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# CROSS LAYER APPROACH FOR ENERGY OPTIMIZATION IN IOT NETWORKS

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**ABSTRACT**
Network of IoT devices enables a connected future and brings many benefits to human society in saving of time/money and better comfort. The devices are heterogeneous with various processing and energy capabilities. Most of the IoT devices are portable and powered by batteries. Energy in these devices must be optimally used to prolong the lifetime of the IoT network. Many attempts have been made in area of lifetime improvement of IoT networks, but still there are many gaps need to be addressed for further energy optimizations and lifetime improvement. The typical challenges in energy optimization cannot be met with solution focused on a single OSI layer alone and thus a cross layer solution is needed. This work proposes a cross layer approach for optimization of energy in IoT network with goal of increasing the lifetime of the network.

**Keywords:** IoT, MAC, QoS,Clustering,Routing, RTT,Swarm Optimization.

## 1. INTRODUCTION

Internet of Things (IoT) is rapidly gaining in root in all walks of life with its applications in many areas like smart homes, intelligent transports, smart grids and healthcare etc. IoT networks are being increasingly adopted with about 30 billion devices connected to internet as on today. IoT devices are heterogeneous with various processing and energy capabilities. The IoT devices connected to internet enables a connected future which can bring many benefits to human society in saving of time and money and better comfort. IoT can facilitate better automation and control in industries, better health care via remote monitoring, smart homes etc. IoT can revolutionize many industries. Most of the IoT devices are portable and powered by batteries. Due to form factor constraints, the size of batteries used to power up these devices are limited. The limited energy availability from these devices limits the capabilities of the components like sensors, processors, wireless access interfaces, memories and displays used in these devices. These devices can be also used as edge computing nodes and integrated to cloud. In addition to sensing, the devices can also share the load of computing needed for novel applications. These applications can drain the energy faster and device can be dead.

Many attempts like low power wireless communication, deep sleep states, low overhead signaling procedures, computation offloading etc. have been attempted in

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area of energy consumption reduction and lifetime improvement. The area is still fresh with lot of challenges that need to be addressed to achieve even higher energy gains. Solution designed in single layer of OSI alone is insufficient to meet these challenges.

This work proposes a cross layer solution for optimization of energy in IOT networks. The solution is composite involving sub solutions at each OSI layers in terms network adaptive sampling and packet rate control in the application layer, adaptive packet aggregation based on clustering topology at network layer, slot scheduling and duty cycling at MAC layer based on application requirements, resident energy-based transmission power control at physical layer. With this cross layer strategy involving solutions in various layers, there is reduction in overall energy consumption and increase in life time of the network.

## 2. Related Work

Hao Wang et al [1] improved the lifetime of the wireless sensor network using cross layer protocol. Joint decoding and multicast transmission is adopted to reduce the transmission power at nodes. The feedback needed for transmission power adjustments was provided from the application layer. Though the approach was promising the gain was lower.

Roberto Petroccia et al [2] attempted to increase the lifetime of wireless network by optimizing the transmission energy. Authors used an adaptive cross layer approach to reduce transmission energy. Multiple criteria like energy, link quality was used in routing path selection. The feedback needed for route selection is collected from various layers.

Guangjie Han et al [3] proposed a cross layer solution combining energy efficient routing selection with selective forwarding for retransmission. Lu et al [4] presented methods to extends the life cycle of industrial IoT wireless sensor networks using I3Mote platform. The lifetime of each of the node is increased using duty cycle optimization. Based on the duty cycle time, the data scheduling and wake up time scheduling is adjusted to increase the network lifetime. But the duty cycle decision is made at node level without consideration of data arrival times and node neighborhood information.Gungor et al [5] made a survey on technological challenges and design principles in industrial IoT wireless sensor networks. Authors specifically focused on three areas of: antenna techniques, energy harvesting approaches and cross layer optimizations. Authors made an important observation that cross layer technologies and optimizations looks promising compared to other techniques in addressing the QoS requirements of industrial applications.

