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Challenges and Implementation on Cross Layer Design for Wireless Sensor Networks

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Abstract Cross-layer design (CLD) has emerged as an important area in wireless sensor networks (WSNs). Cross-layer enables interaction between different non- adjacent layers and, thereby, exchanging information between layers, which, indeed is not possible in traditional architectures. CLD is used for enhancing the performance of the existing architectures by utilizing the flexible prospects of the protocol layers to improve system performance and to satisfy QoS demands of the applications. The CLD leads to increase in network efficiency and optimized network throughput. In this paper, the various cross-layer design methodologies for WSNs have been reviewed, which have basically been designed to enhance the network performance in WSN. At the end, the paper proposes a CLD based on ongoing research.

Keywords Cross layer design (CLD) survey · Wireless sensor networks · Architecture · Performance · Unified

1 Introduction

The Open Systems Interconnection (OSI) layered architecture is widely used in conventional communication architectures, which provides a networking framework to implement protocols in seven layers [1]. Each layer has definite functionalities of a communication system and allows interaction, or procedure calls, between adjacent layers, but it does not allow interaction between non-adjacent layers. However, with the application of wireless

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networks and other new technologies, that have come into picture in the past decade, the developers have to cope with new challenges [2] like narrow frequencies and channels for the transmission, fading, scattering and noisy channel state.

In the recent years, many research works have been presented for WSNs which are based on the interaction between various non-adjacent layers of the network stack, which is termed as CLD [3]. The main aim of CLDs was to improve system performance and to satisfy QoS demands of different applications. The CLD can lead to increase network efficiency and optimized network throughput in WSN, which motivates to introduce the approach to the WSN. The cross-layered approach in WSN is more useful, energy efficient, scalable and secure than with traditional approaches. Cross-layered approach reduces the transfer overhead by sharing the data among different layers; because the protocol stack is treated as a system and not independent layers as in the case of traditional approaches. The development of different cross- layered architectures, protocols and services helps in optimizing different parameters at different layers.

Although, many recent papers have concentrated on CLD approaches to improve protocol efficiency for WSNs, there is a lack of definite architectural view [4]. The good CLD will increase flexibility, interoperability and maintainability [2]. So, in this paper, we present a brief overview of the CLD approaches in WSN. Also, we will discuss about some issues related to CLD which still exists. The paper is organized as follows: In Sect. 2, we discuss some needs for CLD approach in WSN. Section 3 deals with different CLD approaches for WSN. In Sect. 4, we have endeavored to evaluate the different issues and challenges in developing CLD by taking the performance metrics into considerations. In Sect. 5, the proposed Unified model is discussed. The proposed CLD is implemented to increase the location accuracy in WSN. At the end, Appendix calculates the optimum hop distance for different modulation schemes.

2 Need of CLD Approach in WSN

The traditional layered approach follows strict layering principles and provides a platform for designing interoperable systems, but it suffers from more transfer overhead. So, cross-layered approach is used to minimize this overhead by having data and information shared among different layers. The development of various protocols and services are optimized and improved as a whole system. Some of the parameters which can be optimized by CLD are:

2.1 Throughput

Many cross-layer approaches are introduced to maximize the network throughput [5–7]. The throughput in WSN is influenced by many concurrent causes. Limited connectivity and medium access control (MAC) are the few major causes which affect the data throughput. A MAC protocol requires minimum latency and high throughput for many applications. The nodes placed near the sink node will be having more load than the other nodes in the network. Consequently, these nodes will be consuming more energy and facing high congestion in a large scale network. The relay-traffic close to the sink node is very high, and the area is heavily loaded, which causes significant collisions and packet losses.

2.2 QoS

WSN will sense data from the surrounding and forward data towards the sink. Therefore, QoS in WSN has some significant challenges. The major issue to achieve desirable QoS is due to resource constrains like energy, bandwidth, size of buffer, etc which makes room for performance quality and resource management. Along with this, time-delay, data redundancy, heterogeneity of the node, distributed network and topology of the network also affects the QoS.

2.3 Network Lifetime

Cross-layer is a technique for minimizing energy consumption at the physical layer, which minimizes the transmission power while obtaining a given data rate and error probability. There is always a conflict between long lifetime and limited battery power, which creates a gap between power consumption and power supply in an application. Literature [8–10] points out that CLD techniques help in improving energy conservation in WSN. An optimized MAC protocol design for location accuracy of nodes is proposed in [11]. Increasing network lifetime by making use of residual energy levels has been dealt with [12].

2.4 Resource Constraint

WSN has limited resources like energy, memory, communication bandwidth, buffer size etc. WSNs are power constrained, which makes sensor’s energy a priceless resource. After the energy exhaustion of one or more nodes of a WSN, the application they were supposed to nourish becomes compromised.

2.5 Scalability

For WSN applications large amount sensor nodes have to be deployed, which impose a potential impact on hardware components. This may affect its communication bandwidth, and computing and storing capabilities. Therefore, the protocol should be scalable and simple. Also, sensor network middleware supports scalability and dynamic network. So, middleware design should integrate with other layers to gain real time priorities of the application.

2.6 Functionality

Some sensor nodes may have multiple responsibilities like sensing the event, collecting data, data aggregation and multi-hop transmission [13, 14]. These multiple responsibilities are also a challenging task to improve the network efficiency.

2.7 Security

WSNs sense the event by directly connecting with the physical environment. This causes security challenges to the nodes and network as whole. Different attacks are possible at different layers [15]. For example, jamming attack at the physical layer, collision attack at

