ENERGY SAVING IN WIRELESS SENSOR NETWORK: A CROSS LAYER APPROACH

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ABSTRACT
Sensor networks are currently one of the most active and exciting research areas in computer networks, because of its usage in application areas such as air traffic control, battlefield management, biomedical application, civil engineering application etc. This paper provides a comprehensive survey of research on energy saving in wireless sensor networks with cross layer design. We first focus on the main reasons for energy consumption, and discuss the main directions to energy conservation in WSNs (Wireless sensor networks) applied with cross layer design. Cross layer interaction means allowing communication of layers with any other possibly nonadjacent layers in the protocol stack. One of the major concerns areas in sensor networks is power saving. Finally we conclude the paper with insights for research direction about energy conservation in WSNs.

Keywords: Cross layer interaction, power management, wireless sensor networks, energy efficiency

INTRODUCTION:
A wireless sensor network is an infrastructure that consists of large numbers of sensor nodes and those nodes comprise of sensing (measuring), computing and communication elements [1, 2]. Basically there are four major components in sensor networks: (a) Localized Sensors (b)interconnecting networks, (c) central point or base station and (d) set of computing resources at central point. Fig.1. consists of sink node and high number of sensor nodes deployed in large sensing field. The power source of sensor node consists of a battery with limited energy budgets. Lot of energy is consumed in data transfer and its processing. Energy for transmitting a single bit of information is approximately the same as that needed for processing thousand operations. Related to wireless networks, the following functionality needs to be supported: intrinsic node functionality; signal processing, including digital signal processing, compression, forward error correction, and encryption; control and actuation; clustering and in-network computation; self-assembly; communication; routing and forwarding; and connectivity management. To support this functionality, the hardware components of wireless networks include sensing, the processing unit, the communication unit, the power unit and other application-dependent units. Many researchers [3, 4, 5] have proved that the energy cost of idle listening is only slightly lower than the cost of transmitting and receiving. Here an important thing to note that energy consumption of sensing subsystems depends on the specific sensor types. Wireless Sensor Networks are different MANETS, cellular systems and other traditional wireless systems. Sensor Networks have their own unique characteristics and constraints. These unique characteristics present many new challenges in the design of sensor networks. Wireless sensors have a great potential of
sensing technology in future time [6, 7, 8]. Some of the major features of sensor nodes include the following [6, 9, 10].

1.1) Sensor nodes are prone to failure
1.2) Sensor nodes are densely deployed
1.3) Topology problem because sensor node topology changes frequently
1.4) Limited power of sensor nodes
1.5) Computational capacities and memory
1.6) Sensor nodes may not have global identification because of large amount of overhead and the large number of sensors.
1.7) Energy Constraints and data redundancy problem
1.8) Self Configurable and application specific
1.9) Non Reliable sensor nodes
1.10) Mostly many-to-one traffic Patterns

Fig. 2 below shows the architecture of a typical wireless networks [11]. It consists of four main components: (i) a power supply unit (ii) a sensing subsystem including one or more sensors (iii) a processing subsystem including a micro-controller and memory (iv) a communication subsystem or a radio subsystem. Sensor nodes may also include additional components such as a location finder to determine position, a mobilizer to change location or configuration etc. these additional components are dependent on the need of the application.

If we talk about historical survey of sensor networks, it could be divided into four major phases [12]. Phase one was during the cold war and during this phase extensive acoustic networks were developed in United States for submarine surveillance; some or very few of these sensor are still being used by the National Oceanographic and Atmospheric Administration (NOAA) to monitor seismic activity in the ocean. Second Phase was during early 1980s with programs sponsored by Defense Advanced Research Projects Agency (DARPA). The time was of distributed sensor networks (DSN) worked to find out if the newly developed TCP-IP protocols and Arpanet’s approach to communicate could be used in the context of sensor networks. DSN postulated the existence of many low-cost spatially distributed sensing nodes that were designed to operate in all collaborative manner [13, 14]. Third Phase led to first generation commercial product. Based on the results generated by the DARPA-DSN research and the test beds developed, military planners set out in the 1980s and 1990s to adopt sensor networks technology, making it a key component of network centric warfare. An effort was made to start employing “commercial off-the-shelf (COTS) technology” and common network interfaces, thereby reducing cost and development time. Sensor networks can improve detection and tracking performance through multiple observations, geometric and phenomenological diversity, extended detection range, and faster response time [12].
Phase four could be called second-generation commercial products. Advances in computing and communication that have taken place in the late 1990s and early 2000s have resulted in a new generation of sensor network technology. Evolving sensor networks represent a significant improvement over traditional sensors [6, 9]. Inexpensive compact sensors based on a number of high-density technologies, including MEMS and Nanoscale Electromechanical systems (NEMS) are appearing. Standardization is a key to wide scale deployment of any technology, including WSN (e.g., Internet-web, MPEG_6 digital video, VOIP). Advances in IEEE 802.11a/b/g-based wireless networking and other wireless systems such as Bluetooth, Zigbee, and Wimax are now facilitating reliable and ubiquitous connectivity.

The remainder of this paper is organized as follows. Section 2 is on review or previous surveys done on sensor networks. Section 3 focuses on sources of power consumption in sensor networks. Section 4 reviews the work on energy optimization protocols based on cross layering. Sections 5 cover energy saving by algorithm (scheduling, data compression, routing algorithm, topology control, sleep/wakeup schedules) by cross layer interaction. Section 6 reviews the works done for pure cross layer approach. Section 7 concludes the paper.

