A Survey on Design and Development of Energy Efficient Cross Layer Approaches in Wireless Sensor Networks

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Abstract— Recently, there has been an increasing trend of research papers in the literature for using the cross layer protocols in the Wireless sensor networks (WSN) domain. Keeping in view these trends in this paper the proposals have been reviewed and an attempt has been done to classify the protocols in order to bring out open issues for researchers. The major challenges in WSN are limited storage, power, battery life, less computation, lower bandwidth and high error rates. Unlike the conventional layered approaches, now days different cross layer proposals are being used to overcome these challenges and used to improve the Quality of Service (QoS) parameters like Energy efficiency, Network lifetime, throughput, delay. Open research issues in the development of cross-layer design for sensor networks are discussed in terms of QoS parameters and possible research directions are indicated to achieve the targeted QoS.

Keywords— Wireless Sensors Networks, Routing, Medium access control, Quality of service parameters.

1. INTRODUCTION

Wireless Sensor Networks consist of a large number of small densely deployed sensor nodes which continuously sense and transmit some specific physical characteristics of the environment to a sink node [1]. A WSN senses specified parameter (s) related to environment, processes data and estimate event features based on information provided by sensor nodes and send it to base station. The base station analyzes information and promotes suitable response if required. Each sensor node contains a sensing unit, a processing unit, a communication unit, and a power source. The main applications of WSN are battlefield surveillance, home automation, and microclimate control in buildings, seismic and structural monitoring, habitat monitoring, bio-medical applications, health and wellness monitoring. Considering the scarce energy sources in WSN the main motive of any WSN application is to analyze the event features from the collective information provided by sensor nodes in such a way so that minimum energy consumption in the network should take place [Akyildiz , I.F et al. (2006)].The main challenge in protocol design for WSN is energy efficiency as the nodes have limited battery .Thus there is need of developing energy efficient and reliable protocols for WSN and frequent battery replacement is not at all possible. There are numerous protocols were designed in past for each layer in the traditional layered protocol design but still there is no standard benchmark protocol available till date. By using joint optimization of multiple layers i.e. cross layer design gives better Quality of service parameters than our traditional layered design. A large amount of research effort has to be done in order to develop energy efficient networking protocols. To this end, the most crucial constraint is energy consumption which has become a prime challenge for the long lived sensor nodes. So efficient energy management needs to be incorporated without ignoring the effects of varying channel quality existing in WSN. However, joint cross layer optimization leads to improvement in terms of energy conservation [Hoesel et al. (2004)]. In this paper, our aim is to provide a motivation for the development of Energy Efficient Cross Layer approaches in WSN and discuss the still-open research issues in this field.

The rest of the paper is organized as follows. Section 2 does the comparison between layered design and the cross layered design. Section 3 briefs the motivation for cross layer approach in WSN. In Section 4, various proposals for possible cross layer interactions have been presented. In section 5 various open issues for targeted QoS have been discussed. Finally, this paper is concluded in Section 6.

2. COMPARISON BETWEEN LAYERED DESIGN AND CROSS LAYERED DESIGN:

The OSI model is a seven layer architecture, where each layer is responsible for specific sub-systems. Layered protocol stack resulted in development of simple, robust and scalable protocols like S-MAC, T-MAC, D-MAC, TRAMA, STEM, SPIN, DIRECTED DIFFUSION, RUMOR ROUTING, GPSR, TBF, LEACH, HEED for wireless sensor networks. These layered protocols are not jointly designed and optimized to maximize the overall performance while minimizing the energy expenditure. Thus the inter-dependencies between different layers can be utilized to get better performances for different network parameters like increase in network lifetime, to minimize end to end delay, to improve energy efficiency and throughput. Also by using cross layer design we can implement the functions such as multi hop routing, load balancing, interference mitigation, frequency reuse which cannot be implemented by using layered design. Integration of the layers is a promising research area for instance, the routing path could be chosen depending on the collision information from the medium access layer.

