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CCLRSP - A COLLABORATIVE CROSS LAYER ROUTE SELECTION PROTOCOL FOR LOW-POWER LOSSY WIRELESS NETWORKS

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ABSTRACT

Route selection in low-power lossy networks (LLN) is a challenging task due to the constrained nature of wireless devices. With the LLN providing the underlying network for several IoT applications, which require devices with high network activity, energy efficiency becomes more crucial in comparison to typical wireless sensor networks (WSNs). Also, most of the works in this direction that are based on cross-layer designs only rely on either physical layer or medium access control (MAC) sub-layer optimizations to select routes. The majority of the contributions identified with Cross Layer Design that depend on just physical layer grandstand where by changing the transmitting power, the energy devoured by the nodes can be upgraded. Additionally, the works that depend on just MAC sub-layer can only target on the issues like contention, impacts with least yields towards the collective advantages. In this work, a novel attempt is made to achieve the collaborative benefits of the node and as well as the network. In this paper, we initially show that considering both physical and MAC layer properties can benefit the route selection process by lowering the individual devices' energy and also the overall network lifetime. Then, we propose a collaborative cross-layer route selection protocol - CCLRSP that relies on physical layer and MAC layer properties to choose a low-cost route. At the physical layer, we employ the adaptive and robust topology control mechanism (ART) that is based on determining the optimal transmission power for a transmitter to reach the next-hop neighbor. At the MAC level, the physical layer findings are cross verified to minimize the contention and interference through the expected transmission count. The proposed protocol combines the parameters from these two layers to select an energy efficient route that employs a balanced approach to prevent few network nodes from draining energy quickly by load-balancing. The proposed protocol is evaluated using extensive simulations and is shown to perform better than existing works.

Keywords: *Low-Power Lossy Networks, Cross-layer Design, Cross Layer Route Selection, PHY & MAC Layers, Wireless Sensor Networks, Internet of Things,*

1. INTRODUCTION

Low power wireless networks like wireless sensor networks (WSNs) have generated renewed interest due to the effectiveness of the solutions offered by Internet of Things (IoT) [1]. In this context, several issues are investigated to fit different applications of IoT [2]. One of the major challenges in IoT is the need for energy efficient protocols for the underlying wireless sensor network of devices [3]. An IoT network, similar to a WSN, is comprised of several wireless devices that are constrained in terms of processing, power, and memory. Lot of research has been carried out addressing these challenges in WSN. However, with the new emerging applications of WSN, and with the capability to control and manage the devices over the Internet (therefore referred to as IoT), most of the existing solutions for WSN are re-designed to meet the requirements of different IoT applications [4]. The different applications of IoT include cities, energy grids, industries, healthcare, transportation, homes, and any possible applications that a human mind can fathom [5]. With the emergence of these smart applications, and with the capability to be connected to the Internet provides the ability for a user to manage and control these devices remotely.