Table 1 Few of the CLD Approaches to Address Challenges in WSN

Paper	Issues	PHY	MAC	NET	TRANS	APPL
Enkitasubramaniam et al. [5]	Max. throughput	Power control	Channel state			
ElBatt and Ephremides [6]	Max. throughput	Power control	TDMA			
Yuan et al. [7]	Max. throughput	Network coding	Channel state	Data routing		
Mohaghegh et al. [20]	Time delay		Channel queue			Priority
Wang et al. [21]	Delay+ heterogeneity	Power control	Queue length, CSMA/CA	Geographic routing protocol		
Hoesel et al. [8]	Network lifetime		TDMA	On-demand routing		
Wang et al. [9]	Power efficiency	Power control	TDMA	Optimal routing for traffic load		
Sichitiu [10]	Power efficiency		On-off scheduling	Query driven routing		Synchronization
Gao et al. [12]	Energy minimization	Node energy		Hop length		
Karvonen et al. [22]	Energy minimization	IR-UWB	Forward error correction coding			
Wu et al. [13]	Data aggregation		Channel queue, retransmission	multi-hop routing		
Yuan and Yu [16]	Total distortion	Power-allocation				Rate allocation
Liang [17]	Fault tolerance	Remaining battery, channel coding, signal-to-noise ratio	Channel fading			Geographical location
Lin and Kokkinos [18]	Hidden-terminal problem	Directive antennas	Channel access			
Fang et al. [23]	Reliability	Physical channel effect	Channel queue	Geographical routing	Congestion	Sensory data management
Wu et al. [24]	Congestion control		Channel access		Flow control	

Table 1 continued

Paper	Issues	PHY	MAC	NET	TRANS	APPL
Shi et al. [25]	Location accuracy	Residual energy	Sliding window			
Medagliani et al. [26]	Mobile target tracking	No. of nodes	Duty cycle, Channel access control			Node location
Isik et al. [27]	Load balancing		Buffer condition	Geographical routing		
Eschenauer and Gligor [28]	Security	Transmission power		Multicast routing		Key distribution
Chen et al. [29]	Security	Transmission power		Communication		Cryptography, key management
Cordeschi et al. [30]	Co-channel interference	Power control, channel coding		Network coding		Source coding
Mezouary et al. [31]	Flow throughput		Channel selection	Rate balance		

the data link layer and routing protocol misdirection at the network layer are some of the possible security concerns.

2.8 Other Issues

Along with above mentioned issues, many other issues like, node distortion [16], mobility [17], heterogeneity, accuracy and latency [18], hidden-terminal problem [19] can be handled using CLD. The Table 1 lists some of the CLD approaches for the solve the issues in WSNs.

3 Cross-Layered Approach in WSN

Different cross-layer design approaches have been proposed in the literature. Different authors have categorized the CLD approaches with different criteria. Raisinghani and Iyer [32] and Srivastava and Motani [3] have categorized the CLD according to the patterns of coupling of different layers. Melodia et al. [4] and Yick et al. [33] have categorized according to interactions or modularity among different layers. The CLD techniques have developed from traditional layer design approaches to layer-less design approaches. We have considered the approaches in terms of:

- Conventional Design Approach
- Complex Design Approach
- Unified Design Approach

Most of the proposed cross-layer designs come under one of these categories. We shall discuss each of these categories in brief:

3.1 Conventional Design Approach

In this approach, the traditional OSI model is maintained and new interfaces are developed between the layers which are used to interact with each other at runtime. Interactions can be done either from downward to upward or upward to downward. Bottom up interactions can be a feedback mechanism. This feedback mechanism is used to stabilize the system performance. Urgent messages in prioritized traffic are described as top down interactions. These proposals are attractive where a few information exchanges are required to be implemented. However, each additional cross-layer feedback code block can reduce the throughput of the layer. If a layer needs to interact with many other layers, the system throughput reduces significantly. Multiple cross-layer optimization could lead to conflicts

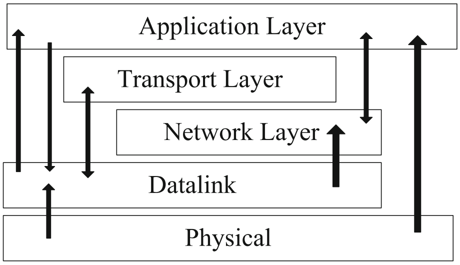


Fig. 1 Concept model of CLASS [35]

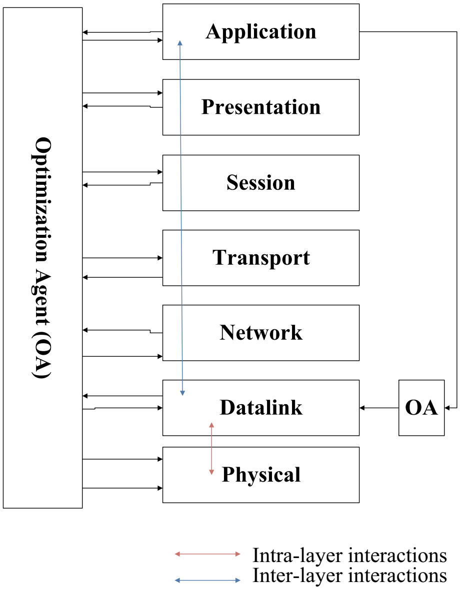
in a layer [34] and hence it is difficult to ensure correctness of the layer's algorithms. The interface is maintained either by a direct communication [35], by sharing database [36] or by adding a new interface [37].

Wang and Abu-Rgheff [35] have proposed a cross-layer signaling concept called CLASS (Fig. 1). The basic idea of CLASS is to propagate messages between different layers by keeping the standard architecture. It has both internal and external signals and it allows direct signaling between nonadjacent layers. CLASS is designed to overcome two major problems. First, it has the lowest propagation latency because of direct signaling between any two layers and second, it has low overhead when applied to the mobile host because it differentiates between the internal and external messages, and applies optimized format for internal signaling and standardized format for external signaling. The external signaling messages are implemented by ICMP protocol. An additional packet header carries forward or indicates cross-layer information. The information may be an additional control signal, or encoded within the packet headers.

Su and Lim [36] proposed optimization agent (OA) to interact between various layers as a core repository (Fig. 2) to extend network life time. The OA works like a repository which holds the information like node identification number, number of hops, energy levels of node, link status, etc to ease interactions between various layers. This information is used for feedback to other layers across the stack to exploit synergy across layers. The interactions between layers can be done in both directions and it may be either intra-layer or inter-layer. The OA is designed to provide an adaptive framework which holds the changes in the network stack according to the application requirements. The framework does not require reconstructing of the existing protocol at layers.

The advantage of the proposal is that it provides a flexible approach for the joint optimization across all the layers without redesigning any existing protocols at each layer. Whereas this approach causes significant overhead to maintain application programming

Fig. 2 Cross-layer design proposed by [36]



interface (API) to exchange the parameters between layers. This may cause an overall increase in power consumption [38].