Singh et al [6] studied the issues in application of cross layer design for industrial IoT sensor networks. Among many factors like lack of standardization, QoS, interoperability, security – quality of service is an important challenge in adoption of cross layer protocol. In addition to energy optimization, quality of service is also considered in this research paper scope. Souza et al [7] proposed a cross layer architecture involving physical, middleware and application layer. The functionalities at middleware and physical layers are adapted based on cross layer communication feedback. This adaptation is done at application layer. Application layer can enable, disable the services or modify the service control parameters. But this work did not consider any objectives like energy minimization, QoS guarantee etc.

Zhang et al [8] designed a routing algorithm for industrial wireless sensor network which is QoS aware and energy efficient. The relay node selection is done is such a way to balance the energy and guarantee higher reliability for packets. The routing facilitates differential QoS for packet based on the timeliness of data. The solution addressed three different timeliness. Liu et al [9] proposed a method to conserve energy in nodes of IoT network by shifting energy consumption to grid. The complex design problem is translated by parametric transformation technique to traceable ones. Liu et al [10] addressed the problem of energy efficiency in task offloading decisions. A collaborative task offload algorithm was proposed. This algorithm achieved energy efficiency by offloading energy intensive computations to Cloud. This increased the lifetime, but it comes at cost of delay and loss of security.

Xiang et al [11] attempted to make the data collection process in sensor network energy efficient. This scheme is based on matrix filling theory. The network is clustered and the data collection schedule is found using matrix filling theory. The schedule achieved balance between energy and delay. But the data collection scheme does not consider the data priority and gives equal importance to all nodes. Wang et al [12] proposed an adaptive duty cycling algorithm with the goal of increasing the lifetime of the network. The duty cycle of network is adapted from ranges of low duty cycle to high duty cycle. Depending on the energy availability in an area, the duty cycle mode is switched between two modes. Though it increased lifetime, it increased the delay and the approach is not suitable for real time data collection.

Du et al [13] used compressive sensing and forecasting to reduce the energy consumption of IoT device. Through compressive sensing, the number of packets to be sent from IoT device to sink is reduced. In addition, forecasting model is implemented at receiver end to forecast data without necessity of data to be sent from IoT devices. Data from IoT devices is needed only during the stage of building models and for synchronization of models. But the model is not suitable for kinds of data from IoT devices. Qawy et al [14] discussed various approaches like reducing the volume of data transmitted, transceiver optimization, energy optimal routing and protocol overhead reduction etc. to improve the lifetime of IoT networks. These mechanisms could be further improved by energy harvesting and machine learning techniques.

Wu et al [15] reduced energy consumption due to congestion by adopting TDMA scheduling at MAC layer. This reduced conflicts in occupying same timeslots. This reduced the energy wastage due to retransmissions caused by congestions. But the scheduling did not consider application characteristics and this affects the service level agreement of the application. Cheng et al [16] used matrix completion based solution for data gathering from sensor networks in an energy efficient manner. The algorithm exploited the low-rank feature instead of sparsity. But relying on features need semantic level knowledge of application data characteristics and thus the solution is application specific.

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Wu et al [17] proposed a compressive sensing method to reduce the data volume to be transmitted to reduce the communication energy consumption. But the compressive sensing methods create large delay at reconstruction side and not suitable for real time application characteristics. Xiang et al [18] used matrix filling theory to design a data collection scheme for sensor with two objectives of reducing the delay and energy consumption. The effective number of transmissions is reduced in the network and this increases the life span of IoT devices.

He et al [19] used sparse sampling for energy efficient data collection. The approach reduced energy consumption by making certain percentage of nodes to sleep. From sparse samples, entire data is reconstructed under the constraints of low rank. A tradeoff is made between the communication energy consumption and accuracy of data. But these schemes are tightly coupled with data characteristics and not generic.Wang et al. [20] reduced energy consumption in IoT network by adopting multiple strategies of transmission power adjustment; channel scheduling and offloading energy intensive tasks. But this scheme did not consider task QoS while balancing power consumption.

