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LQI-Per-Based Range Adaptation For Enhanced Communication Range In Wireless Networks

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Abstract

Wireless networks are key components of contemporary communication systems, allowing for seamless connection and data sharing. Optimizing communication range to guarantee dependable and effective data transmission is one of the most difficult tasks in wireless networks. In this regard, this research provides a new technique dubbed LQI-PER-based range adaptation to improve wireless network communication range. The approach uses the network Quality Indicator (LQI) and Packet Error Rate (PER) measurements to dynamically alter individual node communication ranges depending on real-time network circumstances. When the connection quality is good and the PER is low, nodes may communicate over longer distances, extending network coverage and enhancing connectivity over longer distances. In the event of signal deterioration or interference, the approach decreases the communication range of impacted nodes automatically to retain efficiency and alleviate performance bottlenecks. The study describes in detail the LQI-PER-based range adaptation mechanism and explores its benefits in terms of better communication range, network reliability, and energy efficiency. The simulation findings show that the suggested technique is successful in dynamic and difficult conditions, making it a potential alternative for establishing robust and extended communication ranges in wireless networks.

Keywords: Adaptation, Communication, Link Quality Indicator, Packet Error Rate, wireless networks.

I. INTRODUCTION

Wireless networks have transformed the way we interact, access information, and do business in our contemporary linked world. These networks have made seamless and pervasive communication possible, letting devices and people to interact without the limitations of physical cords [1]. Wireless technology proliferation has permitted the growth of a diverse variety of applications, from mobile communication and internet access to Internet of Things (IoT) devices and smart city infrastructure [2]. The capacity to transport data and information via the air using electromagnetic waves, such as radio frequencies or infrared signals, is at the core of wireless networks [3]. This wireless communication technology has not only revolutionized personal communication, but has also played an important part in the advancement of different sectors such as healthcare, transportation, manufacturing, and entertainment [4]. Wireless network design and deployment are complicated and diverse, with careful consideration of aspects such as coverage, capacity, data rates, security, and energy efficiency [5]. Wireless technologies have grown to meet a broad range of demands and size, from basic local area networks (LANs) to massive wide area networks (WANs) covering cities or nations [6].

Wireless networks have transformed the way we interact and share data, allowing us the flexibility and mobility essential for contemporary connection [7]. Optimizing the communication range in wireless networks, on the other hand, is a significant challenge for ensuring reliable and efficient data delivery [8]. Traditional static range topologies may not be enough for adapting to dynamic and shifting environmental circumstances, resulting in inferior network performance and coverage [9]. To solve this issue, this research introduces a unique technique termed LQI-PER-based range adaptation, which uses the LQI and PER metrics to dynamically alter the communication range of individual nodes in wireless networks [10]. The system automatically modifies the communication range of nodes by monitoring real-time connection conditions, allowing for increased coverage while link quality is strong and limiting range to preserve efficiency in the case of signal deterioration or interference [11]. This adaptive technique attempts to increase network reliability, expand communication ranges, and maximize energy efficiency, providing a viable option for establishing robust and extended communication ranges in wireless networks [12]. We give a detailed explanation of the LQI-PER-based range adaptation approach, its underlying concepts, and the advantages it provides in improving the performance of wireless communication networks [13]. We illustrate the efficacy and benefits of this strategy in dynamic and complex network contexts using simulation results and analysis [14].

1.1 MOTIVATION OF THE PAPER

The importance of wireless networks as foundational building blocks of 21st-century communication systems inspired this study. Because of their ability to facilitate connection and data exchange, such networks are indispensable to a wide range of fields and sectors. However, improving wireless networks' communication range is difficult since it has a direct bearing on the security and efficiency of data transfer. This research seeks to meet this need by providing a unique approach dubbed "LQI-PER-based range adaptation" to extend the effective range of wireless networks. The need of a flexible and effective system that can respond to changing network circumstances in real time inspired this strategy. In dynamic circumstances where signal quality and interference are always changing, the tried-and-true methods of setting up a fixed communication range may not work. The study dynamically adjusts the connection distance of individual nodes based on two critical metrics: the network Quality Indicator (LQI) and the Packet Error Rate (PER). As a result, the suggested method successfully extends network coverage and enhances connectivity across wider regions by allowing nodes to interact over greater distances when the connection quality is strong and the PER is low.