**REVIEW OF PREVIOUS SURVEY**

The importance and popularity of WSN led to several previous surveys [15, 16, 17, 18, 19, 20]. There are many surveys done in WSN on energy saving in wireless sensor networks [11, 21, 22, 23], with cross layer design. TCP/IP model was introduced in 1960. In 1977 an improved version of above model came into existence. And throughout the 1980s, the belief was wide spread that OSI would to dominate TCP/IP. In 1990s, TCP/IP has become firmly established as the dominant commercial architecture and as the protocol suite upon which a bulk of new protocol development was done. There are numbers of reasons for success of TCP/IP protocols over OSI. The Internet was designed using the TCP/IP model and then the concept of OSI (open systems interconnection) model came into force. Cross layer design is currently one of the most active research areas in computer networks. Cross layer interaction means allowing communication of layers with any other possibly non-adjacent layers in the protocol stack. Traditionally, network protocols are divided into several independent layers. The main advantage of this is architectural flexibility. It has recently become evident that a traditional layering network approach (separate routing, scheduling, rate and power control) is not efficient for wireless networks. This is due to interaction of links through interference which implies that a change in power allocation or schedules on one link can induce change in the capacities of all links in the surrounding areas and change in the performance of flows that do not pass over modified link. Cross layering came into existence because of highly variable nature of links used in wireless communication systems and resource poor nature of the wireless mobile devices there have been multiple research efforts to improve the performance of the protocol stack by allowing cross layer interactions by wireless systems. It tries to share information amongst different layers, which can be used as input for algorithms for decision processes for combinations and adaptation. This process of sharing has to be co-ordinated and structured somehow since cross layering could potentially worsen the performance problem that it intends.
to solve. But it should be kept in mind that cross layering is not simple replacement of layered architecture nor is it the simple combination of layered functionality. It is very clear that changes in the protocol of one layer will affect the performance of other layers too. Cross layering came in to existence because of QoS, energy consumption, poor performance, wireless links, mobility, packet loss, delay problems observed in wireless networks. The growing interest in WSN has led to significant progress in recent years, especially in power saving issues. This paper provides a comprehensive survey on power saving with cross layer design.

**SOURCES OF POWER CONSUMPTION IN SENSOR NETWORKS**

Energy conservation networks are becoming extremely popular in sensor networking research. Energy conservation is currently being addressed in every layer of the protocol stack. There are two primary research areas which almost seems identical: maximization of lifetime of a single battery and maximization of the lifetime of the whole network. Maximizing the lifetime of single battery is related to the commercial applications and node cooperation issues while maximizing the lifetime of the whole network is more crucial, for instance, in military environment where node cooperation is assumed. The goals can be achieved either by developing better batteries, or by making the network terminals operation more energy efficient. As to the device power consumption, the primary aspects are achieving energy saving through the low power hardware development using techniques such as variable clock speed CPUs, flash memory, and disk spin down. However, from the networking point of view, our interest naturally focuses on the device’s network interface, which is often the single largest consumer of power. Energy efficient at the network interface can be improves by developing transmission/reception technologies on the physical layer and by sensing in activity on the application layer, but especially with specific networking algorithms. Much research has been carried out at the physical, medium access control (MAC) and routing layers, while little has been done at the transport and application layers. Nevertheless, there is still much more work need to be done. There are many factors responsible for power consumption in wireless sensor networks, and at the same time different methods for reducing power consumption [24] also exits. Some of factors responsible for power consumption are stated below:

- **Idle listening** is the main source of power wastage for any network. For transceiver phase power consumption is of the same order of magnitude as the transmission power [25, 26, 27], and most MAC protocols put the transceiver in receive mode whenever it does not transmit, whether there is the need to receive a message or not.

- **Retransmissions resulting from collision** can be quite frequent if the network load is high and there are more and more chances of collision. This is because energy for transmitting a single bit of information is approximately the same as that needed for processing thousand operations. Collision also increases energy consumption and latency in case of packet deliverance mechanism due to re transmission.

- **Control packet overhead** can be significant for sensor networks which, typically, have small packets (for e.g. RTS, CTS etc) [21].

- **Unnecessarily high transmitting power** not only results in higher power consumption, but it also increases interference at other nodes in the network. This case may arise arrives when sensor node receives a packet while it is in sleep mode. This condition forces the sender to perform new retransmissions that are strongly linked to non-synchronization problem and therefore consume more energy.
Sub-optimal utilization of the available resources is also one of the main reasons for energy wastage, for example, routes that utilize the nodes with the largest (remaining) batteries should be preferred.

The authors of [11] have discussed the general approaches to power saving. Duty cycling, data driven and mobility are three main ways for energy conservation and further more decisions are made on it.

But when we talk about energy saving with cross layer design the concept becomes a little different. With cross layer design it would be more convenient to consider the energy consumption problem on a system basis rather than on a component/protocol basis. Furthermore we show that cross layering is necessary in the design of any system based on sensor network, because cross layer approach can be exploited to reduce the energy expenditure through the entire protocol stack [11]. Energy Conservation is one of the important necessities of wireless sensor networks, so the researchers in this field look at low energy consumption as the main objective, and trade-off other performance measurements like delivery rate, throughput, and reliability for longer lifetime of the networks. And for this the rigid separation between the layers of our traditional protocol stacks is mostly restricted, because the designers need to gather information from different layers, as it would be useful to make the protocol design more and more energy efficient.