From the survey on exiting approaches for reducing energy consumption in IoT networks, following issues are identified. There is a less emphasis towards adoption of network layer in cross layered-based approach which is essential to be considered while forming routing strategy. The core part for energy efficiency calls for considering multiple constraints associated with the resource constraint IoT device, which is missing in existing approaches.Effective balance between the controlling of energy dissipation, upgrading routing performance, and data transmission performance is less seen to be involved in existing approaches. In the proposed cross layer solution, we address these issues.

## 3. Proposed Cross Layer Solution

The architecture of the proposed cross layer solution is given in Figure 1. The proposed cross layer strategies in application, network, MAC and physical layer for optimizing the energy consumption and increasing the life span of IoT network. At physical layer, transmission power is adjusted to reduce the energy wastage. Transmission power is adjusted based on the feedback from network layer. At MAC layer, duty cycling is done in an adaptive manner based on the network topology information and residual energy of node to reduce the energy consumption of nodes. Also, the packets are scheduled for transmission in the network based on priority and network conditions, so that congestion and energy overhead due to congestions can be avoided. At network layer, clustering is done. Adaptive aggregation and routing are done to reduce the energy consumption at same time without much distortion to QoS.

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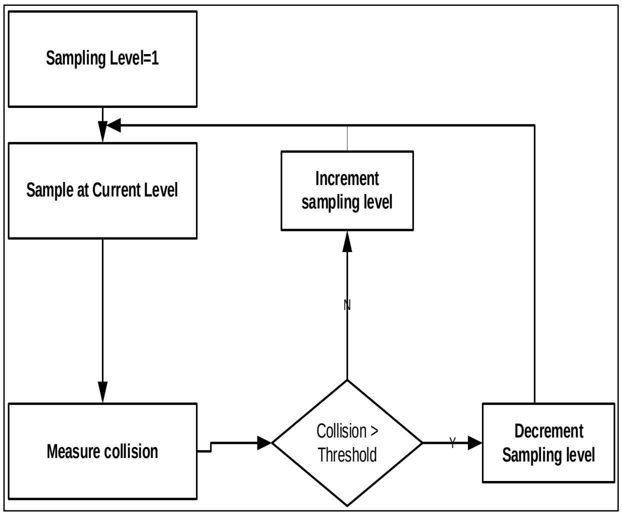


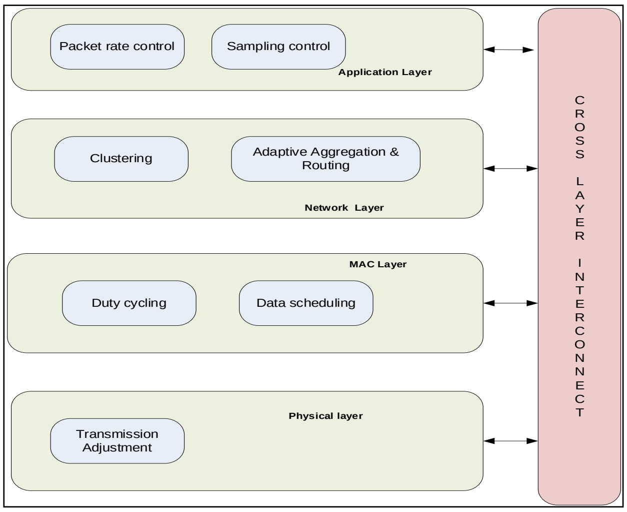


**Figure. 1 Proposed cross layer solution** **Figure 2: Sampling rate control**

At application layer, the sampling time and rate of packets are controlled in proportion to the resident energy available at the nodes and the network conditions. By this way the lifetime of node can be prolonged. Publish subscribe based mechanism is adopted at the cross-layer interconnect. Each layer monitors its layer specific performance parameters and sends it to the cross-layer interconnect. Any layer can subscribe for any events in the cross-layer interconnect. The subscribed events are pushed to the layers on arrival of event to cross layer interconnect. By this way, this issues in interoperability and standardization of interfaces in cross layer is solved. The events monitored at each layer and pushed to the cross-layer interconnect is given in Table 1.

