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Extending Lifespan of Industrial Wireless Sensor Networks using Cross-layer Approach

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Abstract— Enabling a reliable networking performance with an extended lifespan is a stimulating endeavor in industrial wireless sensor networks (IWSN) to achieve long-term surveillance of safety-critical applications and react rapidly to measures that are observed; hence, reduced network lifespan jeopardizes the workforces and assets at industrial sites. Due to network lifespan and other enactment metrics involved in various layers, it is very hard to enhance those parameters from a particular single layer. In this work, a cross-layer approach is developed for IWSNs in which different layers including the physical (PHY) layer, medium access control (MAC) layer, and network (NET) layer are used to realize cooperative communication among them. The proposed approach achieves better network performance and prolonged network lifespan than a conventional layered architecture. Firstly, the energy information and bit error rate are obtained from the PHY layer. According to this data, the MAC layer aids to differentiate the status between congestion and link failure. Eventually, this state information is transferred to the NET layer to appraise its routing metrics. Extensive simulation results demonstrate that the proposed approach significantly decreases the routing costs during the route failure and reduces the energy consumption which leads to the maximization of the lifetime of the network.

Keywords—cross-layer design; energy consumption; industrial WSN; network lifespan; routing cost;

I. INTRODUCTION

The inexorable improvements in Internet-of-Things (IoT) technology enable industrialists to exploit sensor-fortified maneuvers to gather data at low cost and deliver a new model for resolving the multifaceted sensing problems to fulfill the radically increased demands of industrial applications including monitoring systems [1,2], programmed vehicles in eco-friendly transportation [3]smart traffic control [4], and numerous safety-critical systems. A system is considered as safety-critical whose failure might cause loss of human life or severe harm to individuals, property, and the environment [5]. An industrial wireless sensor network (IWSN) usually consists of a few to thousands of nodes, each of which is fortified with sensing elements, a processor, a short-range wireless transceiver, and a power unit. Sensor elements observe the nearby surrounding and transmit the sensed data to an access point, which gathers and sends this information to a control hub.

With the proliferation of sensor technology and wireless portable devices, the exploitation of wireless sensors in the industrial sector becomes the center of attraction [6]. The sensors used in IWSN do not need physical links to be installed at any moment and have simple necessities for difficult applications. They are small in size and easy to implement and has influential tasks that can be employed to sense and observe various invisible and visible parameters in close range with maximum accuracy; and its practicality makes it require comprehensive application scenarios in numerous meadows of manufacturing industries [7], particularly with the development of cloud computing [8] and fog computing [9], to help its growth experiences better prospects.

IWSN also experiences related issues as in wireless sensor networks (WSN), and due to the diverse application scenarios, there is some dissimilarity between WSNs and IWSNs [6]. Primarily, maximum energy competence is immediately needed for IWSNs. In industrial sites, sensing nodes are energized by a power supply unit; hence, the battery power is limited [10]. On the other hand, the sensing nodes are employed in diverse production workshops and industrial equipment. These workshops and equipment are not intended to in place these sensing nodes; therefore, the sensors can only be required to acclimate to the manufacturing scenario. Consequently, it is mandatory to be tiny than other applications to acclimatize to industrial production. However, decreasing the dimension of the sensing nodes implies that the size of the power supply unit also shrinks [11], and it defines the available energy in the power supply unit; hence, in IWSNs, it is significant to develop a more energy-efficient system. Similar to WSNs, the data transmission process in industrial sensor networks consume the major part of the battery power [12]. Therefore, the key to decreasing energy depletion and improving network lifespan is how to enable effective transmission [13].

In IWSNs, sensing elements can transmit apparent information to a control center in a single-hop fashion and can also exploit the multi-hop forwarding method to the hub [14]. Consequently, how to minimize the energy consumption related to the routing process is crucial for increasing lifespan [15]. IWSNs not only demand superior energy competence but also have distinctive requirements for network enactment [16]. Since IWSNs are mostly employed in safety-critical applications of industrial automation, there are numerous monitoring practices in high-pressure and high-temperature scenarios, and the control practices need very precise monitoring processes, and transmitting control parameters entails that time interval is less than industrial milliseconds, viz., the insight of data to the hub and the feedback signal to the controller kit latency is extremely rigorous.

