Australian Journal of Basic and Applied Sciences, 9(16) Special 2015, Pages: 294-300

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

A Comparative Study of Cross Layer Protocols in WBAN

[1]P.T. Sharavanan, [2]R. Kumar, [3]D. Sridharan

[1]*Project Engineer, R&D, Wipro Technologies, Chennai, India*
[2]*Head, R&D, Wipro Technologies, Chennai, India*
[3]*Professor, Department of Electronics and Communications Engineering, College of Engineering, Anna University, Chennai, India*

ARTICLE INFO

Article history:
Received 20 January 2015
Accepted 02 April 2015
Published 20 May 2015

Keywords:
WBAN
Cross layer protocols
Performance optimization

ABSTRACT

Wireless Body Area Network (WBAN) provides monitoring the health parameters of a human body remotely with applications in various fields such as home monitoring, medicine, hospitals, sports, military etc. WBAN is one of the latest research area carried for monitoring efficient physiological conditions. A lot of methodologies has been addressed and tried to solve the issues and challenges involved in improving the performance of the network in WBAN. In this paper we have carried out a comparative study on cross layer protocol design for WBAN which also discussed about the various methodologies carried out for optimizing the performance by using cross layered protocol design. We have also highlighted the comparison of protocols performance.

To Cite This Article: P.T. Sharavanan, R. Kumar, D. Sridharan., A Comparative Study of Cross Layer Protocols in WBAN. ***Aust. J. Basic & Appl. Sci.,*** *9(16): 294-300, 2015*

INTRODUCTION

Wireless Body Area Networks (WBAN) is an emerging technology where many wireless sensor nodes are placed in/on the body to monitor human physiological signals. The tiny sensor nodes placed in the body has the capability to sense these signals from the body and send these parameters to the medical evaluator present in the remote location through internet. In traditional health monitoring system, the health parameters are monitored through a wired system which has connectivity with the static medical equipment that can be monitored only in a hospital based environment.

The development of WBAN can be coupled with the health care management that can be deployed in any environment. These health parameters can be monitored from home, different hospitals, ambulance, military field etc. The sensor nodes which are incorporated with WBAN can monitor various health parameters such as body temperature, heart rate, blood pressure (BP), respiration, electrocardiogram (ECG), blood glucose, electromyography (EMG), electroencephalography (EEG) etc.

Thus the development of WBAN provides a greater advantage of monitoring the health remotely without affecting the patient's normal activity instead of placing the patient under close supervision statically in the hospital for longer time period. WBAN monitors the health parameters by placing the sensor nodes over the human body. Each of these sensor nodes will have the capability of (i) sensing the physiological signals from the human body, (ii) processing the signals from the body, (iii) storing the processed data, (iv) forwarding the processed signals to the mote or controller node. Mote/Sink will act as controller node to forward the received signals to the base station to reach the internet.

1. *WBAN Architecture:*

Architecture of WBAN is classified into flat and multi-tier architectures. The flat architecture consist of single data gathering unit to gather all the sensed information sent from the individual sensor nodes placed in the human body. The multi-tier architecture will have a large data gathering unit to collect the unique physiological signals from multiple mote or controller node placed in different human body to monitor different health monitoring system. The multi-tier architecture is shown in Figure 1.

In the architecture diagram (Figure 1), the first tier is a base tier that holds at the sensor level. The task of this tier is to collect the sensed information from the human body and forward the data to the next tier called gateway at the second tier level which is usually a mote or controller node, this tier will act as an interface between the tier1 and tier3 level and the third tier (highest) is at the server level usually an application server accessed by the general physician

Corresponding Author: P.T. Sharavanan, Project Engineer, R&D, Wipro Technologies, Chennai, India

or medical evaluator. There are certain other multi-tier architectures discussed in (Garth *et al*, 2012) that include *Security centric architectures, Energy efficient architectures, UWB transceiver design, Application specific network design and Node locations*. The architecture also highlights about three types of traffic exchange in each tier: (i) Normal traffic – Monitoring the physiological signals as a medical parameter in a regular interval of time, when there is no need for any critical monitoring. This is a fixed monitoring scheme where the medical parameters and time intervals are fixed. The normal traffic will perform a routine monitoring. (ii) On-Demand traffic – this traffic will contain the data which is monitored based on a demand initiated by the sink/controller node according to the instruction provided by the medical evaluator. The example of 'on demand traffic' includes, monitoring health status after surgery at a random level and recording the information for diagnosis. (iii) Emergency traffic – this traffic will be-handled in emergency situations, whenever there is a sudden drastic change in normal health such as an increase or decrease in heart rate.

