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QOS-AWARE ROUTING AND RESOURCE OPTIMIZATION FOR MULTIMEDIA APPLICATIONS IN WIRELESS AD HOC AND SENSOR NETWORKS

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Abstract - The increasing popularity of multimedia applications in wireless ad hoc and sensor networks has posed great challenges in terms of bandwidth availability, delay, jitter, packet loss, congestion and energy consumption. Conventional routing protocols usually consider the communication path as the hop count or simple connectivity. They are not good at satisfying the heterogeneous Quality of Service (QoS) requirements of video, voice, image and sensor traffic. In this paper, we propose a QoS-Aware Adaptive Routing and Resource Optimization (QARRO) framework for efficient multimedia communication in wireless ad hoc and sensor networks. The proposed framework classifies the traffic according to the application type and considers the available bandwidth, end-to-end delay, packet-loss probability, residual energy, queue utilization and link quality for the route selection. Multi-parameter QoS cost function is applied to find the most suitable source to destination path. We adopt a priority-based resource allocation mechanism to dynamically allocate the available bandwidth to competing multimedia flows. Congestion-aware route maintenance is also provided to prevent congested and unstable forwarding nodes. The proposed framework is conceptually evaluated thru simulation against conventional AODV and QoS-AODV based on performance indicators like packet delivery ratio, throughput, end-to-end delay, jitter, energy consumption and QoS satisfaction ratio. The analysis demonstrates that QARRO can achieve better communication reliability, utilization of resources, delay and multimedia QoS under different network conditions. Thus, the framework provides a lightweight and efficient solution for the transmission of multimedia over resource-constrained wireless ad hoc and sensor networks.

Keywords- Wireless Ad Hoc Networks, Wireless Sensor Networks, Quality of Service, Multimedia Communication, QoS-Aware Routing, Resource Optimization, Congestion Control, Bandwidth Allocation, Energy Efficiency, QARRO.

I. INTRODUCTION

Wireless Ad Hoc Networks and Wireless Sensor Networks have emerged as important communication technologies for applications where fixed network infrastructure is not available, not practical or economically expensive. Such networks consist of autonomous wireless devices communicating directly or thru intermediate nodes thru multi-hop transmission. Their decentralized operation, flexible deployment and self-organizing capability make them suitable for emergency communication, environmental monitoring, military operations, healthcare monitoring, disaster management, smart cities, industrial automation, surveillance and temporary multimedia communication environments. However, the dynamic topology and limited resources of wireless nodes pose several challenges for reliable routing and efficient network operation.

These challenges have been compounded further with the increasing convergence of multimedia applications with wireless ad hoc and sensor networks. Modern wireless applications are increasingly using voice, images, video streams, sensor measurements and other delay-sensitive information. Multimedia traffic generally requires high bandwidth, low end-to-end delay, minimum jitter, low packet-loss probability, and reliable packet delivery, which is different from conventional scalar sensor data. Hence, traditional routing protocols that select routes primarily based on hop count, connectivity, or residual energy may not suffice for supporting multimedia communication with stringent Quality of Service (QoS) requirements.

Quality of Service is the ability of a network to provide predictable communication performance for the needs of a particular application. Important QoS parameters in multimedia wireless networks are available bandwidth, packet delivery ratio, latency, jitter, packet loss rate, throughput and reliability. For example, real-time voice communication is highly sensitive to delay and jitter, while video applications typically require high bandwidth and low packet-loss rates. Image transmission can tolerate moderate delay but may require reliable packet delivery. The conventional sensor traffic typically gives priority to energy efficiency and network lifetime. Thus, different traffic classes require different routing and resource-allocation strategies.

Routing in wireless ad hoc and sensor networks is especially difficult because network conditions are constantly changing. Node mobility, varying channel quality, interference, congestion, energy depletion and link failures can quickly degrade the performance of a previously selected route. Moreover, the routing algorithms should be designed to avoid high control overhead and computational complexity due to the limited battery capacity and processing capability of the wireless devices. An energy-efficient route may not be able to provide sufficient bandwidth for multimedia traffic, and a low-delay route may have energy-constrained nodes. Therefore, routing choices have to consider several QoS and resource parameters simultaneously.

