no choice but to optimize PHY-MAC to improve the overall performance of wireless ad-hoc network, based on the physical layer's information feedback. There are many cross-layer optimization schemes implemented mechanically, without taking the physical link quality into consideration. The improvement of the physical link quality is not only good for physical layer and MAC layer, but also it is beneficial to the network layer, transport layer and application layer. Therefore, fully considering the physical layer's information feedback to optimize the overall performance of the wireless ad-hoc network is very necessary.

A FUSION OF MIMO AND OFDM TO OPTIMIZE PHY-MAC

The physical layer's information feedback, such as Path Loss, BER and SNR, mostly can be obtained by evaluation of physical layer. However, the key is to how to improve the physical link quality for implementing cross-layer optimization.

So we use MIMO and OFDM jointly optimize the quality of the wireless channel. At the same time, the system model constituted by MIMO and OFDM is one of the main alternatives as the next generation of wireless communication link. Therefore, we should be reasonable to use a fusion of MIMO and OFDM to optimize wireless link quality for the purpose of cross-layer optimization.

There exists to be multi-path channel fading in wireless ad-hoc network. In order to change this phenomenon, OFDM is taken as a special kind of multi-carrier transmission scheme. Besides, OFDM can be used as a modulation method, or a multiplexing technique, OFDM has a strong ability to resist frequency selective fading and narrowband interference. The reason why OFDM is used as one of a fusion of techniques is that it can effectively resist multi-path propagation delay.

In addition, we adopt MIMO to optimize physical link quality to enhance channel capacity and bandwidth utilization. The objective of this technique is to improve the reliability of channel and QoS, and reduce BER. On the other hand, MIMO has the ability of overcoming multi-path fading, but for deep frequency selective fading, there is still no way to solve this problem for MIMO. To address this problem, there are two ways, one is to utilize equalization technology, and the other is to use OFDM. On the basis of OFDM space resources allocated reasonably, MIMO/OFDM is good for improving data rate. In summary, it is a necessity to combine MIMO and OFDM to optimize the physical link quality for PHY-MAC cross-layer optimization. A fusion system model of MIMO and OFDM is as shown Figure 2.

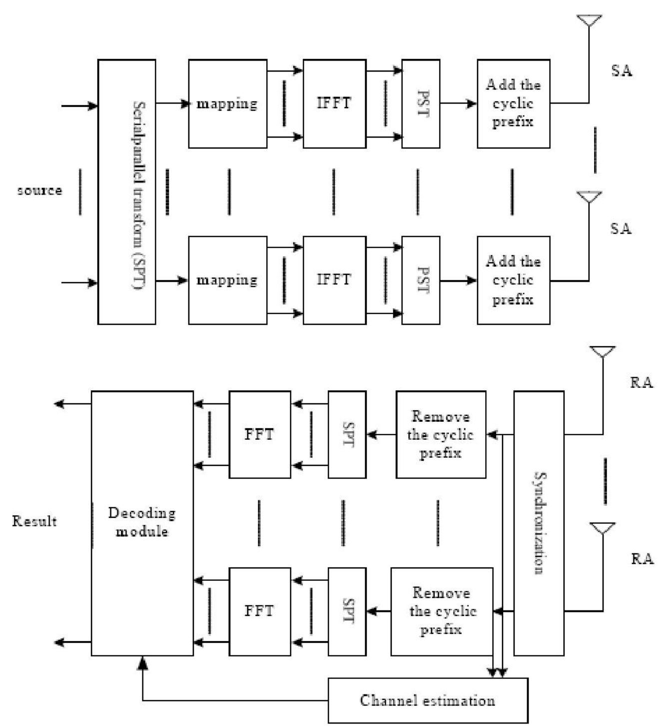

Figure 2 : A fusion system model of MIMO and OFDM

PROPOSED RD-TDMA

In order to improve the fairness and QoS of wireless ad-hoc network, we adopt TDMA as a non-contention protocol at MAC layer. To address energy saving problem, we put forward our own RD-TDMA protocol.