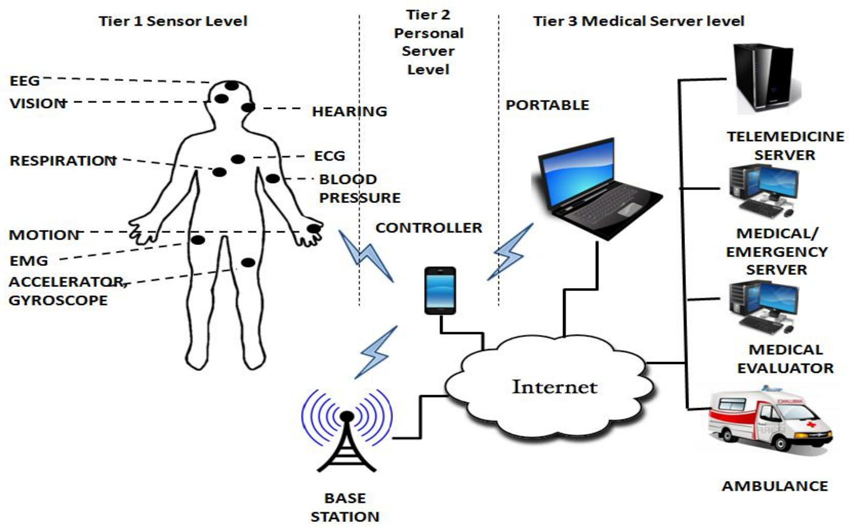

Fig. 1: The multi-tier architecture diagram.

2. *Cross Layer Protocol Design:*

The efficiency of interaction between the protocols and optimization objective can be achieved through designing a cross-layered protocol by merging two or more layers within the protocol stack. Since the traditional protocol stack provides more cost at energy efficiency and performance of the network by hiding the complexity of the layer below and above which does not need to aware of it, offers an advantage of compatibility, network scalability and flexible network design.

Cross layer protocol design provides many advantages in terms of merging functionalities of common layer protocol functionalities to gain resource efficiency, improving the network performance, interaction with other layers. The specific need for cross-layer design approach includes network heterogeneity, QoS, Channel Conditions and performance.

The performance gain of the network in (Hurni *et al*, 2008)(Kozat *et al*, 2004)(Chiang *et al*, 2004) is achieved by cross-layer design that provides a communication between the layers that can be adjacent and non-adjacent layers in the form of energy efficient network design, improved reliability, and scalability of the network, routing and reduced contention. In (Chiang *et al*, 2007) have provided the proposals on the methods that violate the traditional layered architecture which are: (i) *Creating a new Interface*: This connects the adjacent and non-adjacent layers which can use a parameter that is present in another layer. (ii) *Merging Adjacent Layers:* A functionality of combined service of two adjacent layers can be created without violating the traditional overhead of the individual layers. (iii) *Vertical calibration across layers*: adjusting the parameters at different layers either at protocol design or during runtime to enhance the throughput, increase the performance. (iv) *Layering as Optimization Decomposition*: completely replacing the traditional protocol stack with a new one without a layered form. A framework for cross-layer design in (Hughes *et al*, 2012) provides a concept on layering as optimization decomposition in the form of horizontal and vertical decompositions. *Horizontal Decomposition* decomposes the optimization problems into sub problems in which each are associated with the specific protocol layers. *Vertical Decomposition* provides a decoupling of protocol stack where the coordination of energy management, congestion management, routing and error control mechanisms to perform same functions as separate layers.