Merlin and Heinzelman [37] has used a repository to store the information which, may be needed by all protocol layers. This is termed as Cross-Layer Optimization Interface (CLOI) and it is placed between the routing and MAC layer. CLOI used to maintain information through a neighbor table and a message pool (Fig. 3). The architecture follows the conventional layered structure design to make that simple and practical ensuring that all communication functions of each layer is maintained to provide a suitable information platform between the layers. CLOI is placed between the network layer and MAC layer. This is the preferred location because it is easier to get much information about the incoming and outgoing packets on a node in the network also it offers abstraction of the MAC layer. It simply acts as an interface to the protocols in the stack.

Hefeida et al. [39] has proposed a cross-layer design called Cross-Layer Application-aware Paradigm (CLAP) which uses a Information-Layer (I-Layer) (Fig. 4). It connects through all the layers and makes capable to the application layer to access and modify the information of other layers. The I-Layer can store the status and control information. One of the layers is permitted control and it defines how the other information is used by *publishing* control information. All cross-layer information are handled by the I-layer and hence it does not allow unnecessary layers to involve in communication.

Wang et al. [40] has proposed the cross-layer sleep/awake scheduling at MAC layer and service availability requirement at application layer to increase the overall network lifetime. In this technique, the application layer at the base-station of the service-oriented architecture (SOA) based WSN has three layers (Fig. 5). Service composition query sublayer, Service sublayer and Service composition sublayer. Service composition query sublayer plots a query to a service composition query for the required services with their invocation order. Service sublayer holds the service information given by the sensors in the service provider overlay network. The third layer finds the solutions for queries based on the information from the above two layers. The sleep scheduling satisfies the system requirement on the active service providers for each service at any given time interval.

3.2 Complex Design Approach

In this CLD approach, the basic idea is to integrate two or more layer functionality. These architectures ease information flow between joint layers. This results in increased lifetime

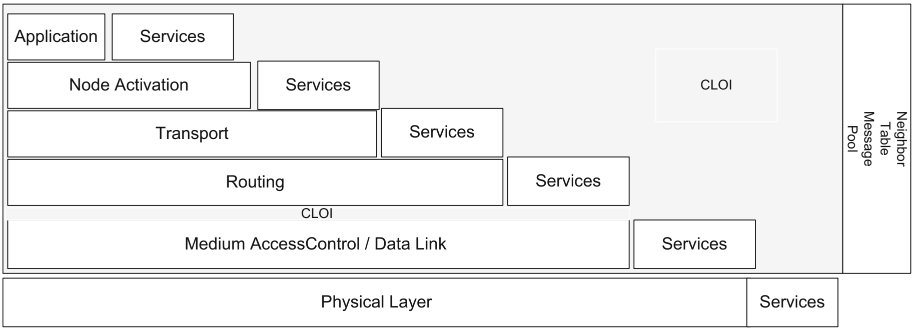


Fig. 3 Information-sharing sensor network architecture for cross-layer optimizations [37]

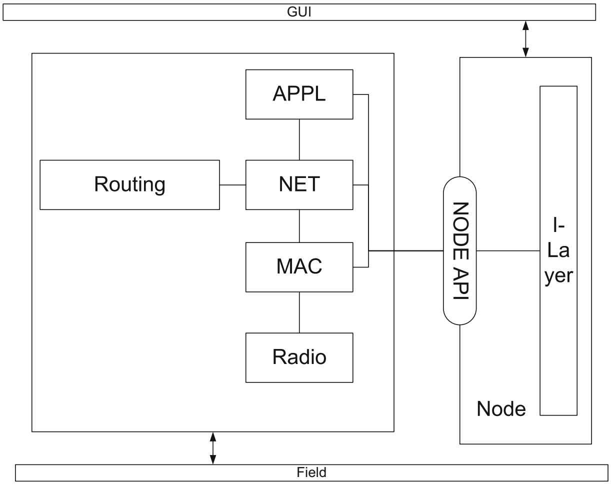
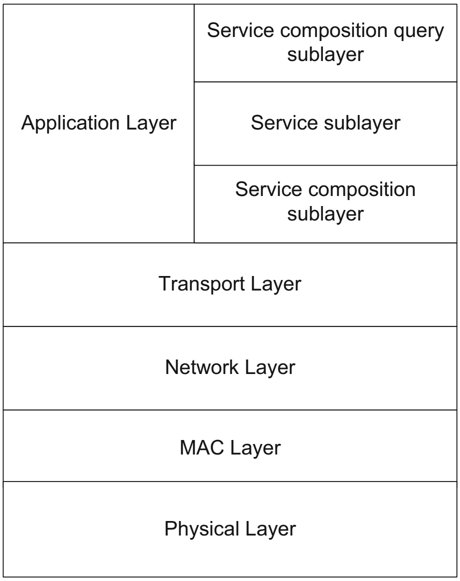


Fig. 4 Cross-layer application-aware Paradigm [39]

Fig. 5 Cross-layer sleep scheduling design in service-oriented wireless sensor networks [40]



of the network and better performance. On the other hand, debugging for errors and adaptation for different scenario are difficult with these architectures. Compared to the conventional approaches, they are more error-prone and bad merging may result in negative direction [41].

In the Address-Light, Integrated MAC and Routing Protocol (AIMRP) [42] (Fig. 6) the MAC and network layers are melt into a single layer. It works as a tier-based network topology in which the sensor nodes are organized into concentric tiers and data transmission occurs from a node in a tier to a node at another tier towards the sink. AIMRP

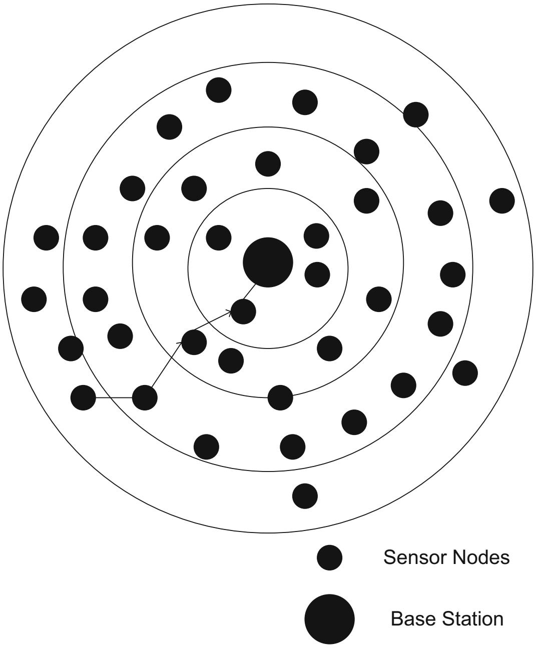


Fig. 6 Routing in AIMRP [42]