TDMA is consisted of a lot of fixed slots, which is used at MAC layer in contention free period. So we make some changes to TDMA. For the sake of reduction of retransmission due to occurrence of error bit, we take advantage of RTS/CTS reservation mechanism to optimize MAC, which reduce unnecessary transmission delay. Retransmission will add energy to data to lower BER. From many respects, the RTS/CTS mechanism is beneficial to improving the overall performance of wireless ad-hoc network. The specific algorithm is as follows:

(1) After setting up wireless ad-hoc network and initialization, the frame structure of TDMA is divided into three parts, namely RTS, CTS and TDMA slot. As shown above in Figure 3.

(2) When source node has data to send, at first, some

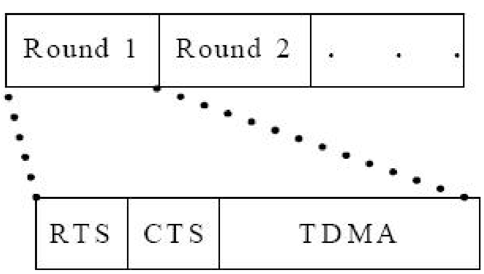

Figure 3 : The frame structure of RD-TDMA

physical link information, such as path loss, BER, SNR, should be estimated at physical layer. At the same time, we will add this information to RTS frame, then to send it to MAC layer. We use the physical layer's information feedback to realize the joint cross-layer optimization of PHY-MAC.

(3) When destination node receives RTS frame at MAC layer, it will decide whether to send CTS and send CTS to control the usage of slots. At last, when source node continues to send data, it will transfer into TDMA mechanism. Meanwhile, if there are any other data to retransmit, they also can apply for slots to send until finishing it, which will have a good effect on reducing unnecessary delay.

All in all, when users request to send data and apply for slot allocation, the first thing is to estimate channel state. Then go into TDMA mechanism if the channel is idle. Otherwise, the system will adjust the carrier mechanism to complete it, so that there exists to be channel for user to send data until finishing transmission.

SIMULATION

Simulation is done in MATLAB. In the experiments, we use the MATLAB simulation software for TDMA, improved TDMA, namely RD-TDMA, and the joint cross-layer optimization of PHY-MAC, namely

MIMO/OFDM+ RD-TDMA respectively. Then we also analyze the two main performances in wireless ad-hoc network, namely energy consumption and throughput respectively. By many experiments, we draw the following results in Figure 4 and Figure 5. Figure 4 shows energy consumption versus data rate curve, Figure 5 is the curve of network throughput along with packet generation rate.

The simulation results indicate MIMO/

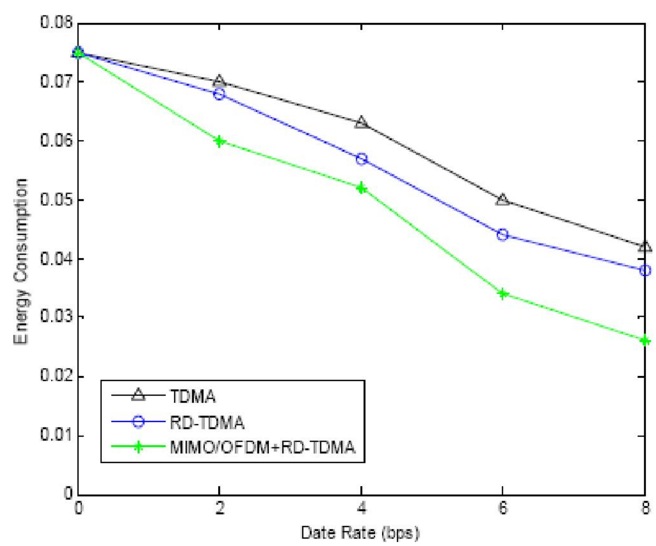

Figure 4 : Energy Consumption versus Data Rate for TDMA, RD-TDMA and MIMO/OFDM+RD-TDMA