Because of the higher latency which may cause severe catastrophes in safety-related applications [5, 17], such as monitoring of furnace metallurgy and boiler temperature, if the control is not real-time, may result in a blast of the boiler, the quality of manufactured goods does not satisfy the constraints and lead to waste. It disturbs manufacturing plan, trashes manufacturing material, abolishes manufacturing apparatus, and extremely affects human lives. Therefore, on top of energy proficiency, in IWSNs, the measures like network lifespan and latency are known as quality of services (QoS) which are significant for IWSNs.

Network lifespan (NL) sturdily hinges on the life expectancy of each sensing element that establishes the network. This parameter does not rely on in what way the NL is measured. Every description can be summarized to the problem of at what time each sensor fails. Hence, if the lifespan of a sensing node is not estimated correctly, the measured NL may diverge in an irrepressible way. The lifespan of a sensing site mostly hinges on two major aspects: (i) how much energy is available for its usage; and (ii) how much energy it ingests over time. As state by Akyildiz et al., maximum energy is expended by a sensing element for detecting, transmission, and manipulation operations [18]. Hence, it is clear that the reliable and accurate modeling of each sensor is extremely imperative.

In this work, we are motivated to develop a cross-layer approach (CLA) in an IWSN. More precisely, we explore the NL maximization by cooperative design for finding energy information and bit error rate at the PHY layer, classifying congestion and link failure at the MAC layer, and controlling data flow at the network layer. The systematic organization of the manuscript is given as follows: In Section II, we summarize the previous research works on cross-layer design to maximize network lifespan. In Section III, we discuss our proposed CLA in detail. In Section IV, we describe the implementation details of our work. Section V describes the experimental results. Finally, we conclude our paper in Section VI.

II. RELATED WORK

Extending network lifespan using CLA provides innumerable benefits than traditional layered approaches. CLA is a method for reducing energy ingesting at the PHY layer, which reduces the energy consumption during data transmission while achieving the required probability of error and data rate. There is always a tradeoff between limited battery power and long lifespan, which forms a research gap between supply source and energy consumption in IWSNs. Ranjan and Varma proposed a CLA optimization with an integrated parametric framework [19]. The authors provide a comprehensive review of different CLAs and the network improvements realized by different cross-layer techniques. The authors classified the prevailing CLAs into three different approaches as traditional methods, complex design methods, and integrated design methods. They also developed an integrated parametric framework to achieve reduced energy ingesting, local congestion avoidance, and adaptive communication decisions. In order to enhance the link quality metrics, they proposed to exploit a variety of modulation techniques. The coverage region is segmented into 4 equal zones with a sink node at the center. This zone is again sectioned into concentric circles. The optimal hop distance is measured based on the modulation technique used. TDMA-based collision avoidance technique is implemented to avoid potential packet collision.

Kozat et al. proposed an energy-efficient CLA-based model for multi-hop wireless networks. The authors explore an integrated link scheduling algorithm that considered QoS and bit error rate (BER) [20]. Afsara and Younis developed a new CLA with energy scavenging and transfer capabilities (CREST) is designed to resolve the hot-spot issue in WSNs [21]. In order to achieve balanced traffic in the network, uneven clusters are formed. The coverage region of the access point is divided into unequal tracks. Every sensing device is having energy harvesting capability. From each track, a cluster head is selected using the degree of the node. The presented approach is related to two standard approaches, eCotrans and sLEACH. The numerical results demonstrate that network throughput has improved by 10% using dynamic clustering and uneven tracking. Boyd and Vandenberge proposed a CLA-based optimization design to optimize lifetime [22].

Kader et al. introduced an energy-efficient and modified CLA to send hypermedia products over WSN [23]. The proposed method comprises a MPEG-4 video encoder, data queue, and a link scheduling technique. The CLA integrates physical, data link, and application layers. A low-energy self-organizing protocol (LESOP) is implemented where both MAC and application layers are utilized. This approach designs a connectionless protocol in which adaptive priority queuing and path scheduling mechanisms are used. The received hypermedia data are classified into high and low priority packets. An adaptive multi-path routing approach is presented which conserves energy and improves the lifespan of the network.