Cross Layering for energy conservation in wireless sensor networks can be divided into 3 major classes:

(a) Energy optimization protocols based on cross layering
(b) Energy saving by algorithmic approaches
(c) Pure cross layering approach

Class first consists of energy aware networking protocols. Papers in this class deals with energy management problem via optimization problems. Energy saving by algorithmic approach deals with problem of increasing the sensor network lifetime through optimization programming techniques. But the serious disadvantage of this approach is that it is very difficult to guess how much these approximations will impact on the performance of real systems. Pure cross layering approach deal with energy management schemes by exploiting information residing at different layers of the network stack

ENERGY OPTIMIZATION PROTOCOL OR ENERGY AWARE NETWORKING PROTOCOL BASED ON CROSS LAYERING

In this section our focus is on the energy networking protocols to reduce the energy consumption. There are many energy saving protocols in wireless sensors networks but all of them does not consider cross layering. Energy minimizing protocols are used to develop energy saving scheme which is applied with cross layer design, to reduce energy consumption. The authors of [28] have proposed energy efficient protocol to scatter data from base node to other multiple sink, and this scattering of data is based on the packet traffic rates and the node locations and the final decision is made on the basis of these two factors. In the same way author in [29], propose energy aware routing protocol, routes are selected based on the error rates and end-to-end reliability requirement of the data to be routed. Also it has been stated that for any routing policy to be energy efficient, it is not enough to take into account just single-link qualities, because the data have to be forwarded over multi-hop paths. So the concern should be on routes cost based on the total time required to reach the destination and not the single hop consideration should be made. All the details in the in the applications are dependent on the reliability scheme that the application uses.

In [30] authors talk about energy aware routing protocol where the routing decision is based on the consideration, that sink node could be
mobile. Authors of [31], [32] also propose energy aware routing protocol but there technique is little different than others, they also assume that sink node should be mobile as in [30] and they jointly identify the best sink mobility pattern, routing policy for sensor nodes to reach the sink that minimizes the energy consumption of the network (or equivalently, that maximizes the network lifetime). But when the sink nodes are mobile overhead increases.

In [33], the techniques is bit different than the above in this article author talk about energy optimization approach named as EOA, which minimizes the aggregate energy consumption in all power states. In this article author proposed a feedback algorithm that computes the proper transmission power level between nodes. Transmission power level is kept as record to make further decision. Then routing protocol can make use of the transmission power as a metric by choosing route with optimal power consumption to forward packets. Finally, the cross layer routing information is exploited to form a duty-cycle schedule at MAC layer. In [34, 35] author has proposes some approaches to control the transmission power to reduce the unnecessary transmission energy consumption and decrease the interference among node while maintaining the network connectivity. In [36,37] author has proposed power aware routing protocol that saves significant energy by choosing appropriate route according to available energy of nodes or energy demand of transmission paths. It is very obvious that wireless sensor networks need to reduce the energy consumed in all states (i.e. reception, transmission, idle) to minimize its energy consumption. In comparison to above author of [33] has proposed a novel techniques to minimize energy in all the states (i.e. transmission, idle, reception). In [38] the authors have discussed method by which energy consumption of physical and MAC layer can be analyzed and has lastly concluded that single hop communication can be more efficient if real radio model are used. But it is also observed that this analysis is based on the linear networks, and the result could not be on the practical basis.

The authors of [39] have proposed cross-layer solution among physical, MAC and application layers. They proposed a distributed spatial correlation-based collaborative medium access control (CC-MAC) protocol based on theoretical framework. In [40, 41, and 42], the author talks about receiver-based routing which is exploited for MAC and routing cross layer modularity. These authors have discussed about the approaches in which next hop is chosen as a result of contention in the neighborhood. The authors have independently proposed receiver based routing and discussed the energy efficiency, latency and multi hop performance of algorithm. In [43] author has extended the work of [41, 42] for a single radio node. In [40], the receiver-based routing is also analyzed based on a simple channel model and lossless links. Moreover, the latency performance of the protocol is based on different delay function and collision rates. In the same way in [44], protocol has been designed which takes routing decision as a result of successive competitions at the medium access level. The next hop is selected based on weighted progress factor and the transmitted power is increased successively until the most efficient node is found. Also the concept of on-off schedules is used. On-off schedules has its own advantages that it saves energy, because when the node have work they wake up or are kept on otherwise they can go to sleep i.e. in off mode. In [45], the concept of on-off is used and a TDMA-based MAC scheme is proposed, where nodes distributively select their appropriate time slots, based on local topology information. The routing protocol uses this information for route establishment.