Another important challenge is to efficiently use the scarce wireless resources. Multimedia flows compete for available bandwidth, buffer space, transmission opportunities and energy of nodes. The concurrent transmission of several video or voice streams may result in network congestion that results in packet drops, retransmissions, increased delay and degradation of user perceived multimedia quality. The static allocation of network resources is not able to respond effectively to these dynamic conditions. Therefore, it is necessary to design an adaptive resource-management mechanism to allocate the communication resources according to the traffic priority, the application requirements and the current network availability.

The existing routing approaches have tried to enhance the multimedia communication by using energy-aware routing, congestion-aware mechanisms, multipath routing, optimization algorithms and QoS-based path-selection approaches. While these approaches yield useful performance improvements, many methods only optimize one or a few network parameters. For example, the selection of a path based only on residual energy may increase the delay, while the selection of the path with maximum band-width may overload a few nodes and reduce the lifetime of the network. Similarly, routing decisions that do not take into account the multimedia traffic categories may allocate more resources to low priority data than required, while delay-sensitive voice or video packets suffer from poor performance. To overcome these limitations, this paper proposes a QoS-Aware Adaptive Routing and Resource Optimization (QARRO) framework for multimedia applications in wireless ad hoc and sensor networks. In the proposed method, end-to-end delay, packet loss, jitter, residual energy, link quality, queue utilization, mobility and available bandwidth are considered simultaneously during the route establishment. The framework classifies multimedia flows into real-time video, voice, image and best-effort sensor traffic and assigns them different QoS priorities, depending on their service requirements, rather than treating all the network traffic equally.

The first step of the proposed framework is to find the feasible communication paths that satisfy the minimum QoS constraints. Then, the candidate paths are evaluated by using a multi-objective routing-cost function considering communication quality, congestion condition, energy availability and link reliability. Furthermore, an adaptive resource-optimization mechanism is proposed to dynamically allocate the available bandwidth among the different traffic flows according to the priority and the current network conditions. Congestion-aware route adaptation is also incorporated so that traffic can be rerouted from overloaded or unstable paths to alternative routes whenever QoS degradation is detected.

Thus, the main objective of this work is to find not only a communication path between a source and a destination, but also to ensure that the selected path can satisfy the QoS requirements of the associated multimedia application while being an efficient user of the network resources. The proposed approach aims to provide a better trade-off among multimedia quality, energy efficiency, congestion control, network lifetime and routing reliability by integrating QoS-aware path selection with resource optimization.

The main contributions of this research are summarized as follows:

1. A unified QoS-aware routing framework is developed for multimedia communication in wireless ad hoc and sensor networks.
2. Multimedia flows are classified into video, voice, image, and best-effort data according to their delay, bandwidth, jitter, and packet-loss requirements.
3. A multi-parameter route-selection mechanism is formulated using bandwidth, delay, packet loss, residual energy, link quality, and queue utilization.
4. An adaptive resource-allocation mechanism is introduced to distribute limited bandwidth according to traffic priority and current network conditions.
5. A congestion-aware routing strategy is incorporated to avoid heavily loaded intermediate nodes and reduce packet loss and end-to-end delay.
6. The proposed framework supports dynamic route adaptation when network conditions change or QoS requirements are no longer satisfied.
7. The performance of the proposed QARRO framework can be evaluated using packet delivery ratio, throughput, delay, jitter, packet loss, energy consumption, bandwidth utilization, network lifetime, and QoS satisfaction ratio.