2.1 Cross Layer Protocols Design:

In order to achieve the energy efficiencies, many researches have been proposed and are on-going in WBAN cross-layer design. The cross layer design scheme can be classified into *loosely coupled design* and *tightly coupled design*. To achieve optimized higher layer, the design should adapt with lower layer parameters in the protocol stack is called *loosely coupled design*. For an optimized solution, different protocol layers are optimized together in *tightly coupled design*

2.1.1 MAC and Physical layer protocols:

To improve the traditional protocol stack, the MAC and physical layers are jointly optimized which are placed closed to each other in the protocol stack. The main physical layer techniques that are available are IR-UWB and WUR. Some of the schemes that use UWB MAC protocols (Kasun *et al*, 2014):

IEEE 802.15.6 standard (2014) – This is the first standard to provide MAC architecture for in-body and on-body communications. This standard provides a physical layer communication using UWB and narrow band technologies that supports three modes of communication *beacon mode, non-beacon mode with super frame boundaries* and *non-beacon mode super frame boundaries*. It provides low power consumption and high data rate, provides robust data transmission. The main *disadvantage* is that it doesn't overcome some limitations in implementation of UWB transceivers. It also ignores the optimization of UWB transmit control through duty cycle and gated pulse transmission techniques.

IEEE 802.15.4a Standard (2007) – This standard is the most adapted one for UWB based MAC applications. This standard also uses beacon enabled super frame structure for UWB PHY layer communication. The super frame structure has a maximum of 16 time slots that is divided into Contention Access Protocol (CAP) and Contention Free Period (CFP). The delay performance is evaluated based on continuous and routine signals in (Takizawa *et al*, 2007) where the application needs a continuous signal monitoring such as ECG, EEG, blood pressure (BP) where the time delay is analyzed for this signals.

The delay is better for continuous signals but not for routine signal monitoring. For on-body communications in WBAN the Bit Error Rate (BER) is analyzed in (Domenicali *et al*, 2007) which increase significantly high when the number of on-body sensors is increased. The drawback is that it does not support high data rate transmission which restricts the advantage provided by UWB. The frequent use of UWB disregards the dynamic power control capability achievable through UWB.

PSMA based MAC (Kynsijarvi *et al*, 2010)(Haapola *et al*, 2009) – This protocol is based on MAC that uses beacon enabled super frame structure that attaches a preamble at the beginning of each data packet to detect the idle or busy channel where the presence indicates the channel as busy. This protocol provides high throughput and energy consumption when compared with IEEE 802.15.4a standard. The *drawback* is that it does not provide solution to eminent collision scenario which occurs when there is simultaneous preamble sensing of two or more sensor nodes and also it ignores the complexities in using IR-UWB.

CAEM Protocol – Channel Adaptive Energy Management Protocol (CAEM) (Lin *et al*, 2007) utilizes the time varying utility property of wireless link to have cross-layer interaction between physical and MAC layers. It reduces the energy consumption by 30% without channel adaptation. Under heavy loads it performs better in efficient channel utilization. Energy efficiency and fairness is balanced by using scheduling and queuing algorithm for equal channel access. The *drawback* is that the local adaptation of physical layer parameters such as transmission power, coding rate and modulation achieve target bit error rate (BER) restrains routing and MAC decisions.

Table 1: Comparison of MAC & Physical layer Protocols.

Protocols	Energy Efficiency	QoS	Traffic Priority	Network Scalability	Channel Access	Latency
IEEE 802.15.6 standard	No	Yes	Yes	Yes	Random – ALOHA	No
IEEE 802.15.4a Standard	No	No	Yes	No	No	No
CAEM	Yes	No	No	Yes	Scheduling and Queuing algorithm	No
UWB –Tx NB-Rx MAC	Yes	Yes	Yes	Yes	Random and TDMA	No

In (Kozat *et al*, 2004) a framework for cross layer design of energy efficient communication with QoS provisioning where QoS is interpreted differently at each protocol layers. There are few problems that still exists in this design where there is no priority exist in routes to reach controller node. The central node holds the global network information, which leads to hold a limited application towards ad-hoc networks. The comparison of other protocols is given in Table 1.