In paper [46], cross layer protocol, XLRP which is based on application layer with the information along with the capabilities of physical layer and energy efficient routing strategy is developed. On-off schedule is used here as in the above quoted paper. The proposed routing algorithm takes decision based on the volume of data being transmitted. The cross layer proposes back-off mechanism by switching off the unintended receivers based on the power of the received radio signal. And also the cross layer protocol developed reduces control message overhead by exchanging piggy-backing information and extracting information from
packets received by unintended receivers. This algorithm has worst result if the volume of the data that has to be transmitted is less. In [47] the authors have proposed a cross layer design which takes the information from application, networks and MAC layer interaction in defining the functionalities of the network. In this for data aggregation application, with information from MAC layer, the network layer constructs the routing tree. In [48] the approach is same as the above paper but here the efficient cross layer routing is obtained by combining the MAC functionality with the routing decisions made at network layer and by this process the overhead of medium access layer is reduced to a greater extent. The protocol that has been suggested in this paper is based on geographic routing mechanism and the route path is set up by a stateless routing mechanism at the receiver end. This process is based on the end-to-end decision making process where the routing decision is made with the knowledge of the source node and the destination node. In paper [49] network layer and the MAC layer functionality help in increasing the sensor network lifetime. The MAC layer organizes the network as a set of active and passive nodes, establishing connectivity throughout the network as a TDMA based scheme. Then the TDMA establish connectivity through the neighbor based on the local information, talk cycles, which shift the routing load from the network layer to the MAC layer. Then the routing decision is made from the connected systems of active nodes, which is mostly dependent on lower layers. In the same ways as the above papers the authors of paper [50] has proposed a unified protocol based on RTS/CTS scheme. This protocol has demonstrated its efficiency in terms of efficiency, local cross layer congestion control and distributive duty cycle.

In paper [51] authors have developed a cross-layer communication protocol which considers transport, routing medium access and physical layer for efficient and reliable communications and they have claimed that there is no other paper till date that has considered these four layer together. The main objective of this protocol is to consume less energy, to make adaptive decision and local congestion avoidance and to provide reliable communications. The authors have proposed a novel technique in which they have introduced a new concept of initiative determination. A node initiates transmission by broadcasting an RTS packet to indicate its neighbor that has a packet to send. Upon receiving an RTS packet, each neighbor of node ‘i’ decides whether it has to participate in communication or not. This decision is given through an initiative determination. This techniques has advantage that those node that has packet to transmit only need to participate in the whole process.

In [52] authors have designed CL-MAC cross layer protocol that is used to wake-up nodes only that belongs to a routing path from the source to the base node or sink node by using the routing information. The other nodes can remain in sleep mode as long possible. The proposed protocol uses the same concept as MAC-CROSS. But the difference between CL-MAC and MAC-CROSS is that level of the number of consecutive nodes that are implied in MAC functioning at each frame is different. Indeed, MAC-CROSS acts on three consecutive nodes while CL-MAC uses all the nodes included in a given routing path from the sink in one frame. In [53] author addresses the challenges of sensor network engineering by proposing an efficient and secure synchronization protocol. This protocol conserves energy by passive participation. It allows a node to infer the canonical time by simply overhearing the communication of its neighbors. It also authenticates protocol messages and uses cross layer control to manipulate counters in an encryption module to prevent attacks. This cross-layer control has the added benefit of conserving program memory, since shared functionality need only be implemented once.

In [54] authors discuss about a coordinated sleep group energy consumption model, and analytically investigated the effect of sleep on sensor networks using three MAC protocols. In [55] authors have worked on physical, data link, and the network layer and developed a MAC routing protocol for cross layer interactions. They have used energy consumption model for transmission and reception of MAC frames originally presented in [54]. And with that they have proved the impact of regular sleep periods on the node energy consumption and present a
comparative study on it. But it should be noted that regular coordinated sleeping extends the lifetime of sensor nodes, but the systems can only benefit from sleeping in terms of transmitted packets if the data arrival rate to the system is low. They came to the results that single hop communications has up to 40% lower energy consumption than multi hop forwarding within the feasible transmission distances of an ISM radio. It can also be concluded that although it has been a ideal scenario that multi hop communication performs better than single hop communication, but for this the selection of energy model is also important, and MAC protocol design also have a significant impact on this. As in the above paper the author in [56] has discussed optimal transmittable packet sizes with respect to energy efficiency over single hop. An energy consumption model has been presented and optimal packet payload sizes for various channel bit error rates and coding scheme has been determined.

A new generation of MAC protocols that is Cross layer MAC protocols using several layers in order to optimize energy consumption has been emerged. These layers can be divided into interaction mode. In the interaction mode, the MAC protocols are built by exploiting the data generated by other adjacent layers. MAC-CROSS Protocol [57] is an example of Cross layer approach which allows the interaction between MAC and information of the network layers by making only the communicating nodes in listening mode and by putting other nodes into sleep mode. In order to avoid collisions, MAC-CROSS uses the control messages RTS/CTS/ACK. Those node that wants to transmit packet sends a RTS request and when it receive CTS signal it can send its data and wait for the acknowledgement(ACK). The chance of packet loss is less in this scheme. On the other hand, a Cross-layer design mode by unification requires the development of only one layer including at the same time functionalities of considered layers

In [58] authors have developed novel cross layer efficient protocol which takes into consideration physical, MAC and Network layer. The physical layer coordinated the transmission power node and then maintains this record in the neighbor table periodically to save the transmission energy. Neighbor table changes as information changes. And with the help of this information optimal routing tables is constructed. And lastly MAC layer uses the routing information to determine the node duty cycle in order to prolong node sleep time. In paper [59] authors have proposed MERLIN (MAC and efficient routing integrated with support for localization), a cross layer protocol that integrates both MAC and routing features. This protocol employs multicast upstream and multicast downstream approach to relaying packets to and from the gateway. Reception and transmission errors are notified by asynchronous burst ACK and negative ACK message. Results show that MERLIN is an integrated approach, which reduces latency and increase in network lifetime. Where in paper [23] Jaehyunkim et al. propose ECLP protocol that utilizes a synchronous medium access control scheme by using the adaptive duty cycling technique with the adaptive time-out and RRTS(reservation Request-to-Send) to improve energy efficiency and solve end-to-end delay problem by reducing idle listening and overhearing. Moreover, tree based energy aware routing algorithm is developed to maximize the network lifetime but minimize the control overhead requires for data delivery.