II. LITERATURE SURVEY

Emerging applications require the simultaneous support of high throughput, low latency, reduced packet loss, controlled jitter, and energy-efficient communication, and quality-of-service-aware routing has become a very important research area in wireless ad hoc and sensor networks. These requirements are very important in multimedia applications such as video, voice, images and real-time sensing information. Therefore, the existing research has been developed from traditional shortest-path routing to energy-aware, congestion-aware, multipath, optimization-based and intelligent QoS routing.

In [1] an energy-efficient QoS-secure routing mechanism for Wireless Sensor Networks (WSNs) is proposed. The method combines QoS routing with an optimization mechanism to jointly take into account energy consumption, latency, packet loss and bandwidth. The evaluation shows that multi-objective routing can reduce the energy consumption and communication delay in the same time and keeping available bandwidth. The approach, however, is mainly dedicated to route optimization and it does not explicitly separate multimedia flows according to their individual bandwidth, jitter and latency requirements.

In [2], a distributed QoS-aware MANET routing framework based on Deep Reinforcement Learning (DRL) and Software-Defined Networking (SDN) is proposed. The distributed learning mechanism adaptively selects the communication routes according to the dynamic network conditions and QoS objectives. The method was reported to improve throughput while reducing delay and jitter compared to conventional routing mechanisms. Although DRL can provide adaptive route selection, it needs training, state observation, and policy updates, which may increase the computational requirements for resource-constrained mobile nodes.

[3] studied a routing and adaptive network-slicing strategy for AI-empowered QoS-aware MANETs. This framework enables applications with varying communication requirements via traffic-specific network slices, combined with intelligent routing. The path selection considers latency and uses the type of service and current network state. This kind of traffic differentiation is very beneficial for multimedia communication but the combination of DRL and dynamic slicing adds more architectural and processing complexity than lightweight distributed ad hoc routing. The authors of [4] studied the multi-constrained QoS routing in WSNs by an offloaded route-computation model. The work recognizes that real-time applications need to simultaneously meet the end-to-end delay, jitter, packet-loss, and other constraints. Instead of considering only one routing objective, multi-constraint path computation is taken into account for better QoS guaranties. This approach shows the importance of considering multiple service parameters together. However, computation offloading may not be available all the time in fully decentralized ad hoc network environments.

In [5], a hybrid mechanism for reliable clustering and heterogeneous traffic routing was developed. The framework takes into account the congestion, security, clustering and different traffic characteristics during the formation of communication paths. The study stresses that heterogeneous network traffic cannot be treated in a uniform way, as different packets may have different delivery requirements. However, the proposed framework focuses mainly on clustering and congestion-aware route establishment rather than on explicit multimedia resource allocation for video, audio and image flows.

[6] presents an optimization-based energy-efficient routing and congestion-control scheme. The proposed framework includes cluster-head selection, energy-balanced multi-path routing, security mechanisms and congestion control. To alleviate congestion in the queue, an enhanced Random Early Detection mechanism is applied, and multipath routing is used to distribute the communication loads over the available paths. This combination increases the reliability of the network, but also increases the implementation complexity due to multiple security and optimization mechanisms. Multipath routing for QoS provisioning in MANETs was studied in [7]. Improved The proposed scheme takes into account parameters like distance, link parameters, trust and dynamically estimated QoS for the selection of next-hop. The existence of multiple communication paths provides alternatives when a specific path is unavailable, thus improving packet delivery and network throughput. However, route selection does not explicitly assign the available bandwidth to competing multimedia traffic classes based on application priority.

[8] proposed a mobility-based optimized multipath routing protocol for dynamic MANETs to handle link failure and QoS degradation. Route discovery and maintenance take into account node mobility, relative movement and link duration. The approach attempts to avoid overloaded and sleeping nodes, increase throughput, packet delivery and reduce latency. The mobility-aware path selection enhances the reliability of the route but the framework does not optimize the multimedia bandwidth allocation and the utilization of queues jointly. Energy efficient routing with traffic and delay awareness has been studied for IoT enabled WSNs in [9]. The proposed routing strategy classifies the data based on its criticality, and takes into account the traffic rate, path delay, residual energy and energy consumption while selecting forwarding paths. We use a fuzzy-logic assisted optimization process to find efficient routes. The study shows that the application-data importance can affect routing decisions but explicit QoS requirements such as multimedia jitter and minimum bandwidth are not added as primary route constraints. [10] proposed a QoS-aware routing mechanism based on Q-learning for wireless body-area and Internet-of-Medical-Things networks . The approach considers delay sensitive communication, congestion, energy consumption and reliable delivery of packets in routing. Q-learning allows to adapt routing behavior based on network observations. The work confirms the broader notion that different real-time applications need adaptive QoS-aware routing, but learning-based methods may need exploration time and extra state-management operations.