There are innumerable works proposed to evaluate the effectiveness of IWSNs to maximize network lifespan. On the other hand, there are several important concerns in these works that demand an additional investigation. The majority of the research works found in the literature focused on a single layer, hence there is a restriction for ideal performance. For example, NET layer optimization (e.g., choosing the suitable forwarding hosts to make the energy ingesting balanced), MAC layer optimization (e.g., analysis of the competition window, duty cycle (DC), adaptation of slot frame structure, etc.). Apparently, if IWSN is optimized from more than one layer, the quality of service can be improved considerably. Even though decreasing the energy ingesting of sensors is an optimization objective, this is not the decisive objective. The key objective is to improve NL instead of decreasing energy ingestion. While several techniques are developed to decrease energy ingestion, some works have been optimized from the overall interpretation of the communication system. In a network, the sensor placed nearer the control hub is required to transfer information that is from the sensor away from the hub, so its energy consumption is higher than that of the other sensors. Hence, even though the sensor adjacent to the hub has minimum energy ingesting, the sensor away from the hub has the remaining energy. Therefore, in this case, the energy consumption of the sensor away from the hub is augmented, so that the bit error rate of the communication is decreased and the communication latencies are decreased. Therefore, the communication latency is reduced, and the entire system enactment is optimized.

III. PROPOSED SYSTEM

In this paper, a method to implement cross-layer design across PHY, MAC layer, and the NET layer is developed which achieves greater energy efficiency than a conventional layered architecture. The BER and energy information are obtained from the PHY layer. According to this data, the MAC layer facilitates the differentiation of the status between congestion and link failure. Finally, this state information is transferred to the NET layer and will help appraise its routing metrics.

3.1 Problem Formulation

In IWSNs, the NL is measured as the interval between the time of beginning and the time instant when the network becomes inactive. Mostly, the lifespan of IWSN hinges on the nature of the application (e.g., object identification, temperature measurement, pressure measurement, etc.). In the IWSN environment, we can consider the network as inactive when the first sensing device expires, a fraction of sensing devices expire, the loss of reporting and the network partitions are realized. For an IWSN, the NL is defined as follows [24].

$$NL = \frac{E_i - E_w}{E_{pd}} \qquad (1)$$

where E_i represents initial energy, E_w is unused (wasted) energy, and E_{pd} is per day energy consumption of the network. The value of E_{pd} is measured by

$$E_{pd} = E_s + \rho . E_{exp} \qquad (2)$$

where E_s is the energy expended by all sensing nodes, ρ is data arrival rate, and E_{exp} is known as expected energy ingestion of nodes. The per-day energy depletion relies on the type of data traffic, the mean of energy depletion of sensing site in send, receive, sleep, and idle mode of operations.

3.2 Proposed cross-layer model

The proposed cross-layer approach will decrease the routing costs when the route failure occurs owing to congestion in the communication path and will conserve the energy which causes the maximization of the lifetime of the network. The energy depletion due to network elements and protocols is calculated using the energy model in the Netsim simulator [25]. The information acquired from the trace file shows that the consumption of MAC protocols is lower than that of PHY layer protocols.

3.2.1 Physical layer

The channel model for radio propagation among sensors is the standard log-distance path loss model with log-normal shadowing. The path loss exponent and shadowing standard deviation are assumed to be 2.91 dB and 4.58 dB, correspondingly. These estimates are suitable for non-line-of-sight transmission in a monitoring application. Small-scale fading will be quite small or even static owing to the stationary sensing elements in an industrial scenario. It has also been demonstrated that the coherence bandwidth of the medium is less than the frequency hopping range of the sensor nodes. Hence, it is expected that this frequency hopping is capable of reimburse for any small-scale deviations. Consequently, small scale fading is not considered in our work.

The PHY layer mode employed by the device is offset quadrature phase-shift keying (OQPSK) spread spectrum operating at 2.45 GHz. The signal has a 2 MHz bandwidth due to a chip rate of 2 Mchip/s and a bandwidth of 250 kB/s which implies that the spread spectrum gives a linear processing gain of 8. The power of the thermal noise deteriorating the signal is -110.8 dBm and the frame error probability is defined by $1-(1-\rho)\eta$ where η is the number of data and overhead bits in the frame and ρ is the bit error probability for OQPSK measured by the received signal to noise ratio. It is considered as the packet payload would not surpass 40 bytes since a data frame will usually carry only a single node data and a less cost employed by the application.