In [60] Hui Wang et.al have discussed about maximizing network lifetime of a multiple-source and single sink (MSSS). The optimization problem is formulated as a mixed integer convex optimization problem with adoption of time division multiple access in MAC layer. The main contribution of this paper is that it provides a tighter analytical upper bounds to the optimal network lifetime for liner MSSS networks and planar single source single sink networks in wireless sensor networks.

Powercontrol is one of the most used techniques for minimizing energy consumption at the physical layer, which aims to reduce the transmission power as much as possible while obtain a given data rate and error probability; refer to [61] for an overview on the power control technique for WSNs. Iterative power control algorithms have been proposed in [62]. The above mentioned work on power
control is focused on finding minimal transmission power to get expected data rate over the wireless channel. Moreover, as in [63], cooperation among all sensors may be required for power control in order to prevent that every sensor tries to optimize its SINR value without consideration that the NL can be considerably reduced, e.g., caused by the network congestion and possible overuse of some sensors. In [64], a framework is proposed for cross-layer design to minimize the transmission power in which power control is considered in the multiple access algorithms. [64] also identified the major sources that waste energy at the MAC layer, including collision, overhearing, and control overhead and idle listening. TDMA is used for multiple access in [64]. Cross-layer design on routing and power control is also studied in the literature [65, 66, 67]. Joint optimization of routing and power control is a combinatorial problem for energy constrained WSNs, because the level of transmission power over a link is affected by the transmission distance and the amount of allocated traffic over the link, both depending on the choice of the next hop node. Most of the existing research on cross-layer design over routing and power control only considers minimum energy routing. However, some sensor nodes are more likely to run out of energy more quickly than others with minimum energy routing, if the sensor nodes are in the intersections of many source-destination pairs. Therefore, the solution obtained by [65] is suboptimal in terms of NL for WSNs. Approaches to resolve the above routing problems are represented in [66] [67]. In [66], routing problem for maximizing NL is formulated as a linear programming (LP), and a heuristic method is proposed to achieve a better NL than that obtained in [65]. And distributed iterative algorithms are proposed in [67] to address the routing problem. Cross-layer design on routing, link scheduling and power control has been studied in [68] [69]. In [68], an algorithm has been proposed for link scheduling and power control in order to minimize the total average energy consumption in multi-hop WSNs. Based on the algorithm, a routing strategy is designed with application of sensitivity interpretation of the Lagrangemultipliers. In [69], the NLM problem is studied under the constraints of physical, MAC and routing layers. The NLM optimization problem is formulated as a mixed integer-convex programming with TDMA used in the network and is relaxed to a convex programming, which is solved by interior point methods. The main task is to find an iterative algorithm to obtain the optimal transmission schemes to NLM but it only computes the rates and powers for given link schedule during each iteration. From all the above conclusions, we come to the conclusion that energy harvesting, topology control, power management and cross-layering can be regarded as building blocks to design energy efficient networking protocols.

ENERGY SAVING BY ALGORITHMIC APPROACH

Data Compression: In this section, we discuss about energy saving by algorithmic approach like different scheduling techniques, data compression techniques, various routing algorithms. In paper [70] authors have talked about energy consumption tradeoffs associated with data compression, particularly in the context of lossless compression for acoustic signals. And by applying such data compression techniques in wireless sensor networks helps in Data Compression is the way by which raw data shrinks to smaller volume of data. It is very beneficial for the data communication as less data requires less time and less energy for both the transmission and reception. There are various compression techniques. It has not been discussed here but the details can be found in [71-74].

Awake/Sleep Approach: Now let us look at awake and sleep periods in wireless sensor networks as we know that large amount of energy is consumed by node components (CPU, radio, etc) even if they are in idle state. The power consumed when the radio is idle (i.e. it is neither receiving nor transmitting data) is approximately the same as in the transmit/receive mode. So energy or power management schemes are thus used for switching off node components that are not temporarily needed. Node components and specifically the radio subsystem should be put in to sleep mode.
Whenever possible. But it should always be kept in mind that system can benefit from sleeping if the data arrival rate is low. The authors of paper [75] have considered Physical and the MAC layer. Here cross layering is used for forward error correction coding and for the determination of the awake/sleep periods for narrowband wireless sensor networks. Their main goal is to minimize the energy consumption at each node’s transceiver and for this a cross layer design at physical and MAC layer has been used. (Spatial-temporal) ST-MAC protocol has been used to provide an implicit routing path towards the sink by properly sequencing the periods. As in the above the authors of [76] describes that the smaller the number of retransmissions needed, the sooner a node can go to sleep. And in the noisy channel, increasing the amount of coding will usually require more energy for the transmission of each message but the number of retransmission at the MAC layer decreases. If the amount of coding is less the energy used to transmit message is less. In noisy channel with less coding the number of retransmissions most likely increase resulting in longer awake periods, i.e., increased energy consumption. But this sleep/awake synchronization should be very nice to have a better result; if synchronization is not good it will perform very drastic result. Good synchronization is must for better result. And in this way coding at physical layer will directly effect in MAC energy performance. For this the level of coding must be very well defined so that the message can be successfully and energy efficiently transmitted and received during the awake periods. The MAC layer can affect the level of coding needed at the physical layer, because the MAC layer controls the number of users contending for the channel, which is directly related to the multi-user interference. The schedule of awake/sleep periods has an effect on the level of multi-user interference at the physical layer. And this type of scheduling requires some degree of synchronization among the participating nodes. If the schedule is not properly designed multi-user interference will increase.