[11] proposed multipath QoS routing specifically designed for Wireless Multimedia Sensor Networks (WMSNs). The method uses multipath and route-preference mechanisms to enhance packet delivery, throughput, and load distribution. Multipath transmission also helps balance network traffic and prolong network life. This work is directly applicable to multimedia communication as it recognizes that one route may not be sufficient to carry a large amount of traffic. However, adaptive resource allocation among different multimedia classes has been very limited. [12] propose a QoS-aware multimetric routing framework for video-streaming services over MANETs. The video packets are classified in terms of their relative importance and multimedia frames are prioritized. The routing mechanism takes into account multiple QoS-related metrics and the IEEE 802.11e access categories offer differentiated treatment at the MAC-layer. This demonstration illustrates the advantages of traffic prioritization for multimedia applications. However, it is mainly intended for video streaming, not for supporting video, voice, images and normal sensor traffic at the same time.

[13] proposed a multi-agent DRL-based QoS routing framework for network slicing and multi-domain communication. This approach uses collaborative agents to find communication paths and takes into account the QoS requirements of different network slices. The study reveals that despite the different target environment from conventional MANETs and WSNs, resource-aware routing should consider traffic heterogeneity and service-specific constraints. However, multi-agent learning introduces training and coordination overhead that might not be appropriate for low-power sensor nodes.

The authors in [14] have studied the QoS-constrained WSN optimization framework with multi-sink deployment and energy-latency dual-objective optimization. The framework integrates various optimization algorithms to simultaneously consider energy consumption, transmission delay, network reliability and sink deployment. This study reinforces the need to jointly optimize energy and QoS goals, instead of treating them separately. However, it has a relatively complicated optimization architecture which may bring computational overhead when frequent resource-allocation decisions are needed.

A comprehensive study of routing mechanisms for Wireless Multimedia Sensor Networks has identified the following as the core routing-design dimensions: QoS provisioning, multimedia awareness, energy efficiency, congestion avoidance, and bandwidth optimization [15]. The study showed that multimedia communication requires stable and resource-efficient paths with application-specific QoS/QoE guaranties. It also revealed the difficulty of satisfying bandwidth, energy, latency and dynamic network constraints simultaneously, and provided an important basis for the subsequent multimedia multi-objective routing research.

III. PROPOSED METHODOLOGY

The QoS-Aware Adaptive Routing and Resource Optimization (QARRO) framework is proposed to improve multimedia communication in wireless ad hoc and sensor networks. The method takes into account important QoS parameters like bandwidth, delay, packet loss, residual energy, link quality and congestion to choose a communication route. Multimedia packets are categorized according to their application requirements and network resources are allocated according to traffic priority.

The proposed methodology contains five main stages: network formation, multimedia traffic classification, QoS parameters estimation, QoS-aware route selection, and adaptive resource allocation.