II. BACKGROUND STUDY

A.K. Idrees et al. [1] Power-efficient data aggregation in WSNs was presented here using an approach called Integrated Divide and Conquer with Enhanced K-means (IDiCoEK). At both the node and cluster head levels, the IDiCoEK executes the aggregation of metrics. The acquired data is sorted at the node using a divide-and-conquer method to remove any duplicate values before sending the remaining measurements to the cluster's leader. The data sets received from the sensor nodes are clustered using an upgraded K-means approach at the cluster head, and the best representative set from each cluster is then delivered to the sink.

K. Paul et al. [3] It has been claimed that a VEH can power a battery-free NFC sensor node. The FR4-based resonant VEH consists of interleaved, series-connected springs that, when excited, provide a significant amplitude of displacement (2.5 mm) in a relatively compact volume of 9 cm3.

M. K. Brar and R. Singh [5] Many riders who have used Zwift advocate switching to Bluetooth as the connection of choice since it provides a more steady data transmission. This is particularly crucial in Zwift, as losing momentum for even a second may lead you to fall behind the pack. Until an application that uses Ant Wireless is launched, neither the service nor the corresponding system components (such as Wi-Fi or NFC) will execute or consume any system resources. The manufacturer has already put in the necessary effort to get ANT up and running on your mobile device. If you decide against using this feature, your computer won't be affected and you won't have to do anything else. Wireless connections may be enabled if this service is not already present on your phone.

M. Yadav et al. [7] To increase the gain of a CPW-fed monopole antenna, a unique Dual band AMC with a broad bandwidth is presented in this article. Overall, the antenna construction with AMC has bandwidths of 360 MHz from 2.2 GHz to 2.85 GHz and 610 MHz from 5.68 GHz to 6.29 GHz, making it suitable for use in both the ISM and WiFi bands. In these frequency ranges, the integrated antenna achieves a maximum gain of 4.8 dBi and 7.75 dBi, respectively. Because of its tiny size and few back lobes, the suggested antenna is well suited for use as a wearable antenna.

R. Pandurangan et al. [9] The cluster-based LEACH protocol and the SDLEACH protocol decrease total energy usage by spreading load transversely across all of the nodes at different moments. Each node in the cluster is responsible for gathering data from the others, aggregating it into a single signal, and sending it to the sink node. Because of its decentralized nature, LEACH may function without any knowledge of the global network or any control information from either the base station or the sink node. Distributing power to all of a network's nodes at once reduces wasted energy and extends the life of the whole setup. Regardless of the routing protocol in use, it keeps tabs on the energy consumption of all the nodes in a network.

V. Kaveri and T. Deepa [11] To improve spectrum and power efficiency, the RTX-50 based on H-NOMA has been proposed as a practical method for multiple access to satisfy fifth-generation and beyond communications needs.Four users sharing a SIC receiver had their bit error rate (BER) analyzed. When compared to more traditional approaches, the H-NOMA RTX-50 boasts superior performance metrics that are well-suited to MIMO transmission. The suggested solution for 5G networks has the potential to greatly enhance bit error performance and offers a solid foundation for realizing the potential of huge communications.

Y. Qaragoez et al. [13] This study demonstrated an FDD-based sensor node with SWIPT functionality and IM3 backscattering. Connectorized measurements confirmed the functionality of both SWIPT and IM3 backscattering. An average of 30 mW of power was harvested from 100 mW of input power, demonstrating both uplink and downlink communication capabilities. The incident signal (VRFIN) at -10 dBm is backscattered at -31.99 dBm, and the resulting AM data at 1 kbps is demodulated. The dynamic range of backscattering is 4.84 dB.

2.1 PROBLEM DEFINITION

The problem addressed in this research is the challenge of optimizing communication range in wireless networks to ensure dependable and effective data transmission. Wireless networks are integral to contemporary communication systems, providing seamless connectivity and data sharing. However, determining the appropriate communication range for individual nodes in these networks is a complex task due to various dynamic factors that can affect network performance. Traditional static communication range configurations may not be suitable for accommodating real-time changes in network conditions, such as fluctuations in signal quality and interference. Inadequate communication range settings can lead to issues like poor connectivity, data loss, and performance bottlenecks, especially in dynamic and difficult environments. To tackle this problem, the research proposes a new technique called "LQI-PER-based range adaptation." The approach utilizes two critical metrics, the network Quality Indicator (LQI) and Packet Error Rate (PER), to dynamically adjust the communication ranges of individual nodes in response to the current network circumstances. By doing so, the technique aims to optimize the network's communication range in a way that ensures reliable and efficient data transmission.