**Clustering Approach:** Wireless sensor networks are more flexible in terms of ease of deployment and multiple functionalities. This is because of compact physical dimension which permits a large number of sensor nodes to be randomly deployed in inaccessible terrains. Now if we talk about clustering, the concept of clustering becomes more important because clustering sensors into groups, so that the sensors communicate information only to cluster heads and then the cluster-heads communicate the aggregated information to the base station, saves energy and thus help to increase the lifetime of wireless sensor networks. In most of the applications of wireless sensor networks the sensor needs to detect event and then communicate information only to cluster heads which can be studied from [77, 78, 79, 80, 81]. But these papers do not consider cross layer design. In paper [82] authors have discussed about clustering with cross layering for energy saving. An energy efficient technique is proposed keeping in mind a typical application including a sink, whose job is to trigger the wireless sensor networks and the nodes uniformly distributed over a specified area. The paper also discusses the selection of MAC protocols for sensor networks and a complete model characterization spanning from the network layer to the propagation channel. Routing is based on the clustered self organizing as in the above paper the authors of paper [83] talk about cross layer interaction between MAC and networks layers. In this case the MAC layer provides the network layer with the information pertaining to successful reception of packets and in turn network layer chooses the route that minimizes the error probability. With the same concept of clustering in paper [84] a cluster design method that allows the evaluation of the optimum numbers of cluster to realize power saving and coverage is developed and for this a dynamical adjusting protocol has been used in this paper.

Now we shall discuss about LEACH (low adaptive clustering hierarchy) protocol [85, 86] that provides a good relation in terms of energy efficiency for wireless sensor networks. In LEACH, a time division multiple access (TDMA) schedule is defined by the Cluster head to ensure that no collision among data occurs. But for this type of centralized control proposal
at cluster head requires that there is suitable transmission for control packets which makes the protocol more complex and this overhead creates energy efficiency. With the same concept of LEACH in paper [87] a new routing strategy, denoted as LEACH B, has been proposed by the authors and it also shows performance improvement in terms of networks lifetime in large range of concepts. The only difference between LEACH and LEACH B is that LEACH includes a distributed cluster information technique, which helps in self-organization of large number of nodes with one node per cluster acting as cluster head (CH), and the algorithms for adapting cluster and rotating cluster head (CH) roles to evenly distribute the energy load among all the nodes, and in LEACH B nodes forward their data to the sink through the cluster head according to a two hop strategy.

In paper [88] SMACS (self-organizing medium access control for sensor networks) protocol has been proposed which is self-organizing protocol for wireless sensor networks. In this case every wireless sensor nodes maintains TDMA frame in which node schedule different time slots. With this information the node communicates with its neighbors. While a bit different approach has been used in [89], where above coordination is used which avoid packet collisions. Here S-MAC protocol is used which sets the radio in sleeping mode during transmission of other nodes. The contention mechanism is the same as in IEEE 802.11 using request-to-send (RTS) and clear-to-send (CTS) packets. In paper [90] collision-prone MAC technique, (CSMA) carrier-sensing multiple access has been used. The biggest advantage of using CSMA is that no extra signaling is required to schedule transmission and coordinate to data flow, but disadvantage is that in such cases collision may occur and for that some back off algorithms must be used. Back off algorithms are used to cope up when collision occurs. Also authors have concluded that if collision is reduced to suitable dimension the average cluster size, this will helps in increasing the high energy efficiency. A relevant energy waste in CSMA protocols is owed to idle listening that occurs when the node is sensing the channel to check whether packets are sent. To avoid this energy loss, an ON/OFF modality which consists in turning off and on periodically radio components can be implemented as usual in wireless sensor networks.