**Table 1. Event information**

| **Layers** | **Events pushed to cross layer interconnect** |
|---|---|
| MAC layer | Number of collisions |
| Application layer | Round trip time (RTT) |
| Physical layer | Residual battery energy |

MAC layer measures the number of collisions and pushes to the cross-layer interconnect. Application layer subscribes to this event “number of collisions”. Application layer adapts the sampling rate according to collision statistics. Figure 2 details the collision statistics-based sampling rate adjustment process. The sampling level is made discrete. Node starts sampling at default or current level and it observes the collision every periodic interval once. When the collision is above threshold, sampling level is reduced, thereby reducing the number of packets generated at

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source. This reduction is repeated till the congestion drops below a threshold. When congestion drops, sampling level is increased. In addition to sampling control, packet generation is also controlled at source. Packet generation control is realized with aggregation at source. The packets are aggregated in such a way, a representative value which least error to all values is created and single packet with representative value is sent, instead of multiple packets. By this way, packet sent from source is adapted to the current congestion level.

Network is clustered and a cluster head is selected for each cluster area. The cluster head node aggregates packets from multiple nodes and send the aggregated packet to sink. Due to aggregation, the effective number of transmissions is reduced and this in-turn reduces the energy consumption. An adaptive aggregation is implemented at the cluster heads, based on the current RTT measurements at application layer. Based on past delay in forward and backward direction, RTT is calculated in term of probability mass function of distribution of delay. It is given as,

$$\mathrm{RTT} = \begin{cases} \sum_{i=0}^{\infty} f_i(a).f_i(b) & , x = 0 \\ \sum_{i=0}^{\infty} f_i(a).f_{2x+i}(b) + \sum_{i=0}^{\infty} f_i(b).f_{2x+i}(a), & x > 0 \end{cases} \quad (1)$$

Where a represents the forward path from transmitter to receiver and b represents the backward path. The probability mass function on delay is given as f. The number of packets to be aggregated is calculated based on predicted RTT as

$$N_p = \frac{N*K}{RTT} \quad (2)$$

Where K is the minimum value for RTT and N is maximum number of packets that can be aggregated at a cluster head. Once the number of packets to be aggregated $N_p$ is calculated, cluster head has to proportionately allocate $N_p$ according the packet priority.

By dynamically adjusting the sampling rate at nodes and aggregation rate at cluster head, the effective congestion is reduced and this in turn reduces the packet retransmission and the energy wastage due to packet retransmission.Energy efficient clustering topology is achieved in this work using particle swarm optimization (PSO). The cluster are created using Particle swarm optimization (PSO) considering reducing overall energy consumption and increasing life time of network. Particle swarm optimization is a search optimization algorithm. Swarms search for local solutions. The most best solution is made as global solution and in next iteration swarms search for optimal solution near the global solution. This process is repeated till a optimal solution is found. The solution to be optimized in defined in terms of fitness function. Fitness function is evaluated at every iteration and solution space with higher fitness value is decided as optimal solution is very round.

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The fitness function for clustering is based on three factors of

Average density of cluster ($F_1$)

Average energy of cluster ($F_2$)

Effective hop count to sink ($F_3$)

Fitness function tries to maximize these factors. It is written as

$$FV = \alpha_1 F_1 + \alpha_2 F_2 + (1 - \alpha_1 - \alpha_2) F_3 \quad (3)$$

$$F_1 = \frac{\sum_{i=0}^{M} d(currentnode, memberi)}{n} mf(i) \quad (4)$$

$$mf(i) = \begin{cases} 1, & ifmemberiiscoveredbycurrentnode \\ & 0, else \end{cases} \quad (5)$$

M is the number of cluster members in the current cluster node.

$$F_2 = \frac{\sum_{i=0}^{M} E(memberi)}{E(currentnode)} mf(i) \quad (6)$$

$$F_3 = \frac{1}{Numberofmemberscoveredbycurrentnode} \quad (7)$$

$E(i)$ is the residual energy on node i. $n$ is the total number of nodes and$\alpha_1$, $\alpha_2$, $\alpha_3$ are the weighting factors such that