OFDM+RD-TDMA is superior to TDMA and RD-TDMA in improving the overall performance of wireless ad-hoc, especially in energy saving and throughput. Specifically speaking, when data rate have a sharp increase, MIMO/OFDM+RD-TDMA outperforms TDMA and RD-TDMA in energy consumption, which has a lower consumption. The main reason is that a

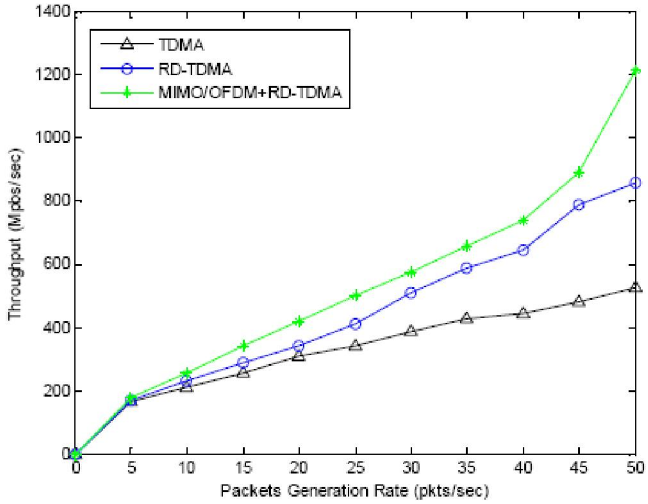

Figure 5 : Throughput versus Packet Generation Rate for TDMA, RD-TDMA and MIMO/OFDM+RD-TDMA

technical integration of MIMO/OFDM is applied to RD-TDMA. Besides, when network load is high, the proposed cross-layer optimization of PHY-MAC has an advantage over TDMA and RD-TDMA in throughput, which also maintains an increase in throughput.

CONCLUSION

In this paper, according to the characters of wireless ad-hoc network, we propose a optimization strategy as a cross-layer optimization scheme of PHY-MAC jointly, based on the physical layer's information feedback, with aims at improving the overall performance of wireless ad-hoc network, significantly in energy saving and throughput. On one hand, we utilize a fusion system of MIMO and OFDM to optimize physical link quality at physical layer. On the other hand, we adopt RTS/CTS reservation mechanism to optimize TDMA at MAC layer. To the end for achieving optimal network performance, we carry out our cross-layer optimization design of PHY-MAC scheme. Eventually, it is obvious that this optimization scheme can not only improve the fairness and QoS of wireless ad-hoc network, but also reduce energy consumption and BER, and have an increase in throughput. At the same time, it will ensure the reliability and robustness of wireless ad-hoc network.

ACKNOWLEDGMENTS

This work was supported by Liaoning Provincial Office of Education Fund (2013, Research on evaluation and reengineering based on reliability for Internet of Things software, L2013157 and #L2013156) and Liaoning Provincial Office of Industrial projects (2012219001).

REFERENCES

[1] Venkatesh Rajendran, Katia Obraczka, J.J.Garcia-Luna-Aceves; Energy-Efficient, Collision-Free Medium Access Control for Wireless Sensor Networks, Wireless Networks, 63–78 **(2006)**.

[2] Maciej Jan Zawodniok, Sarangapani Jagannathan; Energy-efficient Rate Adaptation MAC Protocol for Ad Hoc Wireless Networks, Int.J.Wireless.Inf.Networks, DOI 10.1007/s10776-007-0068, 251–263, **(2007)**.

[3] Jhunu Debbarma, Sudipta Roy, Rajat K..Pal; Cross-Layer Design Approach with Power Consciousness for Mobile Ad-Hoc Networks, International Journal of Wireless & Mobile Networks (IJWMN), June, **4(3)**, **(2012)**.