Energy Efficient Routing and Scheduling: Power is very important factor for wireless sensor networks, because once lost it is difficult to charge or replace these batteries. In paper [91] an energy efficient routing algorithm which considers physical, network and MAC layer has been proposed. The result in this paper shows that collision of propagation is alleviated and power consumption in their routing decision decreased. Cross layering has improved network performance. The physical channel condition which is distributed in the sensor nodes is transmitted from physical layer up to network layer. The parameters such as power and data rate were transmitted from network layer down to the physical layer. Then this information is used as metric. By doing this the goal in this paper is to optimize the parameters of the lower layers on which routing is performed and given to the routing algorithms the means to control the interface setting. As we all know that routing algorithm two are of types: proactive and reacting routing. In this paper author had used the approach of reacting algorithm. The algorithm consists of three phases: route discovery, route maintenance and route reestablishment. Recent works in [92,93] reveal that cross layer interaction and design techniques result in significant improvement in terms of energy conservation due to three main reasons. First, the energy, storage, and processing capabilities of wireless sensor nodes necessitate such an approach. The significant overhead of layered protocols results in high inefficiency. Moreover, recent studies necessitate that the properties of low power radio transceivers and the wireless channel conditions be considered in protocol design [93, 94]. Finally, the event-centric paradigm of WSNs requires application aware communication protocols. Considering the scarce energy and processing resources of WSNs, joint optimization and design of networking layers are needed; that is cross layer design stands on the most promising alternative to inefficient traditional layered protocol architectures. Power control is a difficult
problem in wireless sensor networks. To minimize the total average transmission power it is necessary to minimize the average data rate per link, as well as the peak transmission power constraints per node, has been investigated by authors in [95]. The problem of maximizing the network lifetime of WSN also has been tackled by investigating joint resource allocation at the physical, MAC, and routing layers [96]. The joint optimal power control, scheduling, and routing problem is also formulated for time hopping ultra-wideband networks with the objective of maximizing log utility of low rates subject to power constraints nodes [97]. This problem can be solved using centralized algorithm. In [60] author instead of traditional concept for routing they discusses a different routing strategy. They use the concept of maximum distance intermediate node for routing. The benefit of this algorithm is that it reduces control overhead. In the same way authors in [98, 99] also uses the intermediate node concept for routing, and they have also applied scheme for retransmission.

Several scheduling algorithms have been proposed in [100] to minimize the energy consumption by efficient spatial reuse and therefore increase the lifetimes of the sensors. The energy-efficient transmission scheduling problem with constraints on packet deadline and finite buffer size in [100] is reduced to a convex optimization problem and solved to obtain an optimal scheduling scheme by an iterative algorithm. Similar to the power control technique used at the physical layer, the scheduling scheme design alone at MAC is unable to maximize NL for WSNs.

**PURE CROSS LAYER APPROACH**

Energy Conservation based on pure cross layer approach are based on the energy conservation scheme, by exploiting information at different layers of network stack. Recent works in paper [101] talks about improvement in network performance and by this efficiency is improved. Many researchers in their research work have talked about cross layer optimization and this is not a new concept, but it can be applied to other various wireless technologies. This cross layer optimization engine (CLOE) software will reside in every wireless device. The working of CLOE is divided into two major modules: measuring module and decision making module. At the measuring module information is gathered from environment and that information is used by the decision making module. This decision making module consists of various algorithms and utility module. The measurement is stored and updated when new information arrives. Examples of other context-aware application and systems are discussed in references [102, 103, 104, and 105]. Paper [106] discuss about the functional requirement for designing a context-aware system. This requirement includes many things like storage, management, subscription, delivery, and analysis of the stored context. In the work of paper [107] the authors have taken the assumption that due to limited battery power sensors nodes can only transmit a finite number of bits. Also they have assumed that the information that is gathered by the sensor node becomes irrelevant after a finite amount of time. Hence all the bits or the information that is collected by the node should be send to the base station within the declared deadline. Therefore the system that should be designed should consider joint design across all the layers.

A good example, in paper [108] authors have proposed a joint design optimization across physical layer, link layer, MAC, and routing layer. Point-to-point link is chosen to minimize the total energy consumption for transmitting a given number of bits. And this is achieved by considering circuit processing energy and transmission energy. For MQAM (multiple quadrature amplitude modulation) and MFSK (multiple frequency shift keying) transmission energy is dependent on transmission time and the product of transmission bandwidth. So if total energy is to minimized then the transmission time should be minimized. Without minimizing the transmission energy it seem difficult to minimize the energy consumption. For MFSK systems, coding can only reduce energy consumptions where the transmission distance is large. And for MQAM systems coding increases energy efficiency and this can be improved by increasing the transmission distance. The above observation is shown for trellis-coded narrow-band MQAM systems. In addition in paper [109] a multiple access scenario is developed where multiple sensor nodes are sending data to a
central node or base node. A variable Time Division Multiple Access (TDMA) scheme is jointly designed by considering the link layer and MAC layer to minimize the total energy consumption. In addition in [110, 111] analysis of delay performance of transmission using variable length-TDMA. For this purpose a link scheduling algorithm is designed to find the minimum delay. The result of this is combined to the result of the previous work on energy-optimal cross layer design to minimize the delay in transferring a fixed number of bits from the source nodes to the sink, in an energy constrained manner. The tradeoff between total energy consumption and delay is studied. As in the above paper in the paper [112] joint optimal routing with consideration of Mac layer and link layer where non-orthogonal MAC schemes are used such that interference between different transmissions links becomes a performance-limiting factor. In paper [113] authors have shown that cross layer approach can be extended horizontally to allow the cooperation among multiple nodes. Virtual MIMO systems are constructed via node cooperation on receiving side and transmitting side. And the result shows that energy saving and delay can be achieved by this with a specified range by deploying such cooperative MIMO systems. In paper [114] source coding and channel coding both are considered jointly. Authors have considered problems of optimal power scheduling for decentralized estimation of a noise-corrupted signal in an inhomogeneous sensor networks. Based on the observation on sensor noise levels and channel gains from sensor to the fusion center, optimal quantization levels and transmit power levels at local sensors can be chosen to minimize the total transmit power, while ensuring a given Mean Squared Error(MSE) performance. This joint optimal power scheme gives result that sensors with bad channels or poor observation qualities should decrease their quantization resolutions or it should become inactive to conserve energy. For the remaining active sensors, their optimal quantization and transmit power levels are determined jointly by individual channel gains, local observation noise variance, and the targeted MSE performance.