Also, with the emergence of other allied technologies like cloud-computing, which provides a custom-fit solutions to store and organize the humongous amount of data generated by these devices, newer solutions are desired [6]. In contrast to WSNs, that are typically employed to meet the needs of a particular application, devices in IoT can be more active, typically support multiple types of tasks, and have higher commercial outlook [7]. For example, a cyber-security solution offered in the context of a smart city may involve several wireless devices that provide knowledgeable data to multiple governmental agencies like police, traffic control, intelligence agencies, and other task centers [8][9][10]. These devices operate cooperatively and constantly report events of interest. Therefore, the wireless network of such devices must be highly energy efficient, latency sensitive and meet pre-defined performance requirements [11]. Further, networks need to be more reliable, robust and also fault-tolerant. These issues have motivated researchers to pursue several challenges in low-power, low-rate, lossy wireless networks, also called as LLNs [12]. Several standardization efforts by IETF [13], IEEE LAN/MAN [14], 3GPP [15] and industries are also on the way to standardize operations, development, and deployment of these networks. The RPL (routing protocol for low-power lossy networks) routing protocol is one such standardization effort by IETF that defines a routing protocol for LLNs [16]. The foremost challenge in a LLN is in the energy front. The wireless devices are power constrained and all efforts are focused on minimizing the energy consumption of these devices to increase the lifetime of the devices and in turn the lifetime of the network. Lowering the energy consumption of the devices not only boosts their lifetime but also helps in maintaining the crucial network connectivity, and also prevents missing out of crucial sensed information from the environment. The criticality of an application underscores the importance of continuous information and also the hostile environment prevent timely replenishment of energy sources. Thus, majority of the research is focused on enhancing the effectiveness of protocols, techniques and other underlying technologies [17]. Specifically, in a layered network architecture, at the physical layer the signal processing hardware, modulation schemes, power adjustment, etc. are optimized [18]. At the medium access control (MAC) sub-layer, focus is on minimizing contention, accounting for the various types of interference, quality of links, etc. is emphasized [19]. Similarly, different factors that impact the energy of devices at the network and higher layers of the network stack are identified and efforts have been carried out to address the different factors [20]. But, through the research on cross-layer design it has been clearly established that wireless networks immensely benefit by facilitating interactions across layers in a non-conventional way. Most of the research in this direction aim to develop cross-layer protocols that optimize energy savings by employing parameters specific to one layer of the network stack at a different layer [21][22][23]. The design of the routing metric, Expected Transmission Count (ETX) is an example of a cross-layer optimization that uses the transmission count at the MAC layer as a metric for multi-hop route selection at the network layer [24]. As significant amount of energy is spent on communication, most of the research is focused on radio communication techniques of these wireless devices. In this paper, we propose a low-overhead energy efficient cross-layer route selection protocol for LLNs. The proposed protocol, in contrast to other existing techniques that use either PHY or MAC sub-layer properties, considers different parameters from both PHY, MAC to make an energy efficient route selection decision. The proposed protocol also strikes a balance between individual node energy optimization and overall network lifetime optimization dynamically. This allows load-balancing among network devices and thereby prevents devices from energy drain out. It combines the best indicators of energy consumption at PHY and MAC to make an efficient multi-hop route selection decision.

Motivation: The most prominent challenge in a Low power Lossy Networks is the energy front. As it is well known, the devices are generally power restricted and all efforts are focused on reducing the energy consumption of these devices to maximize their lifetime and in turn the overall network lifetime. Minimizing the energy consumption of the devices obviously prolongs their lifetime and contributes in maintaining the crucial network connectivity. This further, paves a way in preventing the loss of significant sensed data even from the hostile environment. Hence, majority of the research is focused on betterment of the effective protocols, mechanisms and more underlying technologies.

Existing route selection schemes form WSNs that aim to conserve energy are not directly applicable to IoT applications as the devices in the latter tend to be more active, i.e., these devices typically are involved in higher network activities, generate data more frequently, and usually serve multiple applications. Further, the routing protocols based on cross-layer design for WSNs are either based on physical layer properties or MAC layer parameters that are applied at the routing layer for energy efficient route selection. Works that rely on PHY showcase that by adjusting the transmitting power, the energy consumed by device transceivers can be optimized. Further, it has been shown that by adapting the transmission power of devices, contention at the MAC layer can be significantly lowered, thereby increasing the network capacity. Also, most of the existing schemes either aim to optimize overall network lifetime without optimizing the nodes' energy levels or vice versa. Therefore, there is a need to address these challenges in the context of LLNs.

***Contributions**:* In this research work, we aim to design a cross-layer route selection protocol that makes a route selection decision based on interactions with MAC and PHY layers. More specifically, the following are the main contributions of this paper:

a) A system-model that identifies the properties that impact the energy of a device at the PHY layer, and how these properties when adapted, can be employed at the MAC layer for facilitating the route selection decision.

b) A cross-layer route selection scheme that is neither solely based on optimizing the overall network life-time nor individual nodes' energy, but balances between the two factors by load-balancing route selection decisions.

c) Analytical and simulation results to analyze the performance of the proposed scheme under different network conditions.

In this paper, we propose a collaborative cross-layer route selection protocol - CCLRSP that relies on physical layer and MAC layer properties to choose a low-cost route. The proposed protocol combines the parameters from both the MAC and Physical layers to select an energy efficient route that employs a balanced approach to prevent few network nodes from draining energy quickly by load-balancing. The remainder of the paper is organized as follows. Section 2 provides a brief review on the related work carried out in the area of route selection in low-power lossy networks. The proposed collaborative cross-layer route selection protocol – CCLRSP is presented in Section 3 along with detailed discussion on the phases of Route selection process. Section 4 provides performance evaluation and experimental results and discussion along with comparative analysis of the approaches. Finally, Conclusions and future directions are presented in Section 5.