3. Motivation for Cross Layer approach in WSN

Cross layer design is a technique of breaking of OSI hierarchical layers in communication network which can potentially be used to improve the overall performance of WSN by exploiting the interactions between various layers of the network protocol stack [Zang and Zang (2008)]. In Cross Layer design the inter-dependencies between different network layers can be utilized to get statistically optimal response for different network parameters like Network lifetime, throughput, latency or energy efficiency. A cross layer interaction between the physical layer and MAC layer, network layer and MAC layer, or application layer provides further efficient use of limited network resources and improves energy efficiency [Hurni et al. (2008)]. Moreover, WSN offer several avenues for opportunistic communication that cannot be exploited sufficiently in a strictly layered design. For example, the time-varying link quality allows opportunistic usage of the channel. In addition, the wireless medium offers some new modes of communication as the layered architectures do not receive multiple packets at the same time. Thus, use of such "novel" modes of communication in protocol design requires violating the layered architectures. Moreover, cross layer architecture delivers the QoS reliably and flexibly to heterogeneous applications in WSN as compared to layered architectures.

4. Proposals for possible Cross layer Interactions

In this section, important existing proposals for cross-layer design have been presented in terms of possible interactions among the Physical, MAC, Network and higher layers.

4.1. MAC and Network layers

In WSNs the interactions between the MAC and Network layers are mostly used and in such cross layer interactions a joint scheduling and routing mechanism is proposed to form on-off schedules for data flow in a network where the nodes are not kept active for the entire time. The possible energy efficient cross layer protocols proposed by the researchers which uses the interdependencies of routing and scheduling at MAC layer have been summarized for sensor networks in Table 1.

4.2 Physical and MAC layers

Some Cross-layer design techniques combine the MAC layer and physical layer together for the optimization tasks on network throughput and energy efficiency. On a MAC layer, energy efficient communication protocols can reduce packet overhead on each layer, congestion control and reduce energy consumption. On a physical layer optimizing transmission energy using low power modulation schemes. The possible energy efficient cross layer protocols between MAC and physical layer have been enumerated in table 1.

4.3 Physical, Mac and Network layers

Normally cross layer approach is limited to two layers in the literature. But few exceptions using physical, Mac and network layers has also been noticed in the recent past i.e. considering Mac, physical and network layers together .This three tier approach is considering the routing algorithm , duty cycling , radio power control and enhances the performance in terms of throughput, reliability and energy efficiency.

5. Open issues for targeted Quality of service

It has been observed from the recent proposals that considering the performance metrics like network lifetime, energy efficiency, throughput and latency a plethora of interdisciplinary concept has been used in the literature for enhancing the performance of WSN through cross layer design. Now it is time to move ahead from these traditional layered solutions to holistic solutions. This requires comparative quantitative and detailed study of the different cross-layer design proposals, and is an open challenge for the society. Based on the proposals surveyed in the previous section the open issues have been classified in terms of QoS parameters below

5.1 Network lifetime

Network lifetime can be defined as the time of the first router failure. To extend lifetime of WSN is still an open issue for researchers. In the literature reviewed, two main methods are mainly utilized for improving the lifetime. One is to equalize energy consumption of networks, and another is to improve energy efficiency of nodes in networks. Utilizing aforesaid methods various proposals are discussed below.

