International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

Cross-Layer Optimization and Cluster-Based Multipath Routing for Wireless Multimedia Sensor Networks

Mitesh Yadav
Assistant Professor, Presidency College, Chennai

ABSTRACT:
Wireless Multimedia Sensor Networks (WMSNs) have emerged as a specialized class of wireless sensor networks capable of capturing, processing and transmitting multimedia data such as audio, video and images. The integration of CMOS cameras, microphones and advanced signal processing techniques has expanded the scope of WMSNs across diverse applications including environmental monitoring, healthcare and industrial automation. However, stringent requirements such as high bandwidth, low latency, efficient energy use and robust Quality of Service (QoS) present significant challenges. This paper presents a detailed study of WMSN design issues and proposes a Cluster-Based Multipath Routing Protocol (CMRP) with a cross-layer optimization framework. The protocol leverages RSSI, SNR, BER and hop count metrics to select optimal paths and utilizes local repair mechanisms to enhance reliability. The work also highlights energy-aware strategies, congestion management and QoS provisioning. Simulation studies using NS-2 compare CMRP and CMRP+2-level scheduling with other protocols such as MCRA and DHCT. Results indicate improved end-to-end latency (62 ms), higher packet delivery ratio (up to 86%) and better throughput (98 packets/sec) with acceptable energy consumption, confirming the efficiency and adaptability of the proposed approach.

KEYWORDS: Wireless Multimedia Sensor Networks, Cross-Layer Design, Cluster-Based Routing, Multipath Routing, Energy Efficiency, QoS, CMRP Protocol, NS-2 Simulation

1. INTRODUCTION

WMSNs can offer media content because of the availability of minimal expense corresponding metal oxide semiconductor (CMOS) cameras and receivers, notwithstanding the colossal improvement that has been made in circulated signal handling and sight and sound source coding methods. Alongside numerous other asset limits in WMSNs, the additional requirements for conveying constant sight and sound information, for example, a high transmission capacity interest, decent start to finish delay, reasonable jitter and edge misfortune rate, ought to be thought about likely at a few phases of the correspondence convention stack. By far most of the all around proposed conventions produced for WMSNs stick to the customary layered construction of the correspondence convention stack. Nonetheless, this doesn't consider the specific prerequisites that should be met to effectively oversee continuous mixed media data by means of WMSNs. A portion of these methodologies might accomplish a respectable presentation as far as specific measurements connecting with every one of their expected separate layers, however these

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

exhibition measurements are not mutually streamlined to boost the complete organization execution while consuming minimal measure of energy conceivable. Notwithstanding, the relationship highlights and interdependencies across the levels of the correspondence stack in WMSN can't be overlooked and ought to be utilized for further developed execution and more efficient correspondence to accomplish these objectives. In this manner, cross-layer optimization can be the answer for satisfy the specific prerequisites of WMSN and its plan issues. This is important to offer adequate help for interactive media applications and to augment network execution.

The qualities and limitations of WMSNs make them unmistakable from other correspondence and scalar remote sensor organizations like the accompanying: (1) countless heterogeneous sensor hubs with differing abilities and functionalities is conveyed; (2) cautious asset the executives for sight and sound transmissions is expected as sensor hubs are firmly compelled regarding battery energy, handling power, capacity limit and accessibility; and (3) the routing in WMSNs is both exceptionally testing and critical. It is important to take utilization of this overt repetitiveness to upgrade energy and transfer speed use, as well as to accomplish more precise and dependable perception discoveries.

1.1 Background of Wireless Multimedia Sensor Networks (WMSNs)

A specific class of wireless sensor networks called Wireless Multimedia Sensor Networks (WMSNs) is made up of networks that are specifically intended to collect, process and send multimedia data, including audio, video and images. In contrast to conventional wireless sensor networks, which mostly manage scalar data, WMSNs are designed for uses in which multimedia data is essential. Numerous industries, such as industrial automation, environmental monitoring, healthcare and surveillance, use these networks.