2. RELATED WORK

Route selection in low-power lossy networks is a challenging task as majority of Internet of Things applications involve high network activity. Existing solutions for wireless sensor networks cannot be adapted directly to underlying LLNs for IoT applications, even though device characteristics are similar. This is due to the inherent assumption that WSNs involve applications where data is reported by devices less frequently compared to its IoT counterparts. In IoT applications, network of devices is more engaging with the environment and report data almost in a continuous fashion. This has motivated researchers to revisit the problem of route selection in LLNs.

Routing protocol for low-power lossy networks is one such standardized protocol that has been designed for low power lossy networks [25]. Further works in this direction have been mainly focused on improving device and network parameters like device energy consumption, network throughput, latency, etc. [26-30]. However, it has been shown that the design of cross-layer metrics typically out-perform network-layer metrics [31-34].

The work presented in [35] is one such cross-layer mechanism that uses adaptive transmission power control at the physical layer to adjust energy consumption for transmission under different network conditions. It aims to strike a balance between power reduction, and also minimizing interference to boost network performance. However, considering only physical layer properties in route selection leaves out scope for bettering performance. The authors of [36] present a new energy consumption equilibrium model based on shuffled frog leaping algorithm to boost network lifetime and QoS. It considers physical layer properties like transmission power, receiving power, and signal bandwidth aimed to optimize total energy consumption of devices. It uses wavelet neural network to reduce the long-range dependence of the signal that is used to optimize energy savings.

The use of power control techniques for route selection has been widely studied and has been shown to achieve better results [37-38]. The authors in [37] analyze how transmission power changes affect the quality of low power RF wireless links between nodes. It shows how significant variation in link qualities occur in real-world deployments and how these effects strongly influence the effectiveness of transmission power control. It further proposes a packet-based transmission power control mechanism that incorporates blacklisting to enhance link reliability while minimizing interference. The work presented in [32] presents a cross-layer objective function for RPL that aims to address the latency and reliability requirements using a combination of route design and power control. It uses a fuzzy logic-based combination of expected transmission count (ETX) and estimated latency across protocol layers.

In [39], the performance of RPL routing protocol along with Contiki [40] medium access control protocol, specifically the CCA threshold is evaluated. It explores the correct parameter tuning that is needed for WSN in an interference-poor environment. Even though, a few works exist that focus on a cross-layer modeling of metrics for LLNs, majority of these models focus on either physical layer properties combined with routing metrics at the network-layer or MAC layer properties with the network layer. In this work, we aim to show that employing both physical and MAC layer properties for route selection and verification can boost energy performance of network devices in IoT networks.

3. PROPOSED CCLRSP APPROACH

In this section, we present our collaborative cross-layer route selection protocol - CCLRSP that relies on physical layer and MAC layer properties to choose a low-cost route.

3.1 NETWORK MODEL

We consider a wireless network where devices (also called as nodes) are connected in an ad hoc mode. Each node may be connected to multiple neighboring nodes through wireless links. Wireless links can be asymmetric, i.e. the forward link to a neighboring node can be good (operational), whereas, the reverse may be weak (non-operational). This is represented using a graph $G= [N, E]$, which is a set of nodes N and set of edges E. A unidirectional edge on the graph G represents an asymmetric link and a non-directional edge represents a bi-directional link. Nodes sense and report events of interest to one or more base stations in a multi-hop fashion. Nodes may have varied energy levels to reflect the real-life network scenarios. Nodes are considered to be self-configuring, and once deployed can cooperate to make the network operational. Each node may optionally be connected to the Internet, therefore a suitable IP address mechanism is considered. The nodes can be controlled and managed for the change in configurations via the Internet.

3.2 PROPOSED CROSS-LAYER ROUTE SELECTION PROTOCOL

The proposed route-selection protocol is designed to operate in two phases. In the first phase, the parameters necessary for route-selection are computed and in the second phase, an energy efficient route is selected. It is based on the fact that setting the transmitting power to an optimal value (typically to a minimum) such that the graph that represents the network comprising of wireless links between nodes is connected. Each node broadcasts a sequence of messages to compute the desired power level that is necessary to maintain the required packet reception rate (PRR) for each link. Computing the optimal power levels not only contributes to energy saving, but also lowers the contention at the MAC level, lowers the interference (as simultaneous communications at higher transmission power results in packet collisions, resulting in retransmissions, back-off, etc.), and increases the network capacity. The chosen power levels are cross-verified at the MAC level to measure the contention and interference in terms of number of transmissions required for successfully sending a message over a wireless link. On computing the required values for each node, a route selection decision is based on selecting a next-hop node based on the energy required for a transmission, the remaining energy levels of a node. The details of the proposed route-selection process are as follows:

Phase I - Physical Layer Properties: The optimal power selection strategy at the physical layer is based on an adaptive and robust topology control mechanism, namely ART. It is based on the Packet Reception Ratio (PRR) metric, which is shown to lower energy consumption, contention and interference. For any given edge (wireless link), the PRR is computed for the nodes connected to it with one of the nodes (sender) transmitting a set of pre-defined size messages in a fixed interval, maintaining the inter-arrival time (μ) between messages. The transmission power, P_{tx}, can assume different values distributed in discrete levels provided in the radio transceiver. When a packet is correctly received, an ACK is sent back for confirmation. PRR is calculated as the ratio of the number of received packets over transmitted packets, within a window W of N transmitted packets. Needless to say, the number of received packets is equal to the number of received ACKs. Then, PRR is compared with two thresholds, η_l and η_h, chosen in order to keep it in the specified range of values. η_l is calculated as the product of the window size and PRR target p ($\eta_l = N*p$). Similarly, $\eta_h = N*p'$, where p' represents PRR upper bound as the maximum acceptable performance by the system. Tuning Ptx to the lowest power, the failures should be kept under the threshold $1-\eta l$. Because of the bimodal relationship between PRR and Ptx, decreasing the power may lead to a PRR lower than p. For this reason, a trial state is introduced, following a reduction of power level, to evaluate the effects on the PRR. In this case, if the number of failures in W is higher than $(1 - \eta h)*N$, the calculation of PRR is stopped, the previous Ptx is restored, and W is flushed. Otherwise, if the trial is successful, the new power is confirmed. Moreover, ART protocol provides a gradient-based mechanism to monitor the contention on a link, which is enabled when PRR is lower than ηl. Thus, if the contention is low, Ptx is increased; otherwise Ptx is decreased. If PRR is greater than ηh, Ptx is decreased by one level; otherwise, PRR is lower than ηl, Ptx is raised by one level. In any other case, Ptx stays constant. After the comparison, W is flushed and the calculation starts again.

Phase I – MAC layer: Once the transmission power P_{tx} for each neighboring node is computed, it is cross-verified for its performance at the MAC layer. The P_{tx} represents the amount of energy to be spent by a transmitting node to reach the next neighbor. It does not incorporate the amount of energy spent by a receiver to receive a message. This being a non-negligible component, the total cost of a link is the energy spent by a transmitter and receiver to transmit and receive a signal. To measure the contention and interference on the wireless link, a node transmits a sequence of messages within a window of time *t*, and computes the number of successfully received messages within the time-interval. Even though, this is an indirect measure of interference and contention, it acts as a near approximate metric for computation of the same. The computed transmission count metric is not directly employed in the route selection decision but is used as a metric to verify the suitability of selected $P_{tx.}$ If the transmission count does not match with the selected $P_{tx,}$ i.e. for a selected P_{tx} if the transmission count is higher than a threshold, it implies that the selected $P_{tx,}$

even though is a minimum, it is not ideal for transmission.

Phase II – Route Selection: The route selection process involves selecting a route based on the inputs received from the PHY and MAC sub-layers. The selected route aims to minimize the energy consumed to transmit a message to the selected base station, thereby maximizing the life-time of the network. The route selection decision also considers individual energy levels of the nodes to prevent few selected nodes from being repeatedly selected and thereby draining out of their energy. This is done to prevent network disconnection. To select a route, each node considers the minimum transmission power required to reach the next-hop towards the destination (base station). The MAC layer in coordination with the PHY is responsible for providing the necessary information obtained during the Phase I. This information is maintained in the form of a neighbor selection table that contains list of all the neighbors and the minimum t_x (*min* t_x) power needed to reach the respective neighbor. All the nodes along the route towards the base station repeat the same process of selecting the next-hop. A route selection decision is made based on the cumulative energy consumed to reach the base station. However, each node tries to avoid nodes whose energy level are below a pre-defined threshold limit. This is time-bound condition that allows nodes to load-balance traffic among all its neighbors. The remaining energy levels of nodes is obtained in Phase I when MAC layer measures the expected transmission count of the neighbors. Avoiding nodes that do not meet the threshold momentarily allows nodes to increase the network life time and postpone network disconnectivity. The proposed algorithm is summarized below:

Algorithm I: ***Routing Tree Selection Process:***

```
1. Each node $n$ determines the min $t_x$ for all the neighboring nodes $k$ in its range.
2. Determine the contention and interference for all $k$ at the MAC layer.
3. On receiving $RS_{req}$ from the ROOT node $R$, a node processes it to select the next-hop towards BS.
4. If ($EL_{SN} < Min_{thresh}$)
       Increment $N_{min}^{count}$, number of nodes with remaining energy level below the $Min_{thresh}$;
5. Compute the cumulative energy metric.
6. Rebroadcast the $RS_{req}$.
7. On receiving multiple $RS_{req}$ from different neighbors, the $BS$ chooses a route with lower $min_{cum}^{energy}$ and $N_{min}^{count}$.
8. Send $R_{rep}$ towards $n$.
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The route selection process aims to avoid routes that has higher number of nodes whose remaining energy levels are below the threshold. The threshold can be adapted dynamically based on the network requirement. For example, in a network with higher user involvement like an industrial network can have lower percentage threshold, which allows nodes to adjust to such network requirements. On the other hand, in hostile environmental conditions where monitoring of network is difficult, the network can choose a higher Min_{thresh} for nodes.

4 PERFORMANCE EVALUATION & EXPERIMENTAL RESULTS

In this section, we present the performance results of the proposed protocol. The simulations are carried out on NetSim v12.2, a discrete event network simulator. These results are compared with other popular route selection metrics like ETX (expected transmission count), and ETT (Expected transmission time). A network of 64 IoT devices is set-up that are connected through the gateway to the sink-node as shown in figure 1. The sensor devices are equipped with IEEE 802.15.4 radios that operate in 2.4 GHz bandwidth spectrum. A maximum data rate of 250 kbps is chosen. The table 1 shows some of the important simulation parameters.

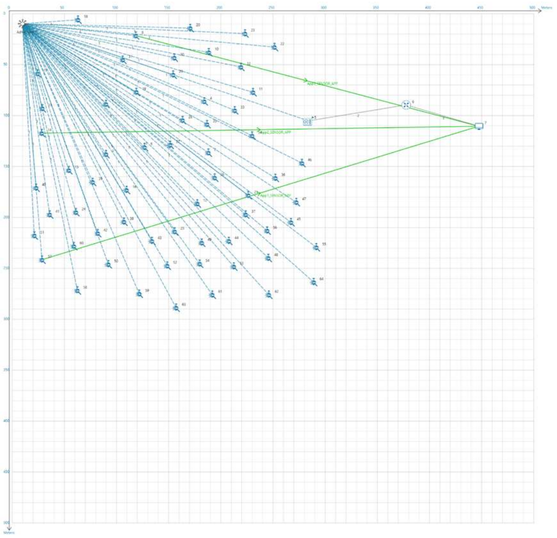

Figure 1: Network Of 64 Iot Devices

At the outset, we determine the performance of the proposed protocol in terms of overall network throughput and application throughput. Figures 2 and 3 showcase the performance of the proposed route selection mechanism and how the throughput varies over time. In comparison to the average throughput over time, the total network throughput is higher when only one application is active. It averages out as network activity increases. This shows that the proposed protocol provided a constant network and application throughput once a device selects best next-hops with minimum transmission energy.

Table 1: List Of Simulation Parameters

Parameter	Value
Data rate (kbps)	250
Receiver sensitivity(dBm)	-85
ED threshold(dBm)	-95
Transmitter Power (mW)	1
Distance between nodes (m)	2-8
Battery (mAH)	0.5
Frame retries	3
Max CSMA backoff	5
IP Protocol	IPv6
Simulation Time (secs)	10,000

The correlation between application throughput and link throughput is that the link throughput takes into account the entire traffic that was sent through the link. It includes data packets and control packets and includes retransmissions, errors or collisions. This would also include packet flows from multiple applications that may flow through the same link. Also note that the packet size at the link (physical layer) is the packet size at the application layer plus overheads added by different layers in the stack. The application throughput only takes into account those data packets (application layer packet size) that were sent from the source and that were successfully received at the destination.