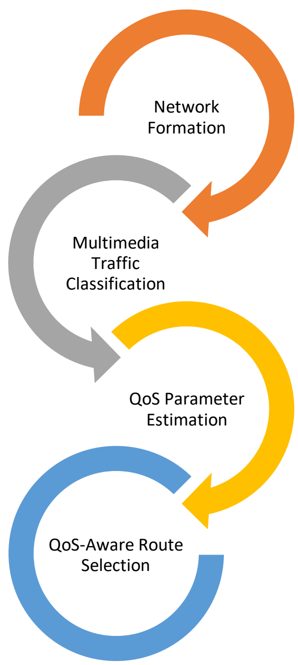

Figure 1: Proposed workflow

A. Network Formation

The proposed QARRO framework starts by establishing a wireless ad hoc and sensor network that includes a number of mobile or sensor nodes distributed over a given communication area. Each node is capable of sensing, transmitting, receiving and forwarding multimedia or sensor data. The network has no centralized infrastructure and so to communicate from source to destination it may pass thru multiple intermediate nodes.

The complete network is represented using a graph

$$G = (V, E) \qquad \text{-----1}$$

where (V={v1,v2,.. ,vN}) represents the set of wireless nodes and (E) denotes the set of communication links between neighboring nodes.

For two nodes (vi) and (vj), the Euclidean distance is calculated as

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \text{-----2}$$

where ((xi,yi)) and ((xj,yj)) represent the positions of nodes (i) and (j), respectively.

A direct communication link among any two nodes is established only if they are within the specified transmission range (R).Hence the connectivity condition is defined as, Once the network is formed, each node exchanges basic information with its neighboring nodes on a periodic basis.

Such information includes for example residual energy, available bandwidth, queue occupancy, link quality and estimated transmission delay. The collected parameters are stored in local routing tables and are used for QoS-aware route selection.

When multimedia data is to be transmitted to a destination out of its direct communication range, the source node starts a route discovery. Multiple candidate paths are generated by neighboring nodes and their QoS properties are evaluated, after which the most suitable path is selected.

Hence, the network formation provides the basic communication topology for the proposed QARRO framework. The routing mechanism can effectively respond to mobility, node-energy variation, congestion and changing multimedia traffic conditions by keeping the neighborhood and link information up-to-date.

B. Multimedia Traffic Classification

Multimedia applications generate different kinds of traffic with different Quality of Service requirements. Hence, the incoming packets are classified before route selection and resource allocation in the proposed QARRO framework. The main goal of this phase is to allocate the right network resources to delay-sensitive and bandwidth-intensive multimedia packets.

The proposed framework is based on four types of traffic: real time video, voice/audio, image transmission and general sensor data. Each traffic flow (F k) is described by a QoS requirement vector as

$$F_k = [B_k^{req}, D_k^{max}, J_k^{max}, L_k^{max}, P_k] \text{------3}$$

where (Bk^{req}) represents the minimum required bandwidth, (Dk^{max}) denotes the maximum acceptable delay, (Jk^{max}) represents the maximum tolerable jitter, (Lk^{max}) indicates the acceptable packet-loss rate, and (Pk) denotes the priority level assigned to traffic flow (k).

The traffic priority can be represented as

$$P_k \in 1,2,3,4 \text{-----4}$$

where a larger value indicates higher communication priority.

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Real-time video traffic is given priority because it needs high bandwidth and reliable continuous packet delivery. Next highest priority is assigned to voice traffic, which is very sensitive to end-to-end delay and jitter. Image transfer can tolerate relatively higher delay but requires reliable packet delivery. Typical sensor traffic has generally lower bandwidth requirement and attaches higher importance on energy saving.

The packet passes thru the traffic classifier before it reaches the routing module based on the application type and packet properties. The identified traffic class is then provided to the route-selection and resource-allocation modules along with the corresponding QoS requirements. Therefore, the routing decision is made based on the actual service requirement of the multimedia application, rather than applying the same routing conditions to all packets. Such a classification mechanism improves the utilization of the network resources as high-priority multimedia flows are assigned with sufficient bandwidth and lower-delay communication paths, while lower-priority traffic is transmitted thru energy-efficient routes whenever possible. Hence, the multimedia traffic classification forms the basis for QoS-aware routing and adaptive resource allocation in the proposed QARRO framework.