Nefzi et al. (2009) revealed that SCSP, an energy efficient cross layer protocol does not need route maintenance or discovery and works jointly with the MAC layer to enhance its fault tolerance properties. For example, routing path could be chosen depending upon the collision information from the medium access layer. Simulation results show that such cross layer design extends the network lifetime and connectivity in comparison with IEEE 802.15.4 MAC. Xiong et al. (2011) proposed a regulated scheduling strategy DTBP (discrete time based scheduling strategy), based on a token-based service discipline, for shaping the per-hop delay distribution to obtain highly desirable end-to-end delay performance, joint flow control, routing, and scheduling algorithm achieves loop-free routes and optimal network utilization. Cordeiro et al. (2013) proposed an energy-efficient cross-layer design for the network layer and medium access control (MAC) layer that minimize energy consumption and prolongs network lifetime i.e. Minimum transmission energy consumption (MTEC) routing protocol is proposed for selecting the MTEC path for data transmission, based on the proportion of successful data transmissions, the number of channel events, the remaining node energy of nodes and the traffic load of nodes. Here the authors have proposed an adaptive contention window (ACW) for the MAC layer for a channel to save energy. Wang and Li, (2007) proposed hybrid ALOHA for improving throughput, stability, improved delay collision-free channel estimation and simultaneous multiuser transmission. Unlike traditional ALOHA, there are more than one pilot sub slots in each hybrid ALOHA slot and each user randomly selects a pilot sub slot for training sequence transmission. Park et al. (2011) suggested the efficient, reliable Breath protocol in which routing, MAC, and physical layers all together to enhance the network lifetime using dynamic duty cycle concept. Breath is tunable and meets reliability and delay requirements. Breath exhibits a good distribution of the working load, thus ensuring a long lifetime of the network. Wang et al. (2008) provided tighter analytical upper bounds to the optimal NL using an iterative KKT algorithm (karush-Kuhn-Tucker) to solve sub optimally NLM problem .This algorithm provided an analytical expression of the optimal NL and can also provide significant improvement on the performance of NL.

However various approaches have been used to increase network lifetime, but still there is ample scope to derive cross layer protocols for network lifetime maximization.

5.2 End to end delay

In real time systems, it is very important to consider end to end delay because timely delivery of data is very crucial. Delay refers to the amount of time spent by a packet in the MAC layer before it is transmitted successfully. Delay depends not only on network traffic but also on the design choices of the MAC protocol. Proposals to achieve targeted end to end delay in the literature have been presented here.

Ji et al. (2008) proposed a power controlled MAC protocol called cross-layer power alternative MAC (CLPA-MAC) that advances energy efficiency, collision avoidance and channel capacity is proposed for wireless sensor networks. Moreover, due to the decrease of collision, end-to-end time delay is also lower in CLPA-MAC. Nodes send packets with two different transmission power levels for saving energy, avoiding collision and reducing time delay. Kim et al. (2009) proposed an enhanced cross-layer protocol which provides efficient tradeoff between energy efficiency and long end to end delay in WSN. In general, the duty cycling schemes can improve energy efficiency but they suffer from long end-to-end delay because of the periodical active and sleep state's repetition resulted in the per-hop long delay. However, ECLP has more significant improvements since the adaptive duty cycling scheme utilizes the enhanced RRTS technique with the adaptive time-out scheme, which can avoid overhearing and reduce the long end-to-end delay compared with SMAC based protocols. Cui et al. (2007) minimizes the total network energy that includes both transmission and circuit energy consumptions, where the tradeoff between the two energy elements using minimum delay scheduling algorithm. In this case routing flow, TDMA slot assignment, and MQAM modulation rate and power on each link improves delay and energy efficiency. Secondly, based on the solved optimal transmission scheme, quantify the best trade-off curve between delay and energy consumption, and derived a scheduling algorithm to minimize the worst-case packet delay

5.3 Energy efficiency

Energy efficiency is the major challenge in the design of cross layer WSNs. Many researchers are working to improve the energy efficiency.

Vuran et al. (2010) proposed a cross-layer protocol XLP for the analysis of error control schemes in WSNs to improve energy efficiency. Bouabdallah et al. (2009) proposed a cross-layer design that considers the joint optimization of MAC and routing layers. The designed protocol sends the traffic generated by each sensor node through multiple paths. It was showed that by efficiently balancing the traffic inside the network and by sensibly allocating the retry limit to each link at MAC layer, further energy conservation was achieved by reducing idle listening, overhearing and retransmissions. Amadou et al. (2011) proposed PFMAC (Pizza-Forwarding Medium Access Control), which combines beaconless routing and energy efficient MAC protocol via a cross layer design to save more energy with higher reliability and reduces radio interferences, asymmetric radio links, etc. Wang et al. (2009) proposed a PHY/MAC/NET cross-layer analytical approach for high-density sensor networks in deciding the optimal number of clusters. Specifically, this cross-layer analytical model integrates the effects of the transmission distance, power, and shadowing in the PHY layer; the possibility of being a cluster representative and the retransmission times in the MAC layer, as well as the number of hops in the network layer.