3.2.2 MAC layer

The MAC layer deploys the TDMA technique through superframe format which contains P timeslots of γ duration. The network model considered in our work utilizes a fixed value of $\gamma = 10ms$. On the other hand, the network model permits γ to be varied. The packets in this work involve 60 bytes of payload and 29 bytes of the additional cost. This provides an actual frame size of $\eta = 712\ bits$ which equals a frame length of 2.8 ms. Consequently, the minimum value of γ that can be employed in the proposed IWSN application 5.1 ms (i.e., 2.8 ms frame duration + 2.3 ms) as idle time at the

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beginning of a slot. The TDMA schedule during the superframe is defined by multiset schedule (Γ) where $|\Gamma| \leq P$ and the k^{th} coefficient of the set is the 2-tuple $\Gamma(l) = (n, m)$ which represents that sensors n and m are arranged to communicate in the k^{th} timeslot. Generally, a TDMA method may reclaim the timeslots to facilitate two sensors that may concurrently disseminate packets if they are separated by an adequate distance. On the other hand, due to the comparatively small communication region, we implement identical small network assumption where we do not permit timeslot reuse since most of the sensors are placed within range of each other and the advantage of exploiting timeslot reallocation would be extremely restricted.

3.2.3 Network layer

In our work, multi-hop routing is established by exploiting the source routing approach. In the routing method, each host creates and inserts a list to every packet it creates. This list comprises the addresses of all the hosts in the network along the multi-hop path to the sink node. The packet is transmitted by the source to the first address in its list. When a forwarding host accepts the packet, it stamps out its address from the list in the packet header and directs the packet to the subsequent hosts in the list. The address list introduced by host n into its packet header is signified by the ordered set O_n. The coefficients of O_n, $n \in [1, N]$ are measured cooperatively with the TDMA schedule by the central scheduler.

Source routing is an alternative to the graph routing method widely employed in IWSNs. It is prevalent since it increases the trustworthiness of the network by providing multiple paths to each node to transmit its packets. Conversely, our proposed method is implemented to determine an appropriate route that extends NL. Since these techniques propose distinctive solutions, each host will have only one optimal path for these packets. Hence, graph routing can be seen as improving reliability but it will constantly decrease NL since any other paths it provides to a host will be sub-optimal from an energy point of view.

IV. IMPLEMENTATION

4.1 Network Model

We consider an IWSN network with a group of 100 MICAz stationary sensors and a static sink where all sensed data (temperature/proximity/pressure level etc.) will be gathered and transmitted to the access point through a gateway node. Sensors are organized evenly using the Netsim simulator as given in Figure 1. All the sensors are positioned at a stable location in a topographical region. The nodes are deployed with the same initial energy, processing capacity, and highest coverage range. A distinctive identification number and an IP address are allocated to each host in the network.

The maximum bandwidth of the given IWSN is 250 kB/s. All the sensors carry out the sensing process at a rate based on the DC and the sensed data to be forwarded to the sink in each reporting epoch. The sensors employ a multi-hop routing method to transmit the sensed parameters to the nearby forwarding host. From each sensing host, there is at least one path (perhaps using other hosts) to the sink. The length of a path between a sensor and the sink is calculated as one plus the number of intermediary hosts on the route. In a reporting epoch, a sensing host requires to send not only the parameters observed in the vicinity but also all the data transferred from its parent hosts. Conversely, if a sensing host has more than one child host, the forwarding mechanism finds what percentage of the data to be sent to which relay node.