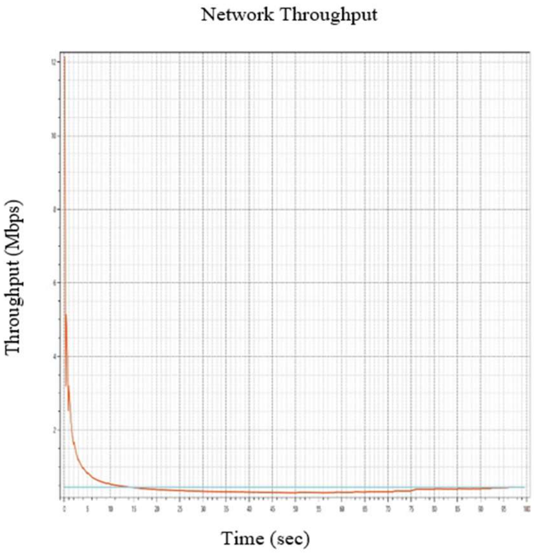

Figure 2: Average Network Throughput (In Mbps) Over Time

Next, we compare the performance of the proposed protocol with other widely employed metrics like ETX and ETT for computing the residual energy in devices over time. Computing the residual energy helps in understanding the performance of proposed protocol in terms of energy savings. Higher residual energy in devices implies better energy savings in terms of route selection. The detailed comparison among different metrics/protocols is shown in Figure 4. It can be inferred from Figure 4 that the proposed protocol is energy efficient in comparison to other two existing metrics as it employs cross layer features to select routes.

The minimum transmission power required to reach the next-hop is determined at the physical layer that helps in selecting a node with minimum energy requirement to reach the root. In other words, a next-hop node is selected to which minimum energy has to be spent to reach the root of the tree.

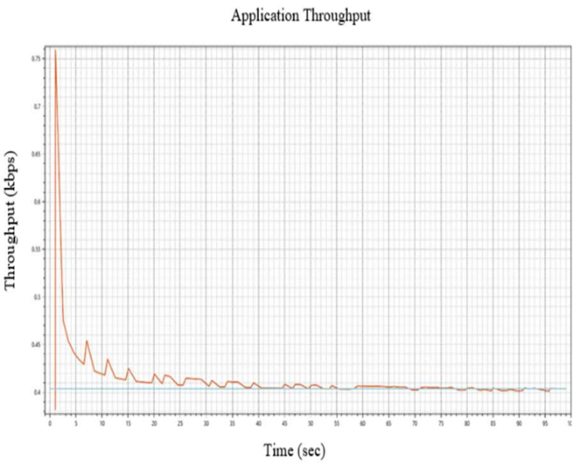

Figure 3: Average Application Throughput (In Kbps) Over Time

The MAC layer verification step allows a node to validate the performance of the selected next-hop in terms of channel contention and interference. Therefore, the routing tree selection process allows selection of nodes that incur minimum transmission cost in terms of energy. Therefore, over network time, the residual energy of nodes is higher using the proposed protocol. On the other hand, as ETX and ETT only employ the expected transmission count and expected transmission time respectively, their performance over a period of time results in selection of nodes that are not energy efficient. So, similar number of data transmissions results over a period of time results in higher energy spending. This is reflected in Figure 4, residual energy of nodes over time.

Further, to analyze the effectiveness of the proposed protocol, we compare the three schemes in terms of network connectivity. That is, the time at which a node expires in the network. Devices running out of energy is a regular phenomenon and, this typically happens quicker in networks with active data transmissions and later when the data transmission are lower. But, networks usually employ several energy conserving schemes to extend the lifetime of the devices. Thus, route selection is one such energy saving avenue that impacts the lifetime of the devices.

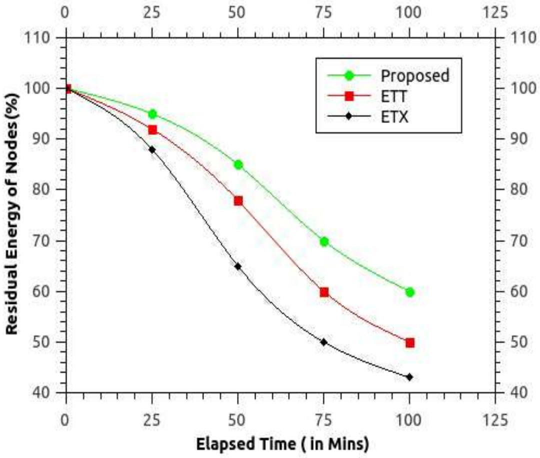

Figure 4: Elapsed Time Vs Residual Energy Of Nodes

As the routes selected determines which of the nodes are chosen to reach the destination, selection of nodes becomes crucial for boosting the network lifetime. In this process, the expiry (device running out of energy) of nodes is an indicator that helps in analyzing the effectiveness of a scheme. A scheme where such an expiry event occurs early indicates that the network may be disconnected. To analyze the performance in terms of expiry of the first node in the network, we set-up multiple continuous traffic flows in the network to determine when such an event occurs in the network. The comparison among the three schemes are shown in Figure 5. In ETT, as the emphasis is on transmission time, nodes are chosen that result in lower latency and lower transmission time. Therefore, the time at which the first node expires is much early compared to other two schemes. But, as ETX focusses on choosing a route that has lower transmission count, it incorporates energy draining factors like interference and contention in the network. Thus, using ETX the time at which first node expires is higher compared to ETT. But, the