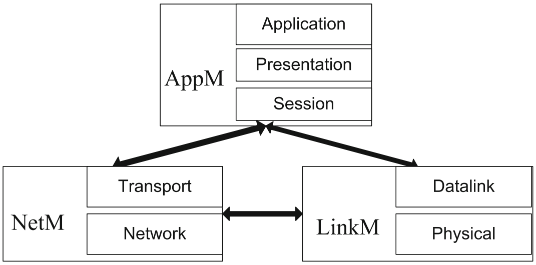


Fig. 7 Overview of TCLA [45]

reduces the route discovery cost and maintenance overhead. Due to the merging policy, network and link creation are performed in a single process. The optimized communication between network and MAC layers minimizes energy cost. In addition, end-to-end delay is reduced because of simultaneous routing and link establishment. The AIMRP cross-layer design is simple and the addressing technique is light-weight but in AIMRP, the base station is placed at the center of the application area and also the approach is not scalable.

Cui et al. [43] proposed a cross-layer design between the data link, MAC, and routing layer for overall energy minimization. They used variable-length TDMA scheme which is assigned to the nodes according to some criteria for optimum energy consumption in the network. By using this, nodes become active in the time slot which they are assigned. The nodes transmit data in active mode and go to sleep mode in order to save energy. It enters the transient mode before switching to the active mode. Link adaptation is introduced for lifetime maximization by which each node in the network adjusts its transmission rate. Optimal routing and scheduling is used to compute total energy consumption. The overall energy minimization problem is formulated as a linear programming problem. Link adaptation minimizes the transmission time in relaying nodes thereby reducing energy consumption. Even if the optimization framework is exhibiting insight or clear and deep perception, the transport layer issues such as congestion control and flow control are not considered .

TCLA: Triangular Cross Layer Architecture for WSNs [45] is a networking architecture for WSNs (Fig. 7). It tries to merge adjacent layers into virtual functional modules, among which communication overhead is high. In TCLA, application, presentation, and session layers are merged to form a new module called AppM module. Similarly, the NetM module is made by merging transport and networking layers. Data link and PHY layers are merged into the LinkM module. AppM module is responsible for the specific applications related aspects. NetM is responsible for managing issues like resource allocation, routing and congestion control. LinkM handles the wireless transmission aspects. All modules have their own agent which distributes information to different layers. Each functional agent has a communication interface with other functional modules. TCLA requires high memory and energy requirements.

In [46], the Cubic Cross Layer (CCL) architecture for hierarchical cluster in sensor network is proposed. The goal of this architecture is to make suitable for the applications-specific sensor networks. In this architecture MAC, network, and transport layers are merged into one layer called Sensor Service Layer (SSL) (Fig. 8). The common abstraction, sensor service protocol (SSP), provides services for applications, and keeps the interface platform-independent.

The interfaces to services are divided into many layers such as power management, synchronization, localization, and security etc. The power management plane manages the use of power by sensor node. The synchronization plane helps in synchronizing local clocks of all sensor nodes. The localization plane finds the location of the sensor nodes with respect to each other and location of an external object, e.g., an intruder. The security layer handles the issues like availability, confidentiality, integrity, authentication, and non-repudiation and also special security requirements. In order to achieve QOS in the mobile application, a mobility management plane would be also taken into consideration.

Low Energy Self-Organizing Protocol (LESOP) for target tracking in dense wireless sensor networks is proposed by Song and Hatzinakos [47]. Cross-layer approach is achieved by entirely avoiding the traditional transport and network layers and thus, direct communications between the Application layer and the MAC layer are developed (Fig. 9). The QoS is achieved by controlling the tradeoff between tracking error and the energy consumption.

The protocol is proposed for target tracking. The communication between nodes requires two criteria to fulfill-the node has detected a target and the signal's energy that indicates its detection exceeds a certain threshold value. The node with the highest energy

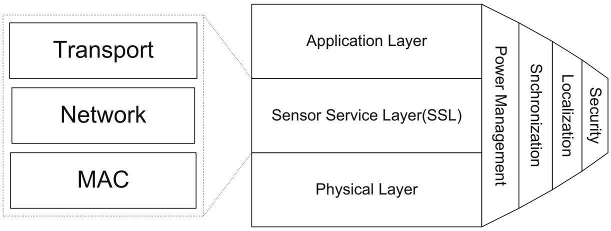


Fig. 8 Cubic Cross Layer (CCL) [46]

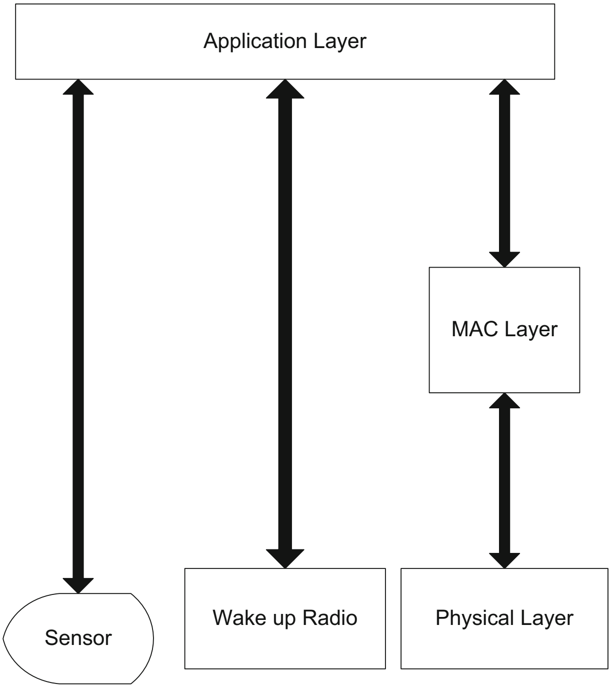


Fig. 9 Low Energy Self-Organizing Protocol (LESOP) [47]

is elected as a cluster head. The newly elected cluster head collects information from the previous head node. Thus, the target's present location and position can be estimated pertaining to the target's previous location and speed. This is not to be applicable for static targets.