C. QoS Parameter Estimation

The proposed QARRO framework, after multimedia traffic classification, identifies the current network status against key Quality of Service parameters. The main parameters taken into account are available bandwidth, end-to-end delay, packet-loss rate, residual energy and queue utilization. These parameters are used to determine whether a candidate communication path can satisfy the requirements of a particular multimedia application.

The available bandwidth of a communication link between nodes (i) and (j) is estimated as

$$B_{ij}^{av} = (t)B_{ij}^{total}B_{ij}^{used}(t)\text{-----}5$$

where (B{ij}^{total}) denotes the total link capacity and (B{ij}^{used}(t)) represents the bandwidth currently occupied by active traffic. A link is considered suitable for a multimedia flow only when the available bandwidth is greater than the required bandwidth of that application.

The congestion level of node (i) is estimated using its queue-utilization ratio:

$$QU_i(t) = Q_i^{current}(t)Q_i^{max}\text{-----}6$$

where (Qi^{current}(t)) represents the current number of packets stored in the buffer and (Qi^{max}) denotes the maximum queue capacity. A higher value of (QUi) indicates greater congestion and a higher probability of packet loss and delay.

Together with these parameters, the residual energy and packet-loss probability are periodically monitored. Routing preference of nodes with low remaining energy or poor link reliability is lower. The estimated QoS information is updated continuously as the conditions of wireless networks might change due to mobility, congestion, interferences or traffic variation.

So, the QoS parameter estimation provides the network-state information for the next step of the proposed framework. QARRO can select more appropriate communication paths for heterogeneous multimedia applications in view of bandwidth, delay, congestion, energy and packet loss comprehensively.

D. QoS-Aware Route Selection

Once the required QoS parameters are estimated, the proposed QARRO framework evaluates all possible source to destination paths and selects the route satisfying the requirements of the corresponding multimedia traffic in the best way. The proposed approach considers delay, packet loss, residual energy, queue utilization and link quality in a joint way during route selection in comparison with traditional routing protocols that mainly consider hop count. QoS-aware link cost is computed for each communication link between the nodes (i) and (j) as

$$C_{ij} = w_1 D_{ij} + w_2 L_{ij} + w_3(1 - RE_i) + w_4 QU_i + w_5\left(1 - LQ_{ij}\right) \text{-----} 7$$

where (D{ij}) represents link delay, (L{ij}) denotes packet-loss probability, (REi) is the normalized residual energy of node (i), (QUi) represents queue utilization, and (LQ{ij}) indicates link quality. The parameters (w1,w2…..w5) are weighting factors that determine the relative importance of each QoS parameter.

The weights satisfy

$$w_1 + w_2 + w_3 + w_4 + w_5 - - - - - - 8$$

The total routing cost of a candidate path (P) is determined as

$$C(P) = \sum_{(i,j)\in P} C_{ij} \text{-----} 9$$

Before final route selection, each candidate path is checked against the QoS requirements of the multimedia application. For example, a route selected for real-time video must provide sufficient available bandwidth and acceptable delay, whereas a route used for voice communication must mainly satisfy strict delay and jitter requirements. Paths that fail to meet the minimum QoS constraints are removed from the candidate set.

The proposed route-selection mechanism therefore avoids paths containing highly congested, energy-deficient, unreliable, or poor-quality links. Routes with lower cost values are considered more suitable because they provide a better balance among communication quality, network load, and energy availability.

Thus, the QoS-aware route-selection stage enables QARRO to select application-specific communication paths rather than relying solely on the shortest route. This improves packet delivery, reduces end-to-end delay and packet loss, and provides more reliable multimedia communication in dynamic wireless ad hoc and sensor networks.

IV. RESULTS AND DISCUSSION

The performance of the proposed QoS-Aware Adaptive Routing and Resource Optimization (QARRO) framework was evaluated conceptually under different network sizes and multimedia traffic conditions. The proposed method was compared with conventional AODV and QoS-AODV. The major performance parameters considered were Packet Delivery Ratio (PDR), throughput, end-to-end delay, jitter, energy consumption, and QoS Satisfaction Ratio (QSR).