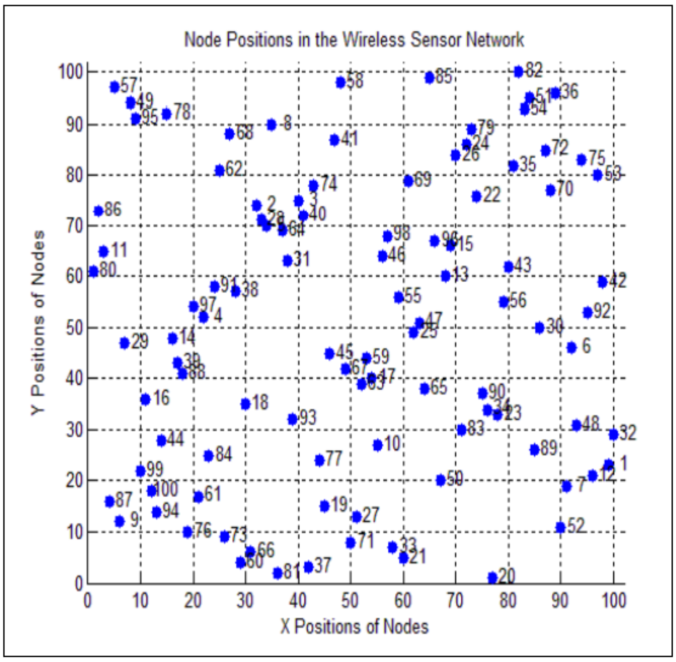

Figure 1: A hundred sensors are deployed for industrial monitoring scenario in the Netsim simulator.

4.2 Network lifetime calculation

The energy consumption of a MICAz sensor is calculated from the manufacturer specification sheets . The initial energy of one sensing element having alkaline 1.5 V, AA size battery, and capacity as 1000mAh can be measured as 1Ah×3600=3600J. Each sensing site contains dual batteries. Hence, the initial energy of each sensor with two batteries is 3600J×2=7200J. Then, the total network energy can be determined by the total number of sensors existing in the network (i.e. 100 nodes). Therefore, the initial network energy (E_i) of 100 sensing sites is 7200J×100 = 720KJ.

Consider that the battery state of charging (SoC) is zip when it is depleted to 60% of its rated energy. One sensor is having maximum energy of 7200J. The 60% of 7200J is measured as 4320J. Consequently, the sensor is considered as expired if its battery energy depletes less than 4320J. For the network with 100 sensing elements, its value is 4320J ×100 = 432KJ. Thus, the anticipated unused energy (E_w) when the network expires is 432KJ. Besides, if the remaining energy of one or more hosts reaches less than the minimum threshold value (i.e., 60%) then these sensing elements are considered as "inactive".

The "inactive sensors" do not partake in the communication activities and envisage their battery recharging. Then, the packets are forwarded through the closest neighboring sensors and network still to operate and continuously transmitting the packets to the gateway. When the battery SoC of inactive sensors reclaims its adequate values from the supply source (i.e. >70%), then they again become "active" and start contributing to the network immediately. Consequently, network lifespan becomes unlimited (preferably) and the network not ever expires totally. The determined values are given in Table 1.

Table 1: Network energy consumption

Parameter	Energy consumption of single node	Energy consumption of network with 100 nodes
Operating voltage	2.3–3.3 V	230–330 V
Wasted (unused) voltage	< 2.3 V	<230 V
Initial energy of sensing devices (E_i)	7200 J	720KJ
Residual (wasted) energy (E_w)	4320J	432KJ

Consider the average energy ingestion in each host is 30mW or 30mJ/s. For the network of 100 nodes, it becomes 30mW×100 = 3000mW or 3000mJ/s. When the sensor is activated for 1 day (86,400 seconds) then energy expended by the sensor for different DCs is measured as below.

In order to calculate the network lifespan for 1% DC, the sensor is energized for 864s out of 86,400s. Hence, the energy expended by one sensor for 1% DC is 30mJ/s×864s = 25.92J. For 100 sensors, we can estimate per day energy ingestion (E_{pd}) as 25.92J ×100 = 2592J. Then, the NL is measured as:

$$NL = \frac{E_i - E_w}{E_{pd}} = \frac{720000J - 432000J}{2592J} \approx 111\ days$$

Therefore, the NL at 1% DC is 111 days only. By exploiting a similar computation technique, the NL for different DCs (5%, 25%, 50%, 75%, and 100%) is computed and given in Table 2.

Table 2: Lifespan for various DCs

DC (%)	Energy ingestion (J)	NL (days)
1	2592	111
5	12960	22
25	64800	4.5
50	129600	2
75	194400	1.5
100	259200	1

The per-day energy depletion of the network for 1% DC is minimum (i.e., 2592J). Therefore, the value of NL is higher (i.e., 111 days). Conversely, if we continuously increase the DC, then energy depletion is also increased. As a final point, at 100% DC the energy depletion of the network is maximum (i.e., 259,200J) and therefore NL is minimum (i.e., 1day). Here, we proved that the lifespan (day) of the network is indirectly related to the daily network energy depletion (J). If per day energy depletion of the network is augmented then its NL drops and vice versa.