III. MATERIALS AND METHODS

Experimental design, techniques, and instruments used in the study should all be included in the Materials and Methods part of a research article or report. Here, you'll find a detailed account of the research process that should help readers grasp the work and, if necessary, repeat it themselves. It provides researchers with a road map they may follow to verify the results and expand upon in the future. This section will provide a comprehensive description of the resources, people, data collecting strategies, and analytical procedures that went into the research. Validity and trustworthiness of the findings depend on the researcher's careful choice of materials and methods. Therefore, we will explain in more detail why we chose the techniques and materials that we did, stressing how they contributed to the goals of the study.

3.1: Network model

The research introduces a new technique called LQI-PER-based range adaptation to enhance communication range in wireless networks. The network model comprises a set of nodes that communicate with each other, forming a wireless communication infrastructure. The approach utilizes two key metrics, the Link Quality Indicator (LQI) and Packet Error Rate (PER), to adaptively adjust the communication range of individual nodes based on real-time network conditions. When the connection quality is high and the PER is low, nodes can communicate over longer distances, thus expanding the network coverage and improving connectivity for longer distances. Conversely, if signal degradation or interference occurs, the technique automatically reduces the communication range of affected nodes to maintain efficiency and mitigate performance bottlenecks. The study provides a detailed explanation of the LQI-PER-based range adaptation mechanism and evaluates its advantages in terms of improved communication range, enhanced network reliability, and increased energy efficiency. Simulation results demonstrate that the proposed technique is effective in dynamic and challenging scenarios, making it a promising option for establishing robust and extended communication ranges in wireless networks.

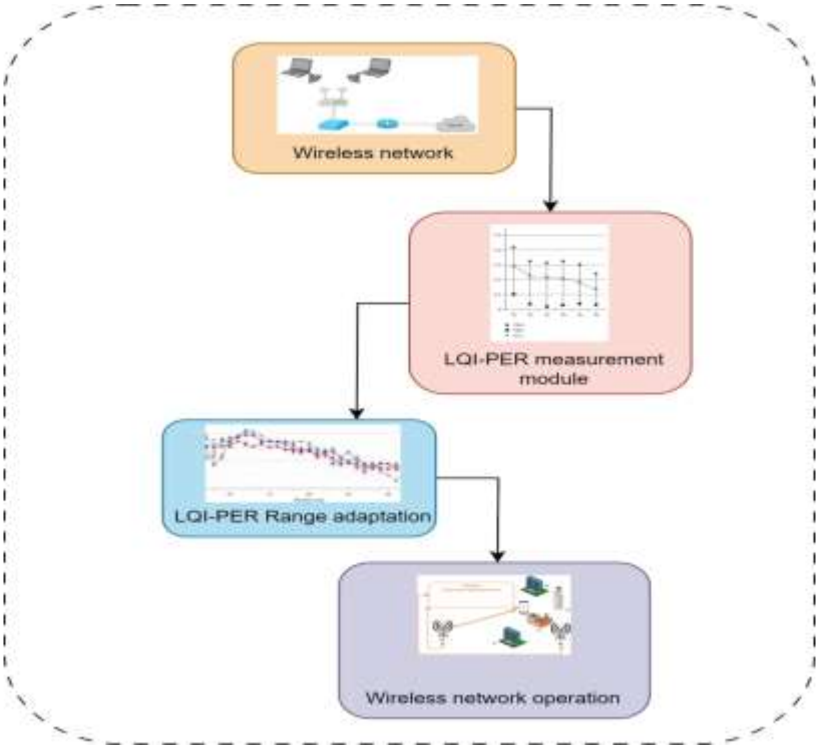

Figure 1: Block diagram

3.2 Link Quality Indicator

A FM modulated transmit signal, as we saw in the previous section, always has the same envelope. When FM transmissions are disrupted, the received signal's amplitude will shift in unexpected ways, as seen in Figure 3. The proposed LQI algorithms use this AM content to calculate a SINR estimate for the received signal. Using this metric plus background info on FM modulation, one may infer the state of the transmitted sound.

For high SINR we can assume $|r(t)| = a_0 + n_i(t)$ and therefore the last term in the above equation gets negligible. With the Taylor approximation p (1 + x) ≈ 1 + x/2 we rewrite equation (1).