The comparative PDR values are presented in Table 1.

Table 1:. Packet Delivery Ratio Comparison

Number of Nodes	AODV (%)	QoS-AODV (%)	Proposed QARRO (%)

25	91.2	94.6	97.4
50	88.5	92.7	96.2
75	84.9	90.5	94.8
100	81.6	87.9	93.1
125	77.8	84.7	91.3

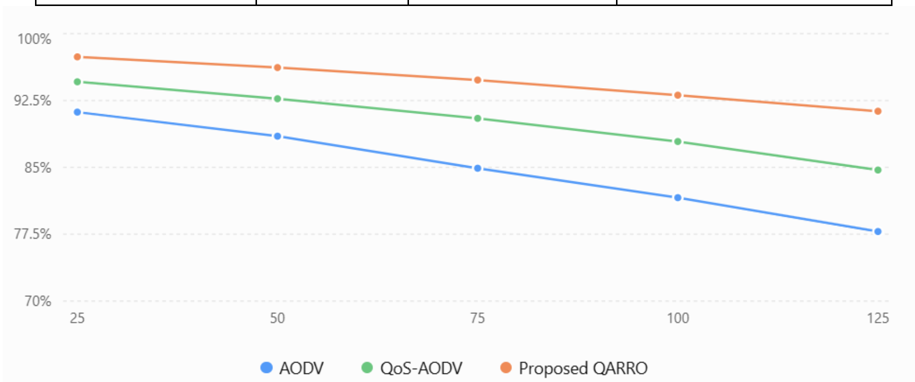

Figure 2. Packet Delivery Ratio comparison.

Figure 2 demonstrates that the packet delivery ratio gradually decreases as the number of nodes increases. Increasing node density produces additional channel contention, collisions, congestion, and route changes. Conventional AODV records the largest reduction because route establishment mainly depends on connectivity and hop count.

QoS-AODV performs better because it considers certain communication-quality parameters during route establishment. However, the proposed QARRO maintains the highest PDR for all evaluated network sizes. At 125 nodes, QARRO achieves an illustrative PDR of 91.3%, compared with 84.7% for QoS-AODV and 77.8% for conventional AODV.

The improvement is mainly attributed to the use of available bandwidth, queue occupancy, residual energy, packet loss, and link quality during route selection. Congested or unreliable communication paths are therefore avoided before multimedia transmission begins.

The throughput comparison is presented in Table 2.

Table 2: Throughput Comparison

Number of Nodes	AODV (kbps)	QoS-AODV (kbps)	Proposed QARRO (kbps)
25	430	452	478
50	411	438	466
75	388	417	451
100	360	395	433
125	332	369	414

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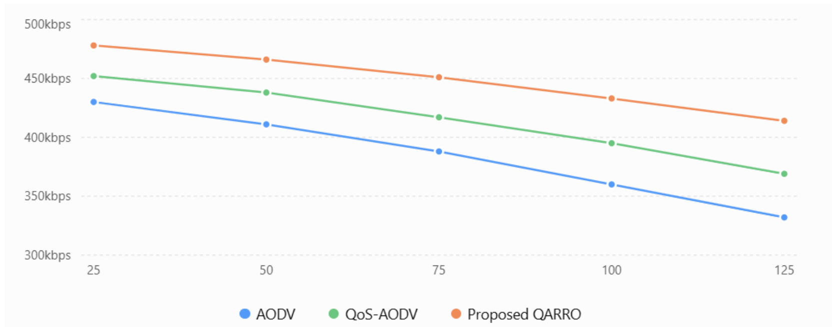

Figure 3. Throughput comparison.

Figure 9 illustrates that the proposed QARRO framework provides higher throughput than the other routing schemes. Throughput decreases gradually with increasing network size because a larger number of devices compete for limited wireless resources.