[4] Baozhi Chen, Myung J.Lee, Yi Sun; A Framework for Crosslayer Optimization from Physical Layer to Routing Layer on Wireless Ad Hoc Networks, Proc. IEEE GLOBECOM, **(2007)**.

[5] An Chan, Soung Chang Liew; Merit of PHY-MAC Cross-Layer Carrier Sensing: A MAC-Address-based Physical Carrier Sensing Scheme for Solving Hidden-Node and Exposed-Node Problems in Large-Scale Wi-Fi Networks, 31st IEEE Conference on Local Computer Networks, ISBN: 1-4244-0418-5, **(2006)**.

[6] E.Adebola, O.Olabiyi and A.Annamalai; Joint-Design of PHY/MAC Layers for Throughput Optimization of Opportunistic Relay Networks, Proc., IEEE GLOBECOM, **(2012)**.

[7] Jain-Shing Liu; Energy-Efficient Cross-Layer Design of Cooperative MIMO Multi-Hop Wireless Sensor Networks Using Column Generation, Wireless Personal Communications, DOI 10.1007/s11277-011-0332-5, 185–205 **(2012)**.

[8] Xiaohao Huang; Research on the Alorithms and protocols of IEEE a's Physical layer and MAC Sublayer, Nanjing University of Aeronautics and Astronautics, **(2008)**.

[9] Sadanand.R.Inamda, Ravi.M.Yadahalli, B.Sathish babu; Smart antenna system using cross layer design in wireless ad hoc networks: trends and challenges, World Journal of Science and Technology, ISSN: 2231 – 2587 Available Online: www.worldjournalofscience.com, 74-79 **(2012)**.

[10] Pham Thanh Hiep, Chika Sugimoto, Ryuji Kohno; MAC-PHY Cross-Layer for High Channel Capacity of Multiple-Hop MIMO Relay System, Communications and Network, Available Online: www.SciRP.org/journal/cn, **4**, 129-138 **(2012)**.

[11] Taesoo Kwon, Howon Lee, Sik Choi, Juyeop Kim, Dong-Ho Cho, Sunghyun Cho, Sangboh Yun, Won-Hyoung Park, Kiho Kim; Design and Implementation of a Simulator Based on a Cross-Layer Protocol between MAC and PHY Layers in a WiBro Compatible IEEE 802.16e OFDMA System, " IEEE Communications Magazine, December, **(2005)**.

[12] H.Luo, A.Argyriou, D.Wu, S.Ci; Joint source coding and network-supported distributed error control for video streaming in wireless multi-hop networks, IEEE Trans. Journal of Multimedia, Aug., **11(7)**, 1362–1372 **(2009)**.

[13] Qian Hu, Zhenzhou Tang; ATPM: An Energy Efficient MAC Protocol with Adaptive Transmit Power Scheme for Wireless Sensor Networks, Journal of Multimedia, **6(2)**, 122-128 **(2011)**.

[14] Hongjiang Lei, Chao Gao, Yongcai Guo, Zhi Ren, Jun Huang; Wait-Time-based Multi-channel MAC Protocol for Wireless Mesh Networks, Journal of Networks, **7(7)**, 1208-1213 **(2012)**.

[15] Xin Hou, Xingfeng Wei, Ertian Hua, Yujing Kong; Self-Adaptive and Energy-Efficient MAC Protocol Based on Event-Driven, Journal of Networks, **8(1)**, 174-181 **(2013)**.

[16] Jayanthi K.Murthy, Suthikshn Kumar, A.Srinivas;Energy Efficient Scheduling In Cross Layer Optimized Clustered Wireless Sensornetworks, International Journal of Computer Science and Communication, January-June, **3(1)**, 149-153 **(2012)**.

[17] Tao Shu, Marwan Krunz; Energy-efficient power/rate control and scheduling in hybrid TDMA/CDMA wireless sensor networks, Computer Networks, 1395–1408 **(2009)**.