Just from the beginning of WSN design energy efficiency has always been a major challenge for the network designers right from its initial stages of development .After through survey of literature it can still be considered as a major constraint in the future development of WSN's .

5.4 Throughput and Latency

Data latency can be defined as time it passes between the time a packet is generated at the source node and the time it is received at the sink. Cabezas et al. (2009) in his paper presents a WSN cross-layer design approach involving the Phy/Mac/Net layers that not only improves the energy efficiency of current alternatives but also coordinates the transfer of packets from source to destination in such a way that latency and jitter are improved significantly. The LEMR protocol using channel polling and an efficient node coordination strategy started from the sink achieves high transmission reliability, low energy consumption, and low latency .It has shown how LEMR (Latency, Energy, MAC and Routing), the proposed protocol, outperforms the well-known TMAC and S-MAC protocols in both energy and latency metrics. Throughput determines the number of packets lost in transmission which never reached the intended receiver. Throughput is defined as the number of packets transmitted in the channel in a given time duration. Ren and Liang (2008) suggested a good solution to reach the target of highly energy-efficient WSNs, and combined MAC layer and physical layer together to optimize the throughput of a network. On a MAC layer, according to the network topology, TM-MAC re divides each pico-net into several subsets in which communication pairs can make communication simultaneously and achieve the maximum throughput using the highest data rate. On a physical layer, it analyzes the relationship among the achievable maximum channel capacity, theoretical maximum channel capacity and the data rate. Akyildiz et al. (2006) XLM uses significantly less energy per packet and hence is highly energy efficient when compared to the other layered protocol suites. The design principle of XLM is complete unified cross-layering such that both the information and the functionalities of traditional communication layers are melted in a single module. The protocol operation of XLM is governed by the new concept of initiative determination. Based on this concept, XLM performs receiver based contention, distributed duty cycle operation and local congestion control in order to realize efficient and reliable communication in WSN. Wang and Li, et al. (2007) revealed that a novel MAC protocol, named hybrid ALOHA, which makes it possible for simultaneous multiuser transmission and collision-free channel estimation that can improve the MAC performance. Comparing with traditional ALOHA, there are more than one pilot sub slots in each hybrid ALOHA slot. Each user randomly selects a pilot sub slot for training sequence transmission. It was revealed that significant performance improvement can be achieved in comparison with the traditional ALOHA protocol based either on the collision model or the MPR model. Gunasekaran and Qi, (2008) proposed XLRP protocol which increases throughput by switching off unintended receivers based on power of the received radio signal.

It has been observed from the reviewed literature that one of the key challenges in deploying a high-density cluster-based sensor network is determining the optimal number of clusters because analytical optimal number of clusters can significantly improve the energy consumption and still less work has been seen in the literature reviewed. Another important issue is the length of the duty cycle. Although few researchers designed protocols to reduce the duty cycle by different means but one problem with most of these protocols is that they trade energy savings for latency. Open research issues range from power efficient transceiver design to simple and low power modulation schemes. Although there are various MAC layer protocols proposed for sensor networks, there is no protocol accepted as standard elsewhere. Considerable work and effort has focused on designing communication protocols for sensor networks. However, no single protocol has emerged as a major contender and research on this issue is very much active and ongoing.

6. CONCLUSION

In this paper we have presented the survey of Energy Efficient Cross Layer approaches in WSN. In literature a lot of work has been reported for cross layer interaction between MAC and Network layers. However, literature is sparse for cross layer interaction in case of Mac, physical and higher layers. Thorough survey has been done here in terms of QOS parameters such as Energy efficiency, Network lifetime, end to end delay, throughput, and latency related issues across the layers. The interface among the different layers has to be redesigned to improve the interactions in the cross layer designs especially in three or more layer designs. There are many energy efficient cross layer protocols available in literature but still there is no standard benchmark protocol available in the current scenario. It is hoped that by referring the information presented in this paper, researchers will be motivated to introduce new protocols to conserve energy. It has also been observed from the survey that physical layer is a largely unexplored area in sensor networks.