2.1.2 Network and MAC layer protocols:

The data packets are routed with the creation of optimal routing path in Network layer. The optimal routing path can be determined to enhance the performance of network layer (Thaskani *et al*, 2011)(Zheng *et al*, 2009)(Hoesel *et al*, 2004)(Bhatia *et al*, 2004) by extracting the key information from lower layers such as link quality, traffic volume, link cost and collision cost.

WASP Protocol (Braem *et al*, 2006) – The energy efficiency is achieved through distributed coordination of separated wireless links. A spanning tree set up is created and time slots called WASP Cycles is used in which the parent and child nodes with unique WASP scheme will communicate the messages and time slots over it to control the traffic. To reduce the coordination overhead WASP scheme is generated by source node and used by both parent and child nodes. It reduces the energy consumption and end-to-end delay. It also performs better in packet delivery ratio when compared to others. The *drawback* is that WASP does not support two-way communication and does not consider link quality. It does not support node mobility.

CICADA Protocol (Latre, *et al*, 2007) – This protocol is designed for multi hop based WBAN by using Time Division Multiple Access (TDMA) schedule with mobility support. This scheme divides the slots in which each cycle is divided into control sub-cycle and data-sub-cycle. The control sub-cycle child nodes can send the information to the parent node about the length of control sub-cycle and tree depth. The data sub-cycle contains length of waiting period and data period also has the slots for new nodes to join during mobility. It outperforms in reducing the delay in packet delivery. The energy consumption is less when compared with other cross layered protocol by having enough sleep time for nodes than WASP. The *drawback* is there is no specification regarding packet delivery ratio.

TICOSS (Ruzzelli *et al*, 2007) – TICOSS is based on MERLIN that supports multi-hop communication over IEEE 802.15.4 standard by dividing the network into time zone through V-Scheduling. The time slot allocation is done by V-Scheduling where the node activity and inactivity is known by the nodes. V-Scheduling table will supports local broadcast, upstream and downstream transmissions. It considers node mobility and node replacement and deployment by using a predefined expiration time for each time zone. It improves IEEE 802.15.4 and performs better in terms of efficient packet delivery ratio, low packet delivery delay and low energy consumption. The *drawback* is Average delay characteristics are not specified.

BIOCOMM & BIOCOMM-D (Ruzzelli *et al*, 2006)(Bag *et al*, 2009) – The MAC and network layer interaction is achieved through CMI (Cross-layer Messaging Interface) which helps to exchange the neighbor node status. Neighbor Status Table is maintained to keep the status as F (Free) or B (Blocked) status of the neighbor. The packets are routed to destination. Biocomm and Biocomm-D performs better in temperature raise, energy consumption, network throughput, packet loss due to buffer overflow and Time to live (TTL). Biocomm has high average packet delivery delay whereas Biocomm-D has low average packet delivery delay. Packet discard mechanism is handled by including hop-count in the packet. The *drawback* is that there is no mobility support by this protocol. Biocomm-D has slightly high temperature raise when compared to Biocomm.

Table 2: Cross layer protocol comparison in Network and MAC layer.

Protocol	Energy Efficiency	Mobility Support	Metrics	Average Delay	PDR	Energy Consumption
WASP	Yes	No	Hop Count and Routing	324 ms	100%	Medium
CICADA	Yes	Yes	Hop Count and Routing	<0.3 ms	NA	Low
TICOSS	Yes	Yes	Hop Count and Routing	NA	>92%	Low
Biocomm & Biocomm-D	Yes	No	Node Temperature, Hop Count and Routing	Medium	75-100%	Medium

By comparing the cross-layer protocols in Network and MAC layer for WBAN in Table 2, TICOSS and CICADA consumes less energy when compared to other protocols, whereas WASP schemes outperforms in terms of efficient packet delivery ratio (PDR) and in-terms of reducing packet delivery delay CICADA performs well among the other protocols (Bangash *et al*, 2014).

2.1.3 Transport and MAC, Physical layer Protocols:

In traditional wireless networks, operating transport layer protocols provides transmission of packets through connection oriented services by TCP and connectionless services by UDP. This has an impact of energy efficiency in low power networks like WBAN, so, standard UDP protocol cannot be considered in WBAN context because it does not have any mechanism for reliable communication and no QoS support. The traffic management can be achieved only by providing the cross layer functionality with physical layer schemes for variable link capacity. Due to this limited transport layer functions such as packet fragmentation and packet re-assembly there is no fragmentation support at the network layer.