$|r(t)| = a_0 + n_i(t)$ ---- (1)

Connectivity between two wireless devices or nodes may be measured using a metric called the Link Quality Indicator (LQI) in wireless communication systems. It is a gauge of the link's dependability and a measure of how effectively the receiver is receiving the sent signal. Signal characteristics such as the Received Signal Strength Indicator (RSSI) and the Signal-to-Noise Ratio (SNR) are frequently used in LQI calculations. The signal-to-noise ratio (SNR) is the ratio between the signal strength (RSSI) and the noise level (BNR). The LQI algorithm evaluates the link's signal quality by considering these factors and producing a single numerical score.

Calculating the power of the absolute received signal gives a measure for the signal plus noise power for high SINR and white Gaussian noise.

$E\{|r(t)|^2\} = E\{a_0^2 + 2a_0 n_i(t) + n_I^2(t)\}$ ------ (2)

A greater LQI value indicates a more reliable connection, hence it's common for this metric to be expressed as a whole number within a range. The LQI number in IEEE 802.15.4, for instance, may take on a value between 0 and 255, with 255 being the best possible link quality and 0 the worst. various wireless communication systems may utilize various mappings between the LQI value and the actual connection quality, which may lead to inconsistent use of LQI values. Because of its importance in many facets of wireless network communication and administration, LQI cannot be overlooked. Nodes employ LQI data to evaluate potential data-transfer pathways based on their quality, making it a useful tool in route selection for routing protocols. For better network speed and consistency in data delivery, routing algorithms might prioritize connections with higher LQI values. Rate adaptation in wireless systems with different modulation and coding schemes is one example of how LQI is utilized in link-layer protocols. By keeping an eye on things via link quality indicators (LQI), nodes may adapt their data transmission rates to the current channel conditions, improving throughput while decreasing error rates. Monitoring and troubleshooting network performance may also benefit from LQI data. Links may be evaluated, and problems like interference, signal fading, and congestion can be spotted by network managers. Keeping an eye on the LQI in real time might assist pinpoint trouble spots in the network and prompt preventative maintenance.

Algorithm 1: Link Quality Indicator

Input:

- FM Modulated Received Signal: The input to the algorithm is the FM modulated received signal, which has an envelope that remains constant under normal conditions but may experience unexpected amplitude shifts when disrupted.

Algorithm Overview:

1. Estimation of SINR: The algorithm begins by estimating the Signal-to-Interference-plus-Noise Ratio (SINR) for the received FM modulated signal using the AM content. The SINR estimate provides valuable information about the transmitted sound's state.

$$|\mathrm{r}(\mathrm{t})| = \mathrm{a}_0 + \mathrm{n}_\mathrm{i}(\mathrm{t})$$

2. Calculating Power of Received Signal: The algorithm calculates the power of the absolute received signal

using equation (2). This measure represents the combined power of the signal and noise components when the SINR is high.

$$\mathrm{E}\{|\mathrm{r}(\mathrm{t})|^2\} = \mathrm{E}\left\{\mathrm{a}_0^2 + 2\mathrm{a}_0\mathrm{n}_\mathrm{i}(\mathrm{t}) + \mathrm{n}_\mathrm{I}^2(\mathrm{t})\right\}$$

Output:

- LQI Score: The output of the LQI algorithm is a single numerical score that represents the link's signal quality. It is obtained by considering factors like RSSI, SNR, and the estimated SINR from the received FM modulated signal

3.3 PACKET ERROR RATE

When evaluating the security of a wireless network, one of the most essential metrics is the Packet Error Rate (PER). It measures the amount of data that is lost or damaged while being sent over a wireless connection. When the timeliness and quality of data is paramount, like in real-time applications, file transfers, or audio and video conferencing, PER becomes even more important. PER may be easily calculated using a few simple steps. Each packet of data sent has a unique number assigned to it by the sender; this number is called the sequence number. The receiver then compares the actual sequence numbers found in the packets with the predicted ones. Packets are deemed lost or corrupted if they are either absent or received out of sequence. The packet error rate (PER) is determined by taking the total number of packets transmitted and dividing it by the number of packets that were either lost or damaged. If the packet error rate (PER) is low, it means that fewer packets are being lost or damaged via the wireless connection. To the contrary, a higher PER score indicates a less stable connection with a greater chance of packet failures.