3.3 Unified Design Approach

In the unified design approach, the entire traditional layer is replaced and all the functionalities of application, transport, MAC, network and physical layers are combined for information sharing. It is more energy efficient. Furthermore, an interface requires an abstraction of network capabilities to applications. That interface decouples the parameters directly in applications at different layers with an unified approach [48].

Mehmet et al. [49] has introduced cross-layer protocol (XLP) to achieve congestion control, routing, and medium access control. XLP is the protocol that joins together functionalities of all layers into a single protocol. The goal of XLP is to achieve efficient and reliable event communication in WSNs with minimum energy consumption, adaptive communication decisions and local congestion avoidance. The protocol works in binary form based on fulfilling four criteria to route a packet. The first condition guarantees that reliable links is constructed for communication. The second and third conditions are used to control local congestion. The fourth and last condition ensures that the remaining energy of a node stays above a threshold value, to ensure even distribution of energy consumption. A sensor node is worked on two tasks namely source task and router task. The first task is to sense the events and generate packets to be transmitted and the other task is to receive and forward the message.

A cross-layer, reliable and efficient communication protocol (CREC) is proposed by Fang et al. [23] which core idea is to jointly consider the medium access, routing, and congestion control in a single protocol. The paper introduced ‘node initiative’ concept, and illustrated how certain functionalities required for successful communication in WSNs. The node initiative concept is used as a binary option for each node to make decision on participation in data transmission. The decision can be made according to its local current state related to the reliability issue. The authors have taken only the wireless channel at physical layer but they failed to explain the effects of different modulation techniques in WSNs.

The CLD approaches are aimed to improve the QoS under various operational conditions. However, different types of CLD approaches are their own strong and weak points. Table 2 summarizes the pros and cons of different CLD approaches in WSN.

4 Issues and Challenges in Implementation of CLD

There are several open research problems toward the development of techniques for CLD of WSN protocols:

4.1 Hard to Redesign

OSI layers are tightly coupled and everything is interconnected with each other. Most of the communication protocols follow the conventional layered protocol architectures. Even though, these traditional architectures suits fine for wired networks it does not suit well for

Table 2 Pros and Cons of CLD approaches

Category	Advantages	Disadvantages
Conventional	Interactions can be done on both sides (i.e. upwards to downwards or downwards to upwards)	Each additional block can reduce the throughput of the layer
	Best for few information exchanges	Difficult to ensure correctness of the layers algorithms
	Traditional OSI model is maintained and hence it is most compatible with wired system	Only asynchronous reaction to the events
Complex	Ease information flow between joint layers	Debugging for errors are difficult.
	Increase adaptability because of better performance	Bad merging of layers results in negative direction
	Benefits exceed the cost of additional complexity due to layer merging	No defined standard for merging the layers
Unified	More resource-efficient	Unplanned modifications can affect the performance
	Can provide a better network abstraction	May not compatible with OSI based networks (eg. wired system)
	Parameters of all OSI layers participate in the resource management	

wireless network. Hence, cross-layer designs are attracted, for wireless networks, due to its properties such as uncovering the dependencies, interaction between conventional layers, sharing knowledge about its dynamic state etc. But, it is hard to review and redesign CLDs, because change in one subsystem may cause change in other parts.

4.2 No Standardization

The OSI model is not suitable for wireless technologies necessarily the correct approach for wireless systems. Hence, researchers have started to make modifications to communication protocols stack which violate the OSI model. A number of general approaches to CLD, called ‘Cross-Layer Frameworks’ (CLF), have been proposed, with none gaining widespread acceptance. One of the reasons behind it is there is still no standard framework for CLD. The lack of standardization can lead to many problems. This may result in reduced overall network performance. There are also primary, unanswered questions for CLD. In general, it is not clear how, where and when different CLD proposals should be implemented.

4.3 Physical Layer Role

The role of physical layer in wired networks is to receive and send packets. But in case of wireless network it plays a bigger role. CLDs relying on advanced signal processing at the physical layer.

4.4 Coexistence with Other Wireless Protocols

The increasing numbers of CLDS are causing serious coexistence problems amongst themselves and other networking protocols. Problems can reach beyond poor decisions and can affect the very stability and reach of a network. A CLD has multiple algorithms at different network entities. So, it may never be able to converge in a dynamic wireless network environment. Researchers have warned about CLD and such unresolved coexistence protocols could cause the approach to be prematurely abandoned. Many CLDs may not be suitable for various applications, due to the impact of above problems.

5 The Proposed CLD Model

Sensor nodes have to manage resources, system and security. Medium access and routing decisions will be having an impact on the power consumption. In the conventional layered approach there is no sufficient interaction to make decision jointly, to optimize these cross-layer aspects. In a distributed WSN architecture, distributed localization methods are more accurate and provides maximum degree of freedom. The nodes must act together in an efficient way to maximize the lifetime of the node and hence the network. Cross-layer design approaches can manage power related variables at several layers to efficiently utilize energy resources. So, the paper has endeavored to propose a unified parametric model for cross-layer optimization which provides:

- Minimum energy consumption
- Adaptive communication decisions
- Local congestion avoidance

5.1 Problem with Existing Proposals

The multihop WSN results in reducing the overall energy consumption and hence increasing the network lifetime. It also helps in increasing throughput and coverage by frequency reuse. However, the short hops increase the end-to-end delay and relay-traffic. The end-to-end delay increases because there is no line-of-sight between source and destination and each node's processing (i.e. receiving and transmitting) of a packet. The relay-traffic of the passing nodes decreases the overall throughput of the network. The Bit Error Rate (BER) in the multihop scenarios increases with the increase in each hops. Along with this, path errors and inadequate sleep/awake mechanism also hampers the multihop routing in WSN.

Collision free communication is very important for distributed system, like, sensor networks. The main cause of the collision is transmission of data by two different nodes at the same time, over the same communication medium or channel. This concurrent transmission increases the collision hence degrades the system performance. The existing multipath routing protocols, like AODV [50] and DSR [51] are based on classic on-demand single path routing methods. They create large communication overhead and does not take into account packet collision due to concurrent transmission from different nodes.