proposed scheme performs much better compared to other two schemes as it not only considers the link parameters that affect transmissions, it also considers the transmission power used by nodes to carry out a transmission. This significantly improves the lifetime of a device as transmissions at optimal power levels incur less energy expenditure, which further increases the lifetime of the device. In addition, the proposed scheme ignores nodes from routing tree selection that do not meet the minimum energy threshold requirements, this further prevents the nodes from expiry. In other words, load balancing of this kind helps in extending the lifetime of a device and prevents pre-mature expiry. The same can be inferred through Figure 6, where the proposed scheme achieves approximately 33% energy efficiency over ETX

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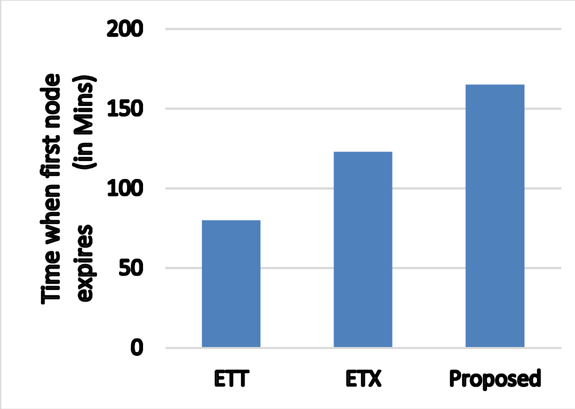

Figure 5 : Network Lifetime Comparison Of ETT, ETX, CCLRSP Approaches

Energy efficiency comes at a certain network cost. For a scheme to be efficient, this network cost should be lower than the achieved energy savings. Only then, the overall scheme is sustainable in comparison to other schemes. To analyze this cost, we carried out further experiments to compute the overhead of each of the schemes to construct routes. Higher overhead indicates that a scheme has to perform more number of network activities to calculate and establish routes. However, only higher overhead does not imply an energy inefficient scheme as earlier stated, the total effective cost in terms of energy savings should be positive (higher the better) after deducting the costs for route establishment. The analysis in terms of route calculation overhead in terms of energy consumed in shown in Figure V. As it can be seen that ETX is the simplest of the three metrics as it involves only periodic computation of number of transmissions required to the next-hop neighbor. But, the cost is still slightly higher compared to the proposed scheme as ETX involves periodic computation of ETX metric by all the nodes to their respective neighbors in the network.

On the other hand, in the proposed scheme, only the neighbors which satisfy the minimum energy criterion at the physical layer are selected for verification for contention and interference at the MAC layer. This lowers the route calculation overhead in comparison to ETX. However, it can be seen that the percentage of gains in comparison to ETX is very minimal, which is about 4% lesser than that of ETX. The major cost involved in the proposed scheme is during the calculation of minimum transmission power selection process that requires multiple transmission between nodes with their respective neighbors. Contrarily, it can be observed that ETT incurs relatively higher route calculation overhead as it packet-size and link capacity of the network. These computations are done frequently at periodic intervals thus incurring higher overhead.

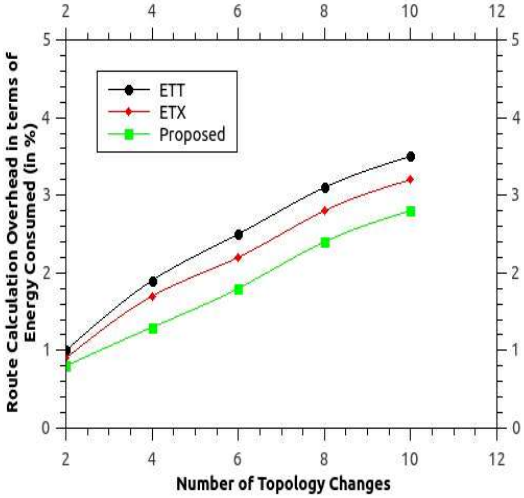

Figure 6: Energy Consumption Vs Topology Changes

Lastly, we analyze the performance of the proposed protocol in terms of network throughput. Even though the aim of the proposed mechanism is not to achieve high network throughput and be more energy efficient, analysis in this direction helps us to understand the quality of routes selected by the proposed route selection process. To evaluate the network throughput under varying network conditions, we measured the throughput in different network conditions. Initially, we measured the average network throughput by constantly increasing the number of independent data