If we assume that nodes in a slotted ring network send out identically sized packets with similar probabilities, we may calculate the packet error at any given node as follows. An error occurs if the center pulse peak of a packet properly designated for node B creates an autocorrelation pulse sequence but is smaller than the threshold due to photodiode noise. It's conceivable that the reverse is true. Let's say node A sent a packet to a destination other than node B. If this is the case, then node B should exhibit a cross correlation sequence. However, with the photodiode noise, there is a chance that node B may mistakenly receive the transmission. Therefore, the likelihood of a packet error occurring at node B may be written as the product of the probabilities of the two types of errors described above.

$$\mathbf{P_e} = \mathbf{P_c P(error|correct\ addr)} \text{ ------ (3)}$$

$$+\mathbf{P_w} \sum_{\mathbf{j=0}}^{\mathbf{p-1}} \mathbf{P(j)P(error|x-cor.)} \text{ ------ (4)}$$

To keep the packet error probability constant in the face of increasing thermal and shot noise, it is necessary to raise the input power. The optical power in a thermal noise constrained system scales as the square root of the data rate.

Algorithm 2: Packet Error Rate

Input:

- Number of nodes in the slotted ring network (N)
- Packet length (L) in bits
- Threshold value for central pulse peak (T)
- Autocorrelation pulse sequence for correctly destined packet (P_c)
- Crosscorrelation sequence for packet destined to other nodes (P_w)
- Number of possible pulse positions (p)

  Algorithm Steps:
- Calculate the probability of an error occurring for a correctly destined packet sent from node A to node B:
  - P(error|correct addr) = Probability that the central pulse peak is less than the threshold (based on photodiode noise).
- Calculate the probability of an error occurring for a packet from node A destined to a node other than node B:
  - For each possible pulse position j in the crosscorrelation sequence:
    - Calculate P(j) = Probability of receiving the crosscorrelation sequence at node B for a packet destined to node other than B.
    - P(error|x-cor.) = Probability that the packet is falsely received by node B due to photodiode noise.

Output:

- Packet Error Probability (P_e)

IV. RESULTS AND DISCUSSION

There must be a thorough presentation and analysis of the study's results in the report's or paper's Results and Discussion section. Data gathered and processed throughout the research process are presented in a clear and straightforward way in this part, which acts as the heart of the study. The findings section of a research paper presents the reader with empirical data that responds to the study's central research question or hypothesis. This part will provide a well-organized presentation of the study's findings, complete with tables, graphs, and statistical analysis. Results will be presented with descriptive headings and labels that help readers fully grasp the information presented.

4.1 Throughput

Throughput= $\frac{\text{Number of Packet Size}}{\text{Arrival Time duration} * \text{Successful average Packet size}}$ ----------- (5)

Table 1: Throughput

	Throughput levels		
Packet Size	HE-MAC	FCDV	LQI-PER
50	0.212	0.277	0.312
100	0.425	0.555	0.625
150	0.638	0.833	0.937
200	0.851	1.111	1.250
250	1.063	1.388	1.562

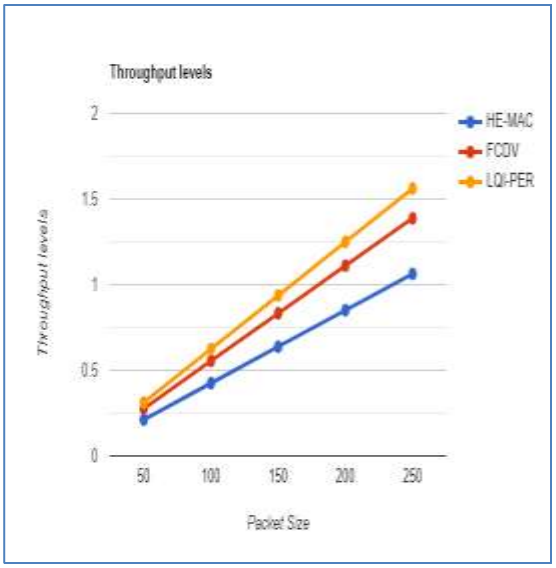

Figure 2: throughput

The table 1 and figure 2 provides throughput levels for three different protocols: HE-MAC, FCDV, and LQI-PER, measured at various packet sizes. Throughput refers to the amount of data that can be transmitted over a network in a given time frame. The values represent the throughput in some unit of data (not specified in the table) achieved by each protocol at different packet sizes. As the packet size increases, all three protocols show an increase in throughput, which is expected since larger packets can carry more data. Among the three protocols, LQI-PER consistently achieves the highest throughput values, followed closely by FCDV, while HE-MAC has the lowest throughput. This suggests that LQI-PER is the most efficient protocol in terms of data transmission, especially for larger packet sizes. It's important to note that the actual performance of these protocols in real-world scenarios can be influenced by various factors like network conditions, interference, and the specific application requirements. Therefore, the choice of protocol should be based on a comprehensive evaluation of all relevant factors to ensure optimal performance for a particular use case.