To overcome the above problems cross-layer solutions are proposed. But, the problem with Conventional design approach and Complex design approach is that it prevents the interoperability between similar systems and thus restricts functionality to specific domains and cannot be easily adapted to other area [52]. They are individually developed and optimized for achieving high performance in terms of the metrics related to a certain networking layer. As a result, it is difficult to combine the protocols that belongs to different layers together in simple and direct manner to maximize overall network performance, while minimizing node energy expenditure. Thus, the necessity for a unified, cross-platform, general purpose model becomes important [48].

5.2 The Proposal

5.2.1 Introduction

The spotlight of our approach will be mostly on node capabilities to adapt to the channel characteristics and communication models, with keeping the energy availability in consideration, as power consumption and available energy is the most challenging part in WSNs. In our model, by taking into account the physical layer parameters, such as transmission power, BER and modulation techniques, the medium access control, routing strategies and congestion control is analyzed. For example, the transmission power of the nodes varies inversely with D^{α}, where D is the distance between source and destination and α is the path-loss co-efficient [53]. The value of α is between 2 and 4 depends on the system, environment conditions ans applications. The higher value of α will reduce the throughput and increase latency and jitter because of routing overhead [54]. The optimized hop distance at routing layer, for different MAC can be obtained using different modulation schemes. This improves the link quality information at physical layer, which in turn improves routing layer decisions. Few other parameters, such as, link irregularity, energy consumption and interference are also considered.

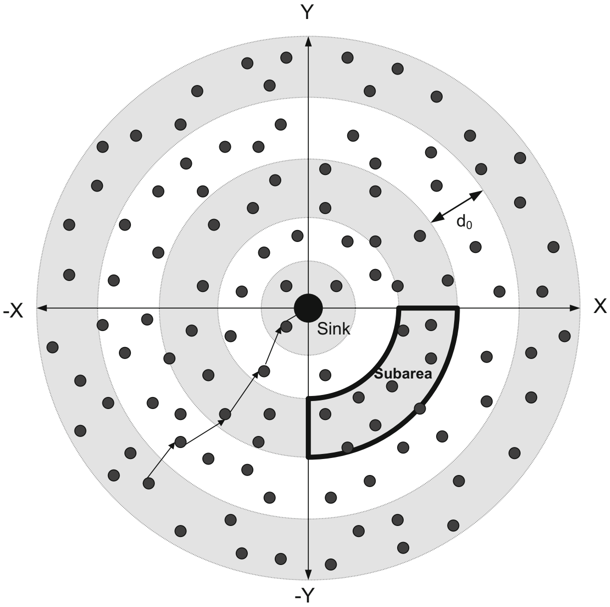
The radio signals by the low-power radios in WSN are affected by several factors which lead to the degradation of its quality. Consequently, the quality of radio links fluctuates over time and space and hence the connectivity is typically asymmetric [55]. Radio link quality in WSNs has a major impact on the network performance in direct or indirect ways and affects as well the design of higher layer protocols. It results in variations in packet loss in different directions and makes sensor radio range non-spherical in nature. It has a significant impact on the routing and the MAC protocols. For example, if the connectivity is asymmetric, a node might not be able to successfully reserve the wireless channel RTS/CTS handshaking.

Consider the energy consumption parameter, the energy efficiency will be directly proportional to the bandwidth used for a given modulation scheme. Along with this, a major source of the energy drain is interference, which is reduced by using the TDMA approach. The transport layer is eliminated in our model as retransmission required for congestion control, are handled by the MAC layer. Designing a unified cross-layer protocol is of great significance, as it considers upper layer functionality with physical layer effects for reliable and efficient communication in WSNs, to improve efficiency and flexibility.

5.2.2 System Design

Consider that the sensor nodes are deployed densely in random and ad hoc way in the targeted area so that every node is separated by one-hop distance from at least a node to ensure full connectivity. Communication takes place over one hop distance, while traffic moves through the network over multi-hops in a much larger infrastructure. We consider that the whole area is divided into four quadrants (Fig. 10), with sink at the center. The area is again divided into concentric circles with inter layer distance equal to d_0- which depends on modulation used. We assign the layer's names as Layer 1 to Layer K from inner most layer to the outermost layer. The farthest node from the sink is D distance away. The divided area is called as *subareas* as shown in the Fig. 10. Let us suppose events occur

Fig. 10 System design for the proposal



at different *subareas* at a given point of time. The problem is to sense the event and send the information to the sink with optimal delay and reliability taking into consideration the resources of the nodes and the network. The sink will locate the event and will take decision accordingly.

5.2.3 Different Phases

In the first phase of the work, the optimized hop distance between nodes is calculated taking into account the modulation schemes (e.g. MPSK, MFSK and MQAM) and respective BER at physical layer for a given load. We also take into account the MAC layer scheduling required in receiving and transmitting the given load. The brief calculation of the optimum hop distance is described in Appendix.

In the second phase, the issue of collision due to transmission of packets by two different nodes at the same time is solved. Collision avoidance, which is required to ensure reliability, is done by using TDMA approach with minimized hop distance, for different modulations. Thus, for different modulation schemes we have a set of conditions to improve the overall throughput of the system. The set of conditions defines how the packet will route. The hop distance for routing is calculated according to the modulation used. Furthermore, in our previous work [56], we have developed an algorithm to reduce the packet collision in accessing the same channel at a point of time. The set of conditions mentioned, is based on the combination both the works.The set of conditions satisfy user's