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 \quad (8)$$

The cluster heads are selected in each round to maximize the fitness function. The cluster head combination which provides the highest value for fitness function is selected as the optimal cluster heads. Once cluster heads are selected, nodes join to the cluster of their nearby cluster heads.An adaptive routing using cluster based geographic routing is realized in the network layer for energy optimized routing. Geographic routing is adapted to select next hop relay based on preference score (PS) in this work. The preference score (PS) for routing path is calculated as weighted function of reliability score and energy score.

$$\mathrm{PS} = \mathrm{w}_1 * \mathrm{ES}_\mathrm{p} + \mathrm{w}_2 * \mathrm{R}_\mathrm{t} \quad (9)$$

With $\mathrm{w}_1 + \mathrm{w}_2 = 1$

The energy score ($\mathrm{ES}_\mathrm{p}$) is calculated as

$$\mathrm{ES}_\mathrm{p} = \frac{10*(\mathrm{E} - \mathrm{TPC} * \mathrm{E}_\mathrm{c})}{\mathrm{E}} \quad (10)$$

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Where $\mathrm{TPC}$ is the total packet transmitted Relay node acknowledges success transmission of packet to next hop with a message. On reception of this message, cluster head increased packet forward success count (PFS). Reliability score is then calculated from PFS and TPC periodically as

$$R_t = \alpha \times R_{t-1} + (1-\alpha)\frac{PFS}{TPC} \quad (11)$$

With $R_0 = 0$

The source node which want to send packet to destination, first send the packet to its cluster head. Cluster node broads a HELLO packet to its neighbor and expects HELLO_RES with preference score (PS). On reception of HELLO_RES, the neighbors are sorted based on distance to sink and first K neighbor are picked from it. Among these K neighbor, the one with highest PS score is used for data forwarding.The process is repeated till the packet reaches sink node. The preference score is joint function of energy and packet reliability (QoS), thereby another issue in cross layer protocols of reduced QoS in terms of packet reliability is effectively solved in the proposed solution.

The IOT devices can be heterogeneous with different capabilities and the depending on the next hop selected for routing, Network and Physical layer cooperate to adjust the transmission power dynamically, so that energy wastage due to transmission can be avoided. In the hello res, the cluster head node sends it location and through it, the receiving cluster head calculates the distance and sends to the physical layer. Physical layer calculates the transmission power based on the distance measurement. The transmission power ($P_t$) is calculated as

$$P_t = P_{max} * d/R \quad (12)$$

Where $P_{max}$ the maximum power is $d$ is the distance to the next hop cluster head provided by the network layer and R is the communication range.

## 4. Results and Discussions

Network simulator 2 (NS2) was used to simulate the proposed solution with following configuration parameters as shown in Table 2.

**Table 2. Configuration Parameters**

| **Parameters** | **Values** |
|---|---|
| Number of Nodes | 60 to 100 |
| Communication range | 100m |
| Area of simulation | 1000m*1000m |
| Node distribution | Random distribution |
| Simulation time | 30 minutes |
| Interface Queue Length | 50 |
| MAC | 802.11 |
| Percentage of nodes sending data | 10% of total nodes. |

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The proposed work is compared against energy efficient QoS aware routing in [8] and cross layer design approach proposed in [9].

The performance is measured in terms of

1. Lifetime
2. Packet delivery ratio
3. Delay
4. Throughput
5. Network overhead

Lifetime is measured in terms of first node death for various numbers of nodes and the result is given below table 3 and comparative analysis of lifetime has been represented in the figure 4.

**Table 3. Lifetime comparison**

| | Lifetime (minutes) | | |
|---|---|---|---|
| **Number of nodes** | **Proposed cross layer** | **QoS routing [8]** | **Cross layer [9]** |
| 60 | 8.4 | 3.39 | 4.39 |
| 70 | 5.9 | 3.1 | 4.1 |
| 80 | 5.4 | 2.59 | 3.39 |
| 90 | 5.2 | 2.39 | 3.2 |
| 100 | 4.9 | 2.19 | 3.1 |