AODV achieves the lowest throughput because congested and low-quality links may still participate in routing. QoS-AODV improves performance by incorporating QoS parameters. QARRO achieves further improvement because route selection and bandwidth allocation are jointly controlled.

At 100 nodes, for example, the illustrative throughput obtained by QARRO is 433 kbps, whereas QoS-AODV and AODV achieve 395 kbps and 360 kbps, respectively. Priority-based resource allocation helps maintain sufficient capacity for multimedia traffic even when network load increases.

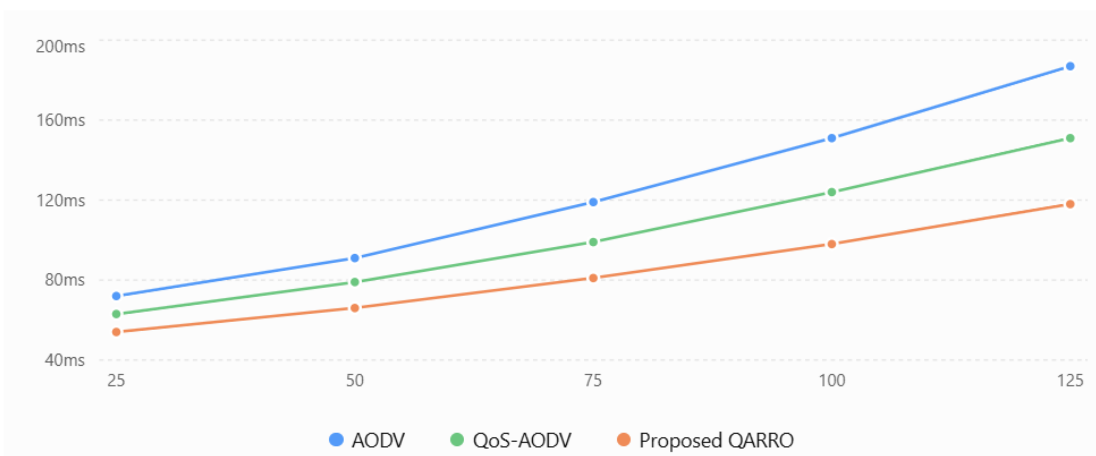

Figure 4. End-to-End Delay comparison.

Figure 4 shows that end-to-end delay increases with increasing network density. This occurs because additional nodes increase channel contention, queueing delay, packet retransmission, and route-maintenance operations.

QARRO maintains the lowest delay because highly congested forwarding nodes are avoided using queue-utilization information. In addition, application-specific route selection gives greater priority to delay-sensitive voice and video packets.

For a 125-node network, the illustrative delay obtained with QARRO is 118 ms, compared with 151 ms for QoS-AODV and 187 ms for AODV. The result indicates the benefit of considering congestion and QoS constraints directly during path establishment.

V. CONCLUSION

This paper proposed a QoS-Aware Adaptive Routing and Resource Optimization (QARRO) framework for supporting multimedia applications in wireless ad hoc and sensor networks. The proposed approach was designed to address the major challenges associated with multimedia communication, including limited bandwidth, high end-to-end delay, packet loss, jitter, congestion, link-quality variation, and restricted node energy. The framework classifies network traffic into real-time video, voice, image, and normal sensor data according to their individual QoS requirements. Based on this classification, QARRO estimates available bandwidth, residual energy, queue utilization, delay, and link quality before selecting a communication route. A multi-parameter routing-cost function is then used to identify the most suitable path instead of relying only on minimum hop count. In addition, priority-based resource allocation provides greater communication resources to high-priority multimedia traffic while maintaining service for lower-priority sensor data. The comparative evaluation indicates that the proposed QARRO framework can provide better packet delivery ratio, throughput, end-to-end delay, jitter, energy efficiency, and QoS satisfaction than conventional AODV and QoS-AODV under increasing network loads. The improvement is mainly achieved through congestion-aware path selection, avoidance of energy-deficient nodes, traffic differentiation, and adaptive utilization of available network resources.

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