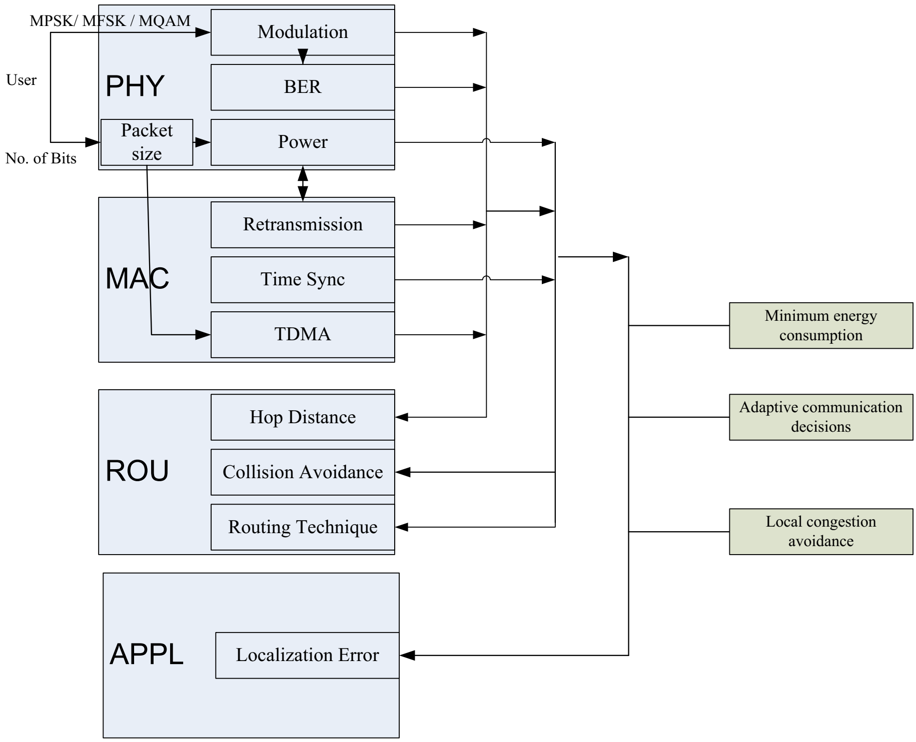


Fig. 11 Work flow of the proposal

requirements according to the selected modulation scheme. Figure 11 shows the workflow of the proposed model. The user has to select a modulation scheme and number of bits in a packet. The output will be a cross-layer unified parametric model (Fig. 12).

In the final stage, the proposed CLD will be implemented to reduce the localization error. The localization error is directly associated with the nodes' energy [57] and it is an ever-decreasing form factor. Furthermore, the error in localization is affected due to transmission power, packet drop, interference and Non-Line-of-Sight (NLOS). For example, Fig. 13a shows that as the node density is increased, the positioning error also increases slightly due to interference, in Gaussian distribution. This is due to the fact that a large number of nodes lead to a stronger interference, and thus a higher number of collisions. The Fig. 13b shows the localization error with respect to number of iterations. Moravek et al. in [58] shows that the expended energy is not related linearly to the localization error. More energy is consumed for additional accuracy improvement. Results show that with the increasing number of measurements the coordinate determination inclines to a certain position with smaller steps. It means that with a high number of measurement samples the influence of uncertainty can be eliminated.

5.3 Cross Layer Localization Scheme

We propose a cross layer localization scheme and compare with existing localization technique. The proposed CLD gives better location accuracy in compared to DV-hop (Niculescu and Nath [59]) and direction-based localization scheme (Wang et al. [60]). We have used COOJA simulator in contiki OS to simulate the CLD approach.

The existing cross layer techniques are mainly implemented on target tracking. For example, Medagliani et al. in [26] has proposed a CLD approach for the surveillance of mobile target detection application. The authors has proposed the CLD which interacts between the sensing layer, communication layer and MAC layer and it was applied in deterministic node deployment. LESOP proposed by Song and Hatzinakos [47], has exploited the application layer and the MAC layer to tradeoff between the tracking error and the energy consumption. Zhan and Li has proposed Active Cross-Layer Location Identification (ACLI) [61] to tackle the problem of locating a static malicious sources the

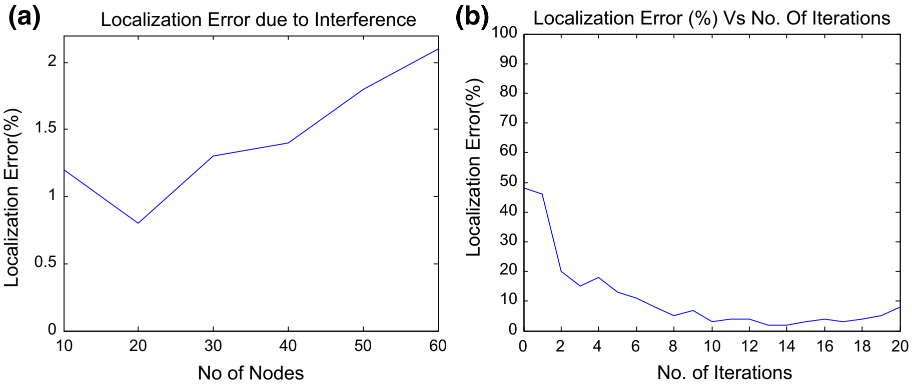


Fig. 12 **a** Localization error due to interference, **b** localization error versus no. of iterations

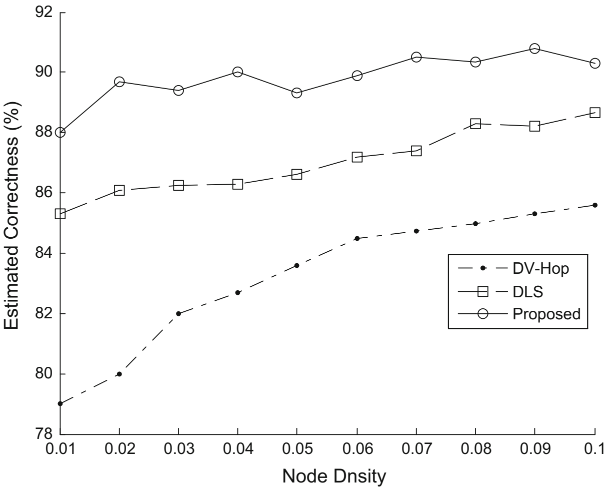


Fig. 13 Comparison of estimated correctness for different node densities

help of a directional antenna. It combines sensor coordination with the traditional range-free localization method.