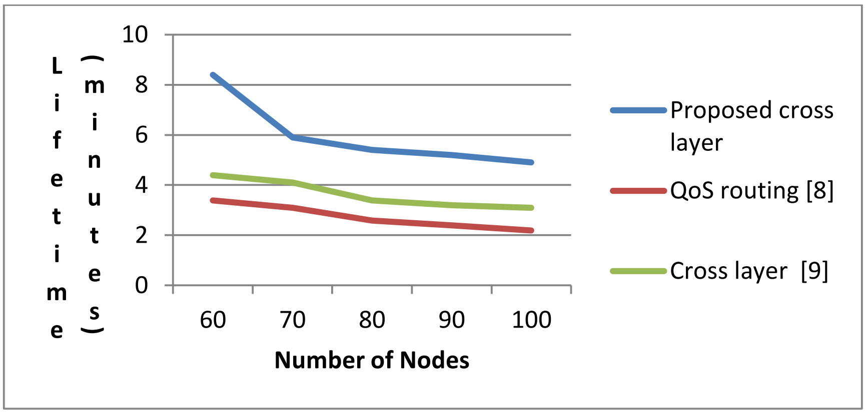


**Figure. 2 Comparative analysis of lifetime**

The lifetime decreases as the number of nodes increases as number of nodes sending data also increases. But the average lifetime in proposed solution is 54.16% higher compared to QoS routing [8] and 39.09% higher compared to Cross layer solution [9]. The lifetime has increased manifold in the proposed solution due to solutions for optimization of energy implemented in application, network, MAC and physical layer. Varying the number of nodes packet delivery ratio is measured and result is given below table 4.

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**Table 4. Packet delivery ratio comparison**

| | **Packet delivery ratio** | | |
|---|---|---|---|
| **Number of nodes** | **Proposed cross layer** | **QoS routing [8]** | **Cross layer [9]** |
| 60 | 94.54 | 92.10 | 83.68 |
| 70 | 98.83 | 93.15 | 83.15 |
| 80 | 97.14 | 93.68 | 87.36 |
| 90 | 98.63 | 95.26 | 86.3 |
| 100 | 98.27 | 95.26 | 86.84 |

Packet delivery ratio increases with increase in number of nodes as there are more reliable paths for routing due to increase in the density of nodes. But the average packet delivery ratio in the proposed solution is 3.59% higher compared to QoS routing [8] and 12.02% higher compared to Cross layer solution [9]. The packet delivery ratio is increased due to effective congestion control and selection of paths with higher reliability in the proposed solution. By varying the number of nodes, average packet delay is measured and tabulated in table 5 and comparative analysis of delay has been represented in the figure 5.

**Table 5. Packet delay comparison**

| | **Packet delay (ms)** | | |
|---|---|---|---|
| **Number of nodes** | **Proposed cross layer** | **QoS routing [8]** | **Cross layer [9]** |
| 60 | 475 | 689 | 755 |
| 70 | 399 | 506 | 515 |
| 80 | 465 | 636 | 475 |
| 90 | 960 | 1356 | 1045 |
| 100 | 1236 | 1511 | 1442 |

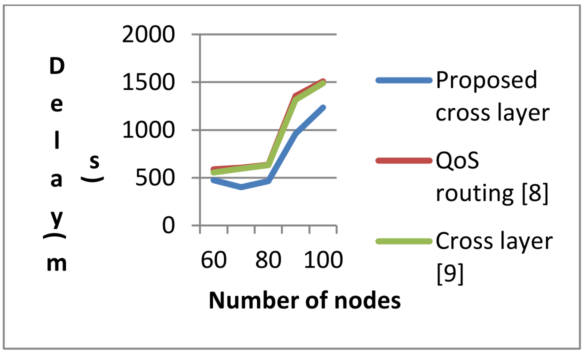


**Figure. 5 Comparative analysis of Delay**

The packet delay increases, due to increase in number of packet sources in proportion to the nodes. The average packet delay in proposed solution is 32.81% lower compared to QoS routing[8] and 29.70% lower compared to Cross layer solution [9].

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The delay has reduced in proposed solution due to reduction in number of packets with increased in the round trip time. With reduced packets in the network, the effective packet traversal delay also reduced.