4.2 Energy

Table 2: Energy level in joules

	Energy level in joules		
Number of Nodes	HE-MAC	FCDV	LQI-PER
10	80	76.92	71.4
20	160	153.84	142.85
40	320	307.69	285.71
60	480	461.53	428.57
80	640	615.38	571.42
100	800	769.23	714.28

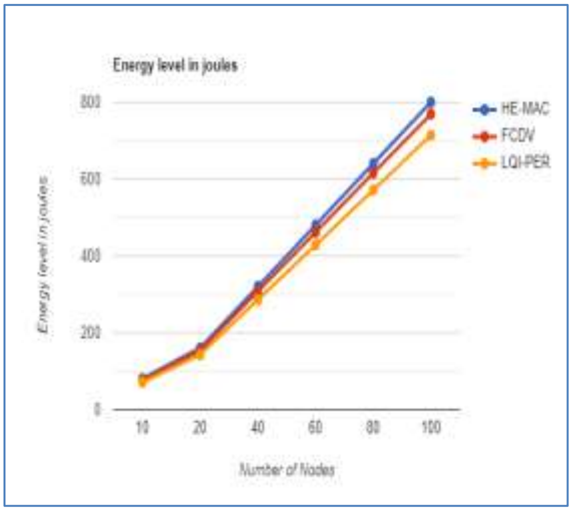

Figure 3: Energy level in joules

The table 2 and figure 3 presents energy consumption levels in joules for three different protocols: HE-MAC, FCDV, and LQI-PER, as measured with varying numbers of nodes in the network. Energy consumption is a critical aspect to consider in wireless networks, as it directly impacts the battery life and overall sustainability of devices. As the number of nodes in the network increases, the energy consumption for all three protocols also rises. This is understandable since more nodes mean more data transmissions and receptions, resulting in higher energy requirements. Among the three protocols, LQI-PER consistently exhibits the lowest energy consumption values for each node count, followed by FCDV, while HE-MAC consumes the highest amount of energy. The results suggest that LQI-PER is the most energy-efficient protocol among the three, making it an attractive choice for scenarios where battery life and energy conservation are critical considerations. However, the selection of the appropriate protocol should still depend on the specific requirements of the network, its intended use, and other factors such as data throughput and reliability. Striking the right balance between energy efficiency and network performance is crucial in designing effective and sustainable wireless networks.

4.3 TIME DELAY

$$\text{Time Delay} = \frac{\text{Number of Sensor nodes}}{\text{energy consumption for sending packets at a times x forwarding time in ms}} \text{ ----------- (7)}$$

Table 3: Time (End to End Delay)

	Time (End to End Delay)		
Number of Nodes	HE-MAC	FCDV	LQI-PER
10	0.075	0.069	0.064
20	0.150	0.138	0.129
40	0.300	0.277	0.259
60	0.450	0.416	0.389
80	0.600	0.555	0.519
100	0.751	0.694	0.648

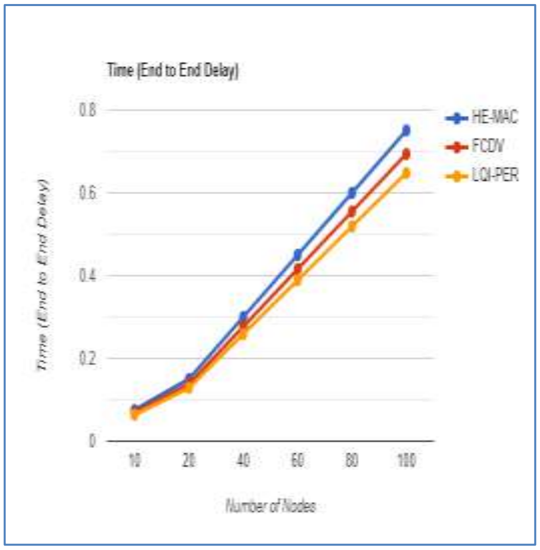

Figure 4: Time (End to End Delay)