Standard TCP also suffers from performance issues due to limited bandwidth, packet loss due to congestion and interpretation of higher BER for wired networks. In order to overcome this problem we have to design a protocol for better performance in-terms of varying link capacity, higher throughput and minimal end-to-end packet delay can be achieved through cross layer operating at transport and physical layer schemes.

In (Stabellini *et al*, 2010) a Energy aware spectrum sensing has been proposed for dynamic spectrum access scheme that provides an efficient algorithm for spectrum sensing to minimize the energy consumption and reducing delay in delivering packets by considering energy constraint system with a cross layer design at transport layer with an energy efficient gain of 50% when compared with other spectrum sensing scheme.

2.1.4 Application and MAC, Physical layer Protocols:

In traditional application layer based protocols which are designed for wired communication will not be applicable for low power wireless communications like WBAN. Therefore, in WBAN in order to improve the performance of the channel conditions from MAC/Physical layer can be considered as a cross layer parameter in application layer design. The other QoS parameters are data reliability, response time and delay tolerance.

QoS Adaptive Congestion Control mechanism (Rahman *et al*, 2008) – This mechanism provides an approach to control the congestion and provides a support for QoS guarantee for different application data. Two congestion control mechanism has been proposed namely short-term and long-term. This scheme is linked with the QoS requirements of the application layer and MAC with certain metrics like collision resolution, packet waiting time and packet transmission time.

CC-MAC (Vuran *et al*, 2006) – Spatial correlation-based Collaborative MAC (CC-MAC) protocol uses the spatial correlation metrics exploited in MAC for cross layer design. The MAC medium is collaboratively regulated to access the redundant transmission from neighbors. Event-MAC (E-MAC) and Network Mac (N-MAC) prioritize the routing of data packets for transmission and achieves gain in-terms of energy efficiency, latency and packet drop rate and also controls the redundant nodes transmission. The *drawback* is that the protocol does not consider QoS requirements.

DQBAN (Otal *et al*, 2010) **–** This protocol design enhances the IEEE 802.15.4 for BAN which extends the research carried in DQRAP (Lin *et al*, 1993) which incorporates the fuzzy rule scheduler for optimizing the MAC for improving the performance by considering QoS and energy consumption. It achieves high reliability when compared with IEEE 802.15.4 in-terms of latency and battery constraints. This protocol does not provide any traffic priority. The comparison of these protocols is tabulated in Table 3.

Table 3: Cross layer protocol comparison in Application and MAC, Physical layer.

Protocol	Energy Efficiency	Traffic Priority	Metrics	Energy Consumption	QoS	Channel Access
QoS Adaptive Cross-layer Congestion Contol	Yes	Yes	Collision resolution, packet transmission and packet waiting time at MAC layer	Low	Yes	Channel Access MAC Protocol
CC-MAC	Yes	Yes	Spatial correlation metrics in MAC layer	Low	No	E-MAC and N-MAC
DQBAN	Yes	No	SNR (Physical layer Signal Quality), system waiting time and residual battery life	Low	Yes	Fuzzy rule Scheduler by considering cross-layer metrics

2.1.5 Multi-layer Cross-layer Protocols:

This cross layer designed scheme is a multi layer tightly coupled approach. For example consider a network where multiple nodes are competing for resources, the QoS will be breached. The solution is to combine the transport layer for congestion control, network layer for routing and MAC for channel access schemes. This joint protocol stack is the only option for achieving performance.

XLM Protocol – Cross Layer Module (XLM) (Akyildiz *et al*, 2006) – The objective of this protocol is to achieve the reliable communication with congestion avoidance, adaptive communication, and minimal energy consumption. This protocol replaces the complete traditional communication layer into a single protocol. The major advantage in this protocol is that it outperforms in implementation efficiency when compared with traditional layered architectures.