Recent works in paper [115] proposes a TDMA based scheduling that balances energy saving and end-to-end delay both. And this balance is achieved by a good scheduling of wakeup and sleep schedules. And this scheduling allows data packets to be delayed by only one sleep interval for the end-to-end transmission from the sensors to the gateways. And by this approach reduction of the end-to-end delay caused by the sleep mode operation and energy savings is achieved. In paper [116] a probabilistic model is defined that allows the evaluation of packet loss probability and this helps to reduce the radio activity save energy consumption. In this probabilistic model cost model can also be defined that calculated the energy consumption of the proposed three schemes. This probabilistic model is designed on the basis of possible communication delays. They estimate the packet arrival intervals at any intermediate hop of a fixed rate data path. In paper [117] authors focuses on sensor networks in which sensors have periodically send their report to the base node or the sink node. The concentration is on the exploiting the temporal correlation of physical quantities which will help to reduce the amount of time a node consume to turn their wireless interface on. The readings that are collected from the environment help each sensor node computes model for future reading. Then this model is send to the nodes that are responsible for storing models. Then this node generates reports and then this report is send to the base node. The sink node then sends new queries directly to the same node responsible for storing models. In this case sensor nodes should periodically poll this node to check for possible new queries. The polling period is dependent on the maximum delay the application is willing to tolerate. In paper [118] power management scheme is proposed that helps to turn off the wireless transceiver of sensor nodes when they are not in use. For this purpose a TDMA MAC protocol is used in the paper, and this protocol defines the TDMA schedules based in the application demands. But of this applications should periodically report to the sink node. The definition of sleep/wakeup patterns is the goal of [119] paper. It is different from standard approaches, in which a node is bound to follow well defined schedule. In this paper nodes can dynamically decide to join different available schedules based on the expected delay towards the destination. Essentially, when a node has to send or forward
In this case, the energy manager exploits topological information in order to decide when to turn the wireless interface on and off. In paper [120] novel cross layer design is proposed for improving energy efficiency in wireless sensor networks that utilizes a multi-channel non-persistent CSMA MAC Protocol with adaptive MQAM modulation at the physical layer. The optimization results show a significant improvement in the per-bit energy requirement. Cross layer interactions is obtained through joint, traffic-dependent adaptation of the back off probability at the MAC layer and the modulation order at physical layer. In paper [121] authors have discussed about the trade-off in maximizing the network lifetime and the application performance. For that a optimal set of source rates, network flows and radio resources at the transport, at the transport, network and radio resource layers respectively, while jointly maximizing the network utility and lifetime. Using dual decomposition authors have decomposed the problems into three sub problems – a joint transport and routing problem, a radio resource allocation problem, network lifetime maximization problem, all of which interact through the dual prices for capacities of links and battery capacities of nodes. Cross layer design of transport, network, and radio resource layers for maximizing the throughput or network utility of ad hoc wireless networks has been studied in [122], [123]. Using the dual decomposition techniques, [122] and [123] show that the cross layer design problems decompose vertically into sub problems that interact through link congestion process. In paper [124] a cross layer detection and allocation (CL-DNA) scheme to solve hidden device problem in IEEE 802.15.4 without the extra cost of overhead involved in data transmissions. Simulation result shows that proposed scheme improves the reduction in power consumption.

In paper [125] mainly focuses on the research for making wireless sensor networks energy efficient, various cross-layer protocols and their enhanced versions have been introduced. That approach is Orthogonal Modulation approach. In [126] discuss that as everything is possible with the help of internet. In this paper, dynamically adapted sleep scheduling mechanism is used with residual energy of each node. Virtual end-to-end packet rate selection and congestion control feedback mechanism are considered for end to end delay. This reduces the packet loss with the support of data-rate adaptation. In [127] authors have discussed about different cross layer design approach in WSN and also have highlighted challenges faced implementing Cross layer design in WSN.

**CONCLUSION**

We have surveyed the main techniques to energy saving issue with cross layering approach. We have summarized and compared different proposed designs, algorithms, protocols, and services. Cross-layer designs improve performance and optimize interaction between layers. Cross-layer design considers the sharing of information across layers. For instance, aMAC protocol shares topology information with the network protocol to assist in route setup and maintenance. Such information can be shared directly between the two protocols. Proposed cross-layer designs have focused on the physical, data-link, network, and transport layers. Future research in cross-layer design can focus on collaboration between all the layers to achieve higher energy saving, network performance, and extend network lifetime. The other interesting topic for future research is combination of lower layers to upper layers. In conclusion we believe that cross layering is the best way to implement energy efficient networking scheme in wireless sensor networks. Advances of cross layering are large. Energy saving with cross layering has become an active research area. It is strongly driven by many promising application such as military application etc. It is exciting to see many researchers gradually spreading their achievement into more intelligent practical applications. There are many challenges in all these approaches. We are persuaded that this class of approaches will get an even greater importance and attention within the research community in the next years.
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