The table 3 and figure 4 provides data on the end-to-end delay in seconds for three different protocols: HE-MAC, FCDV, and LQI-PER, measured with varying numbers of nodes in the network. End-to-end delay is a crucial metric in networking, representing the time taken for a data packet to travel from the source node to the destination node in the network. As the number of nodes in the network increases, the end-to-end delay for all three protocols also increases. This is expected since a larger number of nodes can lead to increased congestion and packet queuing, resulting in longer delays. Among the three protocols, LQI-PER consistently exhibits the lowest end-to-end delay values for each node count, followed by FCDV, while HE-MAC shows the highest end-to-end delays. The results indicate that LQI-PER offers the lowest end-to-end delays, making it a favorable choice for applications that require low-latency communication, such as real-time data transmission or interactive services. However, the selection of the appropriate protocol should consider other factors as well, such as energy consumption, throughput, and reliability, to ensure the best fit for the specific network and its intended use case. Striking the right balance between low end-to-end delay and other performance metrics is crucial for optimizing the network's overall performance and user experience.

4.4 Packet Delivery ratio

$$\text{PDR}=\frac{\text{Number of Packets Receive}}{\text{Total Packets}} * 100 \quad \text{-----------} (8)$$

Table 4: Packet Delivery ratio

	Packet Delivery ratio		
Number of packets	HE-MAC	FCDV	LQI-PER
50	94.2	94.8	95.8
100	97.1	97.4	97.9
150	98.06	98.26	98.6
200	98.55	98.7	98.95
250	98.84	98.96	99.16

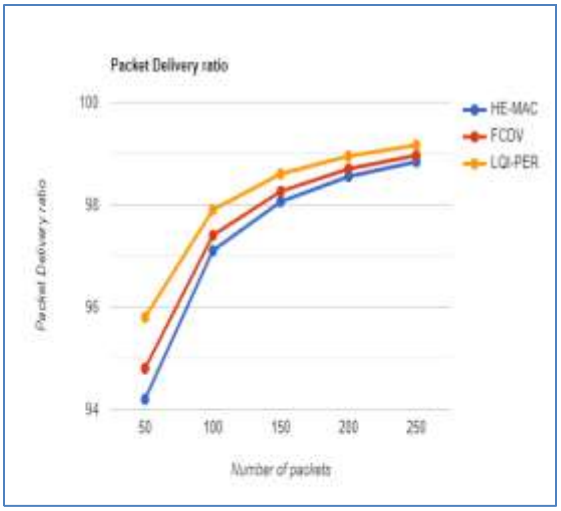

Figure 5: Packet Delivery ratio

The table 4 and figure 5 presents the Packet Delivery Ratio (PDR) for three different protocols: HE-MAC, FCDV, and LQI-PER, with varying numbers of packets in the network. PDR is a crucial performance metric in networking, representing the percentage of packets successfully delivered to their destination without loss or errors. As the number of packets increases, the PDR for all three protocols also improves. This suggests that with a higher number of packets, the networks become more efficient in delivering data reliably. Among the three protocols, LQI-PER consistently exhibits the highest PDR values, followed closely by FCDV, while HE-MAC shows slightly lower PDR percentages. The results indicate that LQI-PER achieves the highest Packet Delivery Ratio, making it a reliable choice for applications where data integrity and minimal packet loss are paramount, such as in critical communication systems or sensor networks. However, it's essential to consider other factors, such as energy consumption and end-to-end delay, to make an informed decision on the protocol selection, as each protocol may have trade-offs in different performance aspects.

V. CONCLUSION

In this research, we introduce and investigate LQI-PER-based range adaptation, a unique technique for expanding wireless networks' transmission radius. Each node in the network is able to dynamically change its communication range depending on the current connection conditions by using the connection Quality Indicator (LQI) and Packet Error Rate (PER) metrics. To maximize coverage and throughput when link quality is strong, LQI-PER-based range adaptation optimizes the transmission range of each node. Moreover, the system automatically lowers the communication range to ensure efficiency and reliability in the case of signal deterioration or interference. This adaptive system guarantees the network's optimum performance in changing and difficult settings, expanding the network's communication range and boosting its overall efficiency. We have shown that the suggested method is successful in attaining resilient and extended communication ranges in wireless networks using simulation results and analysis. Modern wireless communication systems may benefit from the flexibility offered by the LQI-PER-based range adaption approach, which overcomes the drawbacks of fixed-range setups.

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