XLP Protocol – Cross Layer Protocol (XLP) (Vuran *et al*, 2010) **–** This protocol extends XLM approach by considering physical layer in protocol stack and channel effects to provide end-to-end congestion control. This protocol merges the traditional MAC layer, Congestion control and routing in protocol stack to form a cross layered protocol to provide end-to-end congestion control.

3. Conclusion:

In this study we have given an overview of WBAN, multi-tiered architecture of WBAN and reviewed the cross-layer approach for optimizing the performance of WBAN. The study focuses on cross-layer design schemes that are available and compared the performance of the schemes with their unique characteristics.

REFERENCES

Akyildiz, I., M. Vuran, O. Akan, 2006. A Cross-Layer Protocol for Wireless Sensor Networks. In Proceedings of 40th Annual Conference on Information Sciences and Systems, Princeton, NJ, USA, 1102-1107.

Bag, A., M.A. Bassiouni, A. Biocomm, 2009. Cross-layer medium access control (MAC) and routing protocol co-design for biomedical sensor networks. Int. J. Parallel Emerg. Distrib. Syst., 24: 85-103.

Bangash, Javed, I., Abdullah, H. Abdul Anisi, H. Mohammad, Khan, W. Abdul, 2014. A Survey of Routing Protocols in Wireless Body Sensor Networks. Sensors, 14(1): 1322-1357.

Bhatia, R., M. Kodialam, 2004. On Power Efficient Communication over Multi-Hop Wireless Networks: Joint Routing, Scheduling and Power Control. In Proceedings of INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies, Hong Kong, China, 2: 1457-1466.

Braem, B., B. Latre, I. Moerman, C. Blondia, P. Demeester, 2006. The Wireless Autonomous Spanning Tree Protocol for Multihop Wireless Body Area Networks. In Proceedings of 3rd Annual International IEEE Conference on Mobile and Ubiquitous Systems: Networking and Services, San Jose, CA, USA, 1-8.

Chiang, M., 2004. To Layer or not to Layer: Balancing Transport and Physical Layers in Wireless Multihop Networks. In Proceedings of INFOCOM 2004, Twenty-Third Annual Joint Conference of the IEEE Computer and Communications Societies, Hong Kong, China, 2525-2536.

Chiang, M., S. Low, A. Calderbank, 2007. Layering as optimization decomposition: A mathematical theory of network architectures. Proc. IEEE, 95: 255-312.

Domenicali, D., M.G. Di Benedetto, 2007. Performance analysis for a body area network composed of IEEE 802.15.4a devices. In: 4th Workshop on Positioning, Navigation and Communication, 273-276.

Garth V. Crosby, Tirthankar Ghosh, Renita Murimi, Craig A. Chin, 2012. Wireless Body Area Networks for Healthcare: A Survey, International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC) 3(3).

Hurni, P., T. Braun, B.K. Bhargava, Y. Zhang, 2008. Multi-hop Cross-Layer Design in Wireless Sensor Networks: A Case Study. In Proceedings of IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, Avignon, France, pp: 291-296.

http://www.ieee802.org/15/pub/TG6.html, 2014.

IEEE-802.15.4a-2007. Part 15.4: wireless medium access control (MAC) and physical layer (PHY) specifications for low-rate wireless personal area Networks (LR-WPANs): amendment to add alternate PHY. Standard, IEEE 2014.

Haapola, J., A. Rabbachin, L. Goratti, C. Pomalaza-Raez, I. Oppermann, 2009. Effect of impulse radio-ultrawideband based on energy collection on MAC protocol performance. IEEE Trans. Veh. Technol., 58: 4491-4506.

Kasun Maduranga Silva Thotahewa, Jean-Michel Redouté, Mehmet Rasit Yuce, 2014. Ultra Wideband Wireless Body Area Networks, Springer International Publishing Switzerland, Springer Science & Business.

Kozat, U.C., I. Koutsopoulos, L. Tassiulas, 2004. A Framework for Cross-Layer Design of Energy-Efficient Communication with QoS Provisioning in Multi-hop Wireless Networks. In Proceedings of INFOCOM 2004. Twenty-Third Annual Joint Conference of the IEEE Computer and Communications Societies, Hong Kong, China, 1446-1456.