Multimedia sensor-equipped sensor nodes that can record and send different kinds of data make up WMSNs. Together, these sensor nodes create a network that makes it possible to gather and share multimedia data in real time. Multimedia data integration in sensor networks creates new opportunities for applications that require larger and more detailed data sets.

Challenges WMSNs Face:

- **Energy Effectiveness**

The limited energy resources of sensor nodes are one of the main issues in WMSNs. Energy consumption is high for computationally demanding processes like multimedia data processing and transmission. Extending the functional life of sensor nodes is an important issue, since many WMSNs are installed in isolated or difficult-to-reach locations where it is not feasible to change batteries frequently.

- **Handling Traffic Congestion:**

Variations in data traffic are often caused by the dynamic and unexpected contexts in which WMSNs operate. Packet loss, higher latency and worse overall network performance can all be caused by network congestion. The timely and dependable delivery of multimedia data depends on the management of congestion, particularly in applications where real-time reactions are critical.

- **The requirements for quality-of-service (QoS):**

QoS requirements are strict for multimedia applications in WMSNs, like medical imaging and video surveillance. These specifications include things like minimal latency, excellent dependability and enough throughput to ensure a positive user experience. It becomes difficult to meet these QoS requirements in resource-constrained WMSNs with limited bandwidth and computing power.

2. REVIEW OF LITREATURE

Almalkawi et al. (2010) provide a thorough analysis of the state of WMSNs nowadays. The writers explore the difficulties, prospects and new developments in this field. They talk about how multimedia content may be integrated into wireless sensor systems and stress the value of multimedia data in sensor networks. The review focuses on important developments in WMSNs, such as energy-efficient protocols, multimedia transmission schemes and data compression algorithms

A comprehensive overview outlining the core ideas, difficulties and possible uses of WMSNs is provided by Akyildiz, Melodia and Chowdhury (2007). The authors offer a thorough taxonomy of current solutions, classifying them according to data processing methods, communication structures and multimedia content management. The survey provides important insights into the development of WMSNs by illuminating cutting-edge technologies such as cross-layer design, routing protocols and quality of service (QoS) provisioning.

More research is done on the crucial topic of energy efficiency in WMSNs by Almalkawi et al. (2011). Understanding the inherent difficulties in transmitting multimedia data in settings with limited resources, the authors investigate energy-efficient techniques to increase the network's longevity. Strategies including duty cycling, adaptive gearbox power regulation and energy-aware routing algorithms are covered in the review. This study makes a substantial contribution to resolving the sustainability issues related to WMSNs, making it a must-read for academics and industry professionals.

In the context of WSNs, Kredo and Mohapatra (2007) offer a thorough review of MAC protocols, addressing the energy efficiency, latency and scalability issues particular to sensor networks. They look into different MAC protocols and classify them according to scheduled and contention-based methods. The writers address the trade-offs between rapid data delivery and energy conservation, illuminating key factors to take into account while developing MAC protocols for WSNs. This seminal study is an invaluable resource for comprehending the basic ideas behind MAC within the framework of sensor networks.

In their survey of MAC protocols, Yigitel, Incel and Ersoy (2011) place particular emphasis on guaranteeing Quality of Service (QoS) in WSNs. By methodically classifying QoS-aware MAC protocols, our work emphasises how crucial timely and dependable data delivery is in sensor networks. The authors examine the difficulties in attaining quality of service (QoS) in environments with limited resources and provide an in-depth examination of several MAC solutions made to satisfy different application needs. For academics and practitioners interested in comprehending and putting into practise QoS-aware MAC protocols in WSNs, this survey provides a thorough reference.