**Table 6. Throughput comparison**

| | **Throughput (Kbps)** | | |
|---|---|---|---|
| **Number of nodes** | **Proposed cross layer** | **QoS routing [8]** | **Cross layer [9]** |
| 60 | 92 | 84 | 83 |
| 70 | 140 | 136 | 129 |
| 80 | 181 | 173 | 167 |
| 90 | 224 | 208 | 201 |
| 100 | 267 | 251 | 242 |

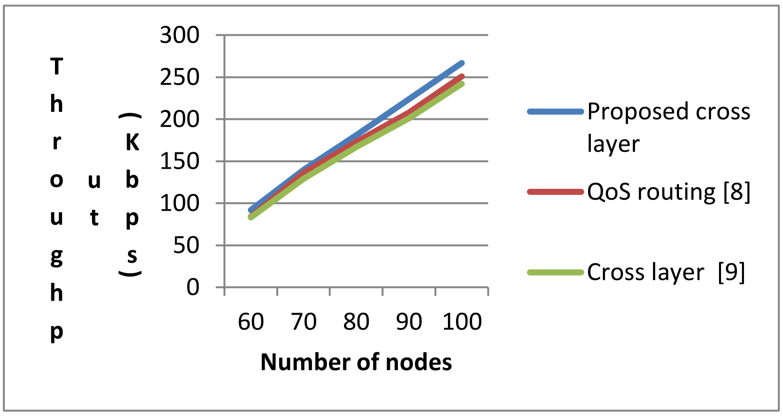


**Figure. 6 Comparative analysis of throughput**

The proposed solution has on average 6.2% higher throughput compared to throughput QoS routing [8], 9.97% higher than Cross layer solution [9]. Two level of aggregation at node level and at cluster head level has increased the throughput in the proposed solution. Network overhead is measured for number of nodes and the result is given table 6 and figure 6.

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**Table 7. Network overhead comparison**

| | Network overhead (Kb) | | |
|---|---|---|---|
| **Number of nodes** | **Proposed cross layer** | **QoS routing [8]** | **Cross layer [9]** |
| 60 | 72 | 80 | 82 |
| 70 | 85 | 92 | 93 |
| 80 | 89 | 97 | 100 |
| 90 | 94 | 104 | 108 |
| 100 | 97 | 116 | 118 |

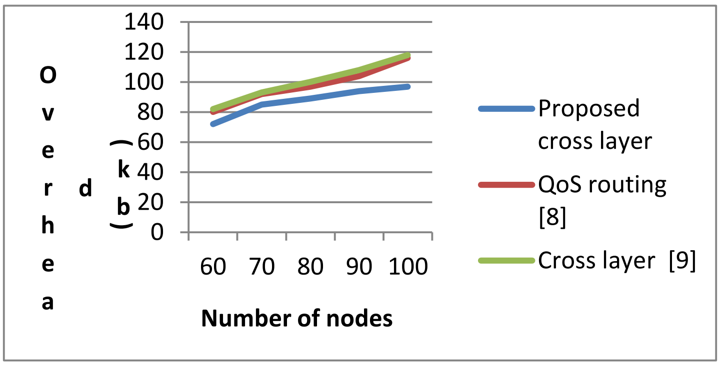


**Figure. 7 Comparative analysis of overhead**

The proposed solution has on average 10.62% lower network overhead compared to QoS routing [8], 12.77% lower than Cross layer [9]. The network overhead has reduced in the proposed solution due to clustering topology and geographic routing. Geographic routing has reduced overhead compared to adhoc routing protocols and results has been tabulated in table 7 and graph representation in figure 7.

## 5. Conclusion`

A Cross layer solution with joint consideration of energy optimization and QoS guarantee is proposed in this work involving changes in application, network, MAC and physical layer. Adaptive sampling and packet generation rate control is realized at application layer. Adaptive Clustering and geographic routing is realized in network layer. Adaptive packet scheduling is realized in MAC layer. Adaptive transmission power adjustment is realized in physical layer. With all these cross layer changes, the proposed method is able to higher life and QOS. Extending the solution for fault tolerance is in future scope of work.

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