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TABLE I. CROSS LAYER PROTOCOLS FOR ENERGY EFFICIENT WIRELESS SENSORS NETWORKS

Author	Protocol Name	Cross layer Interactions	Remarks
Nefzi et al. (2009)	"SCSP" (Sleep, collect and send protocol)	***Network and MAC layers***	***Network Lifetime increases***
Vuranand Akyildiz (2010)	"XLP" (Cross layer protocol)	Network and MAC layers	Error control schemes ARQ and FEC improve energy efficiency.
Bouabdallah et al. (2009)	"HST" (hop based spanning trees)	Network and MAC layers	Energy conservation by balancing the traffic, reduces overhearing and retransmissions.
Kim et al. (2009	"ECLP" (Enhanced cross layer protocol)	Network and MAC layers	Increases Energy efficiency and solve long end-to-end delay problem.
Xiong et al. (2011)	"DTBP" (Discrete time back pressure algorithm).	Network and MAC layers	Long term network utilization and improves end to end delay.
Weng et al. (2013)	MTEC with ACW (minimum transmission energy consumption with adaptive contention window)	Network and Mac layers	Reducing energy efficiency, prolonging network lifetime, better packet delivery rate and high throughput.
Amadou et al. (2011)	PFMAC (Pizza-Forwarding Medium Access Control)	Network and Mac layers	Improved delivery ratio, Shortens end-to-end delay and also reduces communication Overhead.
Cho et al. (2007)	CL Mac (Cross layer Mac protocol)	Network and Mac layers	Reduces Control traffic routing overhead, Extends network lifetime
Fang et al. (2012)	CREC (Cross layer reliable and efficient communication protocol)	Network and Mac layers	Improved network performance, energy efficiency, and improved delay.
Liang, Y. (2010)	EERCP	MAC and Network layers	Extends network lifecycle, Better Energy efficiency
Zhang et al. (2012)	SCL	Network and MAC layers	Improved throughput and reduced latency
Ji et al. (2008)	CLPA-MAC	Network and MAC layers	Good Energy efficiency, Collision avoidance, End to End time delay decreases.
Zhang et al. (2009) [18]	EEFF	Mac and Network layers	Reduced latency
Wang, H.; Li, T. (2007)	"Hybrid ALOHA: A Novel MAC Protocol."	Physical and MAC Layers	Increased throughput, Stability, reduced Delay, Collision free channel estimation.
Ren, Q.; Liang, Q. (2008)	TM-Mac (Throughput Maximized MAC protocol)	Physical and MAC layer	Throughput Maximization
Cui, et al. (2007)	"Minimum delay scheduling algorithm "	Network, MAC and PHY	Improved Delay, Energy efficiency
Wang et al. (2008)	Karush-Kuhn-Tucker (KKT) algorithm	Network, MAC and PHY	Network Lifetime Maximization
Wang et al. (2009)	Analytical approach	Network, MAC and PHY	Minimizing energy consumption in a high-density sensor network.
Cabezas et al. (2009)	"LEMR" (Latency, Energy, MAC and Routing)	Network, MAC and PHY	Improved Energy efficiency, Reduced latency and jitter
Marco, P.D et al. (2010)	"TREND"Timely.Reliable and energy efficient and dynamic WSN protocol"	Network, MAC and PHY	Improved reliability, Reduced latency, improved duty cycling
Park , P et al. (2011)	"Breath"	Network, MAC and PHY	Efficient, reliable, and timely data gathering for control Applications, long network lifetime.
Tang, X; Wang, Y. (2012)	"CodyMAC" (Cross-layer and Dynamic balance energy-consumption MAC)	Network, MAC and PHY	Shorter latency, longer network lifetime, lower energy consumption.
Song, L.;Hatzinakos, D. (2007)	"LESOP"	Application layer and the Medium Access Control (MAC) and physical layers	Target tracking
Akyildiz , I.F. (2006)	"XLM"	Network, MAC and PHY	Improved Energy efficiency and high Throughput, Reduced latency