Takizawa, K., L. Huan-Bang, K. Hamaguchi, R. Kohno, 2007. Wireless patient monitoring using IEEE 802.15.4a WPAN. In: IEEE International Conference on Ultra-Wideband, 235-240.

Latre, B., B. Braem, I. Moerman, C. Blondia, E. Reusens, W. Joseph, P. Demeester, 2007. A Low-Delay Protocol for Multihop Wireless Body Area Networks. In Proceedings of 4th Annual International Conference Mobile and Ubiquitous Systems: Networking and Services, Philadelphia, PA, USA, 1-8.

Hughes, L., X. Wang, T. Chen, 2012. A review of protocol implementations and energy efficient cross-layer design for wireless body area networks, Sensors, 12: 14730-14773.

Lin, H., G. Campbell, 1993. Using DQRAP (Distributed Queuing Random Access Protocol) for Local Wireless Communications. In Proceedings of Wireless' 93, Calgary, AB, Canada, 625-635.

Lin, X., G.C. Su, H. Wang, L. Huang, 2007. A Novel MAC Approach to Combating Fading Channel for Wireless Sensor Networks. In Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing, 2007, Honolulu, HI, USA, 2348-2351.

Kynsijarvi, L., L. Goratti, R. Tesi, J. Iinatti, M. Hamalainen, 2010. Design and performance of contention based MAC protocols in WBAN for medical ICT using IR-UWB. In: IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops, 107-111.

Otal, B., L. Alonso, C. Verikoukis, 2010. Design and analysis of an energy-saving distributed mac mechanism for wireless body sensor networks. EURASIP J. Wirel. Commun. Netw., doi:10.1155/2010/571407.

Rahman, O., M.M. Monowar, C.S. Hong, 2008. A QoS Adaptive Congestion Control in Wireless Sensor Network. In Proceedings of 10th International

Conference on Advanced Communication Technology, Gangwon-Do, Korea, 941-946.

Ruzzelli, A.G., G.M. O'Hare, M.J. O'Grady, R. Tynan, 2006. MERLIN: A Synergetic Integration of MAC and Routing Protocol for Distributed Sensor Networks. In Proceedings of 3rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks, Reston, VA, USA, pp: 266-275.

Ruzzelli, A.G., R. Jurdak, G.M. O'Hare, P. Van Der Stok, 2007. Energy-Efficient Multi-Hop Medical Sensor Networking. In Proceedings of the 1st ACM SIGMOBILE International Workshop on Systems and Networking Support for Healthcare and Assisted Living Environments, San Juan, Puerto Rico, 37-42.

Stabellini, L., J. Zander, 2010. Energy-Aware Spectrum Sensing in Cognitive Wireless Sensor Networks: A Cross Layer Approach. In Proceedings of 2010 IEEE Wireless Communications and Networking Conference (WCNC), Sydney, Australia, 1-6.

Thaskani, S.S., K.V. Kumar, G.R. Murthy, 2011. Energy Efficient Cross-layer Design Protocol by Using Token Passing Mechanism for WSN. In Proceedings of 2011 IEEE Symposium on Computers & Informatics (ISCI), Kuala Lumpur, Malaysia, 572-575.

Van Hoesel, L., P. Havinga, 2004. A Lightweight Medium Access Protocol (LMAC) for Wireless Sensor Networks. In Proceedings of the International Conference on Networked Sensing Systems (INSS 2004), Tokyo, Japan, 205-208.

Vuran, M.C., I.F. Akyildiz, 2006. Spatial correlation-based collaborative medium access control in wireless sensor networks. IEEE ACM Trans. Netw., 14: 316-329.

Vuran, M.C., I.F. Akyildiz, 2010. XLP: A cross-layer protocol for efficient communication in wireless sensor networks. IEEE Trans. Mob. Comp., 9: 1578-1591.

Zheng, F., H. Lu, W. Wang, Q. Sun, 2009. DERACL: A Distributed Energy-efficient Routing Algorithm based on Cross-layer Design. In Proceedings of International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery, 2009. CyberC'09, Sanya, China, 197-200.