transmission flows in the network in a multi-point to point network traffic. Later for a fixed flows in the network, we measured the network throughput for varying network size. It can be observed in figure 7 that ETT achieves best network throughput in comparison to other two schemes. This is in expected lines as ETT not only chooses better links in terms of transmission count but also considers the link capacity. This allows ETT to select links with higher capacity thus boosting network throughput. The major comparison is between ETX and the proposed scheme. This is because the proposed scheme achieves both lower route computation overhead and better network throughput as it not only considers nodes with lower energy cost, but in this process selects nodes that have lower contention and interference thus achieving higher average throughput..

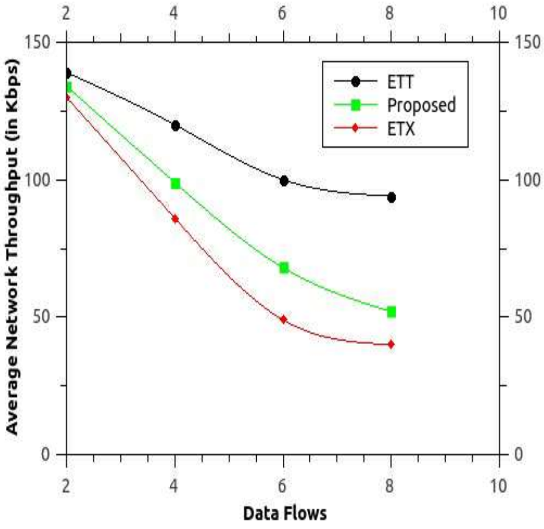

Figure 7 : Average Network Throughput Vs Data Flows

Table 2: Comparison Of Achieved Objectives

Route Selection Metrics	Computation Overhead	First node expiry approx. (in mins)	Average Network Through put	Residual energy of nodes
ETT	high	50-100	high	medium
ETX	medium	100-150	low	low
Proposed	low	150-200	medium	high

Therefore, it can be understood that the cross-layer route selection mechanism not only achieves intended energy savings but also contribute to the performance of the network in terms of improving the average network throughput. The table 2 shows the comparison of achieved objectives with respect to the other route selection metrics.

5 CONCLUSION & FUTURE WORK

In this paper, we proposed a collaborative cross-layer tree based route selection framework that incorporates multiple features from both the physical layer and MAC sub-layer to make a route selection decision. The proposed mechanism exploits the fact that lower transmission power results in less energy spending in the network. However, being aware that only selecting low transmission power may be counter-productive, it uses a MAC layer validation approach to validate the selected *tx* power levels. The MAC layer processes help in identifying the contention and interference at the selected power level, thus reducing retransmissions. These proposed metrics are employed by the routing tree establishment process to select routes to the root node. The proposed route selection protocol CCLRSP results in very less route selection overhead in competence to other existing schemes thereby showcasing an acceptable overall network throughput. The proposed mechanism can also be integrated with the existing standardized route selection protocol, RPL (routing protocol for low-power lossy networks). Through simulation analysis, we showed how the proposed protocol not only boosts the residual energy savings of a device, it also improves network lifetime. Further, we also show how the proposed protocol incurs very less route selection overhead in comparison to other existing schemes thereby contributing to the overall network throughput. Next, we aim to integrate the proposed scheme with RPL by selecting suitable message fields in destination oriented directed acyclic graph (DODAG) information object (DIO). As a future work, a study will be conducted in the direction of reducing control packet over head when a very frequent change of link is demanded by a suspicious kind of traffic in that region. When the nodes have good energy levels up to certain threshold it works efficiently but an indepth study and mechanism are required to support at the time of very low energy level and when a network is almost heading towards its end.

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