In the proposed work, we consider the same System Design as in Sect. 5.2.2, and four anchors with directional antenna attached with sink. The data delivery model in our simulation has singe sink/multi-source. The network density variess from 0.01 to 0.1 nodes per m^2 and all nodes are static in nature. The nodes are positioned uniformly and randomly in a 2-dimensional Cartesian plane of area 1000 m. The radio range of the transceiver of each node is according to the modulation used. Sink node broadcast 30 reference packets for localization. The size of the reference packets is 2 Kbits where as that of the data packets is 10 Kbits. The working of the scheme as follows: The sink sends packet p and *hop_no* 0 to all of its neighbors in layer 1. Among the neighbors of the sink, only anchors require sending the packets with their own directions. The unknown sensors within layer 1 will discard the packet due to no direction information in the packet. Once receiving an packet, an unknown sensor estimates its direction according to the direction information involved in the packet, updates the *hop_no* as 1, and then propagates the direction information to its neighbors. The nodes set location as the direction with the maximum value among all. Nodes in layer 1 transmit reference packets to its outer layer according to the set of conditions to minimize packet collision. The process terminates for a sensor when its direction never changes. Thus the *hop_no* and direction from the sink node is known to each node in the network. The result shows 89.5 % accuracy as shown in Fig. 13.

6 Conclusion

The paper concludes with the discussion of reviews on cross-layer protocols for wireless sensor networks (WSNs). Some of the attributes due to which the CLD approaches are needed in WSN, are also emphasized. Furthermore, we have endeavored to propose a unified design approach keeping in mind the comprehensive list of issues associated with

CLD. We have also endeavored to highlight some open challenges in this area and discussed the issues that will make the ongoing CLD work more holistic and complete. The proposed Unified Design Approach is necessary for efficient, reliable and manageable communication. In the future, we are planning to optimize other resource parameters for WSN and WMSN like, delay, packet load etc. Also, we are planning to implement the proposed technique in real test-bed.

Appendix: Calculation of Optimum Hop Distance

Consider that a node sends L bits of information when a event occurs and retransmits the information when there is an error. Suppose that, n is the maximum number of retransmissions, then the resultant number of bits transferred is given by [62],

$$L_{res} = L * \sum_{j=1}^{n+1} \left(j * PER^{j-1} * (1 - PER) \right) + (n + 1) * PER^{n+1} \tag{1}$$

where PER is the Packet Error Rate and if BER is the Bit Error Rate, PER is given by

$$PER = 1 - (1 - BER)^{L} \tag{2}$$

The circuit has three modes of operation. The on state is used for the transmission and receiving of information. The nodes are in sleep state when there is no data to send or receive. Transient state is the state between on state and sleep state. The total energy consumed in transmitting and receiving L_{res} bits of information to a hop, ignoring the power consumed in sleep state, is given by [63]

$$E_{hop} = ((1 + \alpha)P_t + P_{ct} + P_{cr})T_{on} + P_{tr}T_{tr} \tag{3}$$

where P_{tr} is the power consumed in transient state T_{tr}. The P_{on}, power consumed in on (T_{on}) state, consists of the power consumed by transmitted signal (P_t), the transmitting circuit (P_{ct}), the receiving circuit (P_{cr}), and power consumed by power amplifier (P_{pa}). $\alpha = \frac{\zeta}{\eta} - 1$ with ζ peak-to-average power ratio (PAR) of the signal and η is the drain efficiency of the power amplifier. Assuming an N-th-power path-loss model at distance d (meters), the transmission power is expressed as [53]

$$P_t = P_r G_1 M_l d^N \tag{4}$$

In which M_l= link margin compensating the hardware process variations and noise and G_1 = the gain factor at d = 1 m, Now, if the sink node is k hop away the source node, the total energy per bits is given by

$$E_{tot} = \sum_{i=1}^{k} \left(\left((1 + \alpha)P_r G_1 M_l d_i^N + P_{ct} + P_{cr} \right) T_{on} + P_{tr}T_{tr} \right) / L_{res} \tag{5}$$

And, the received power strength is given in term of SNR (Signal to Noise Ratio) as [64]

$$P_r = \psi(N_o N_f)/T_s \tag{6}$$

where ψ=Received SNR, $N_0/2$= Power spectral density of the noise per dimension, N_f=receiver noise, T_s=symbol period

Applying Jension Inequality, the inter layer distance, $d_0 = d/k$ and differentiating it w. r. t. k and equating to 0, we get

$$d_0 = \sqrt[N]{\frac{\left((P_{ct} + P_{cr}) + P_{tr}\frac{T_{tr}}{T_{on}}\right)\eta T_s}{\zeta\psi N_o N_f G_1 M_l (N-1)}} \tag{7}$$

For M-ary Phase-shift Keying Modulation (MPSK) For MPSK, we use $\eta = 0.35$ which is typical value of class A power amplifier. Also, PAR ζ for MPSK is unity. Also, $m = L_{res}T_s/T_{on}$ where the number of bits per symbol is defined as $m = log_2 M$ Considering B is the bandwidth in Hz of the signal, $T_s \approx 1/B$

$$d_0 \approx \sqrt[N]{\frac{0.35\left((P_{ct} + P_{cr}) + P_{tr}T_{tr}B\frac{log_2 M}{L_{res}}\right)}{\psi N_o N_f G_1 M_l B(N-1)}} \tag{8}$$

M-ary Quadrature amplitude modulation (MQAM) For MQAM, $\eta = 0.35$, PAR= $\zeta = \frac{3(\sqrt{M}-1)}{\sqrt{M}+1}$, $m = \frac{L_{res}T_s}{T_{on}}$ and $T_s \approx \frac{1}{B}$

$$d_0 \approx \sqrt[N]{\frac{0.117\left((P_{ct} + P_{cr}) + P_{tr}T_{tr}B\frac{log_2 M}{L_{res}}\right)(\sqrt{M}+1)}{\psi N_o N_f G_1 M_l B(N-1)(\sqrt{M}-1)}} \tag{9}$$

Multiple frequency-shift keying Modulation (MFSK) For MFSK we use $\eta = 0.75$ which is typical value of class B or higher power amplifier. Also, PAR η for MFSK is unity and $T_s = \frac{M}{2B}$. Also $\frac{2log_2 M}{M} \cong \frac{L_{res}}{BT_{on}}$

$$d_0 \approx \sqrt[N]{\frac{0.375\left((P_{ct} + P_{cr}) + 2P_{tr}T_{tr}B\frac{log_2 M}{ML_{res}}\right)(M)}{\psi N_o N_f G_1 M_l B(N-1)}} \tag{10}$$

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