V. SIMULATION RESULTS

This section discusses the simulation results without embedding cross-layer approach and with cross-layer approach. To evaluate the effectiveness of our CLA, we have employed Netsim simulator software to simulate a real-world communication environment. It is used in networking research which offers significant support for modelling of nodes, communication protocols, and routing mechanisms, and so on.

5.1 Performance analysis of NETlayer

Table 3 shows the simulation results of the NET layer in terms of performance measures. From this table, it is found that all the measures enhance with embedding cross-layer approach in sensing devices. The number of packets transferred increases from 6,625,735 to 216,929,904. Consequently, the data rate improves 32.74 times greater with embedding the cross-layer approach in IWSNs. The number of data packets transferred upturns from 1,517,294 to 45,844,778. The performance increment in terms of the number of data packets transmitted is 30.21. Also, the number of control packets transferred upturns from 5,245,279 to 171,085,126. Hence, the total network throughput or data traffic (bits per second) also improved by 32.60 times using the cross-layer approach.

Table 3: Performance metrics of NET layer

Parameters	Without CLA	With CLA	Performance enhancement factor
Total number of bytes transmitted	6625735	216929904	32.74
Number of data bytes transmitted	1517294	45844778	30.21
Number of control bytes transmitted	5245279	171085126	32.60
Number of data packet collided	16580	103427	6.24
Number of control packet collided	21003	420931	20.04

The collision that occurred in data and control packets is also amplified 6.24 times and 20.04 times correspondingly. The packet collision provides an adverse effect on the sensor network and should be decreased. Another impending exploration in IWSNs can be "by what means to decrease this collision level?" Figure 2 depicts the performance of the NET layer in terms of common network parameters.

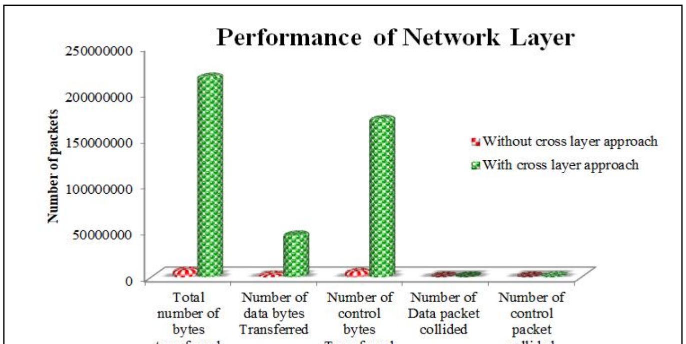

Figure 2: Performance of NET layer with and without using CLA

5.2 Performance of MAC Layer and PHY layer

In our experimental set-up, as given in Figure 1, it is perceived that there are 100 sensor devices with sensing equipment and a sink. In order to measure the performance of the complete network, we have aggregated the value of measures of all 100 sensing devices (i.e. entire network) as depicted in Table 4. Now, the enhancement in different MAC and PHY layer measures is also calculated. From Table 4, it is found that the number of packets transferred in the entire system without a cross-layer approach is 69,294 while with a cross-layer approach is 2,112,755. This reveals 30.49 times enhancements in data rate. In the same way, the number of packets received in the network without using a cross-layer approach is 64,892 while the cross-layer approach is 2,013,664. This shows 31.03 times enhancement in data rate.

Table 4: Performance metrics of MAC and PHY layer

Parameters	Without CLA	With CLA	Performance enhancement factor
Number of packets transferred	69294	2112755	30.49
Number of packets accepted	64892	2013664	31.03
Number of ACK transferred	57698	2002456	34.71
Number of ACK accepted	55987	1898283	33.91
Number of CCA attempts	290260	7636421	26.31
Number of successful CCA	212431	6787453	31.95

The acknowledgments (ACK) transferred and accepted by the neighboring sensing devices without using the cross-layer approach are 57,698 and 55,987 respectively. This parameter is increased by cross-layer approach as 2,002,456 and 1,898,283. This exhibits 34.71 and 33.91 enhancement in ACK transmitted and received respectively. The successful clear channel assignment (CCA) attempts without embedding cross layer approach is 290,260 and with cross layer approach is 7,636,421. This provides a 26.31 times improvements in the CCA Attempts. The number of successful CCAs without embedding the cross-layer approach is 212,431 and with the cross-layer approach is 6,787,453. This provides 31.95 times improvement in number of the successful CCAs. Figure 3 provides a pictorial depiction of numerical results of MAC and PHY layer measures.

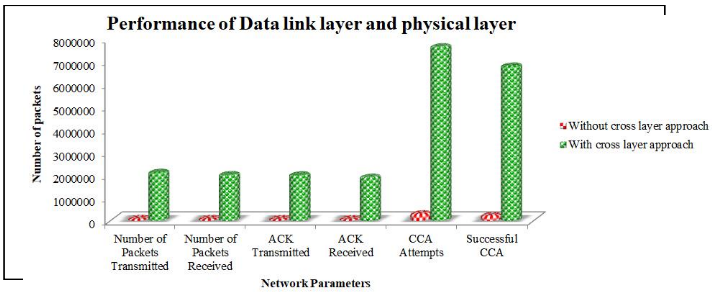

Figure 3: Performance of MAC and PHY layer with and without using CLA

5.3 Network energy consumption performance analysis

In Table 5, network energy consumption parameters 100 sensing elements are given. The energy consumption of all 100 nodes in the network during transmission mode without using the cross-layer approach is 244,093 mJ, but with using the cross-layer approach is 15,323 mJ. The energy consumption of all 100 nodes in the network during receiving mode without using the cross-layer approach is 213,889 mJ, but with using the cross-layer approach is 15,018 mJ. In both cases, the energy ingestion at sleep mode is 0 mJ. The energy ingestion in idle mode without using the cross-layer approach is 2,205,363 mJ and with using the cross-layer approach is 121,633 mJ.

Table 5: Network energy ingestion performance

Parameters	Without CLA	With CLA	Performance enhancement factor
Energy consumption during transmission mode (mJ)	244093	15323	15.93
Energy consumption during receiving mode (mJ)	213889	15018	14.24
Energy consumption during idle mode (mJ)	2205363	121633	18.13
Energy consumption during sleep mode (mJ)	0	0	0.00
Total energy consumption (mJ)	2663345	151974	17.53

Finally, we calculate the total energy consumption in all modes of operation without using the cross-layer approach is 2,663,345 mJ and with using the cross-layer approach is 151,974 mJ in the whole system. This numerical result demonstrates that the total energy expended by the network is decreased by 17.53 times using our CLA implementation. Figure 4 depicts a pictorial view of energy ingestion performance metrics results.

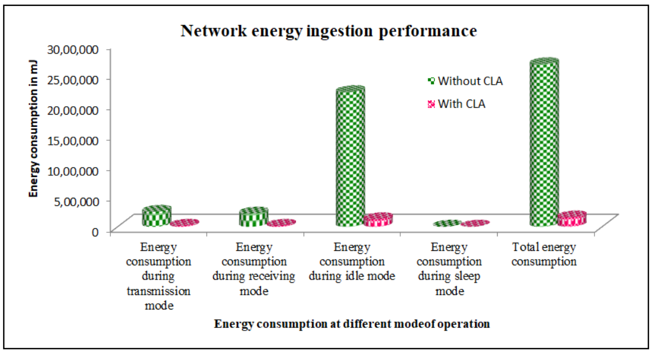

Figure 4: Network energy ingestion performance

VI. CONCLUSION

This work attempts to represent that conventional layered architecture can still be effective if CLA is carried out in it. In this work, a cross-layer approach is developed for IWSNs in which different layers including the physical (PHY) layer, medium access control (MAC) layer, and network (NET) layer are used to realize cooperative communication among them. The proposed approach achieves better energy efficiency and prolonged network lifespan than a conventional layered architecture. Firstly, the energy information and bit error rate are obtained from the PHY layer. According to this data, the MAC layer aids to differentiate the status between congestion and link failure. Eventually, this state information is transferred to the NET layer to appraise its routing metrics. Extensive simulation results demonstrate that the proposed approach significantly decreases the routing costs during the route failure and reduces the energy depletion which leads to the maximization of the lifetime of the network.

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