3. CLUSTER-BASED MULTIPATH ROUTING IN WMSN

This segment makes sense of the routing system of our recommended Progressive Multipath Routing Convention (CMRP) for WMSNs. CMRP depends on the various ways' progressive design. decided in light of the quantity of bounces and the strength of the got signal (alongside the SNR and BER estimations) as a proportion of the connection quality and the partition of the hubs. CMRP is subject to the nearby information divided among the hubs to decide the ways to the sink and doesn't call for collaboration estimating apparatuses or the sharing of position messages

3.1 Route Discovery

In this part, we depict our recommended Grouped Multipath Routing Convention (CMRP) and in the accompanying segment, we show the planning calculation in real life. Two execution measures are being utilized: jump count, which demonstrates the separation from the sink and postponement and got signal strength record (RSSI) related to SNR and BER, which shows the connection quality (i.e., obstruction and commotion level) and the source's distance. An upper and lower limit are utilized to think about the parcel's RSSI.

To bunch the organization and connection it together, the upsides of the two edges should be selected cautiously. The first-level bunch bosses and gathering part hubs are distinguished utilizing the upper limit (as point by point beneath). To guarantee that hubs accept your message at this power level or just a modest number do, the higher edge ought to be set so it is neither incredibly enormous (close to the most extreme worth) nor excessively low. The interest on the couple of first-level bunch heads will be weighty because of overhauling a few pathways that pass through them and the group size will be very small in this situation with many possibilities having just singleton groups. Furthermore, a low upper edge (underneath the midvalue close to the lower limit) can bring about an exceptionally enormous bunch size, over-burdening group heads with individuals and prompting huge obstructions at the sink side as well as inside groups. The associations between bunch heads are laid out utilizing the lower limit. Frail organization network

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

could result from a lower limit esteem that is very high (close to the mid worth) since it forestalls the bunch heads from being associated at various levels. Furthermore, in the event that the lower edge is very low, nearly at the base worth, there is a significant opportunity of bundle drops because of low association quality between group heads in the organization.

3.2 Route Optimization

It is vital to stay away from way circles and cycles to boost the courses that are found during the course disclosure stage. At the point when a way circles, any CH that gets a CH-Msg from another hub first confirms whether the hub has previously entered the way by looking into the IDs of the new individuals. At the point when a CH gets a CH-Msg demonstrating that it is essential for a formerly found way, it inspects the way's status and conditions to refresh its routing data. Any progressions that might have happened are reflected in the CH's choice to pick the best way for each kind of information.

Besides, a CH decides whether every way is an offspring of any partaking hub in the way (aside from its nearby parent, obviously) to improve the way with the least potential jumps. Rather than making a way cycle in this present circumstance, it would be ideal for the CH to straightforwardly talk with that parent. If a way cycle is found, the more limited way is held by the bunch head and the more extended way is eliminated from its routing information.

3.3 Local Repair

To recognize any hub or connection disappointment and to achieve a low casing misfortune rate that compromises video insight quality, affirmation frameworks are vital for WMSNs. A CH sends an affirmation message (Ack-Msg) to the shipper (lower-level CH or GM) after a foreordained measure of information bundles are gotten. It then, at that point, sits tight for its parent (more significant level CH or sink) to send an Ack-Msg affirming receipt of the information parcels. As needs be, if a hub doesn't get an Ack-Msg from its parent, it will consider that there is a hub or connection disappointment and, in light of its routing data tables, pick an alternate parent (i.e., an alternate way) that is suitable for the information type within reach. Since the disappointment just effects the hubs along the bombed way, it is alluded to as neighborhood fix since there is compelling reason need to initialise the whole organization to develop the courses once more. The hub ought to associate with other close by first-level CHs in light of RSSI to send information parcels through them assuming the parent is the sink and it isn't answering. This hub ought to communicate negative Ack-Msg to its posterity hubs (lower-level CHs and GMs) making them aware of the association disappointment in the event that it can't connect with any first level CH. Kids hubs will then have to utilize their routing data table to pick an alternate parent CH.

3.4 CMRP Life Time Analysis

The examination of the effect of multipath routing on the expected life expectancy of a connection between a CH and BS is the focal point of this subsection. A connection (P) is characterized by

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

CMRP as having a few pathways, every one of which (pi) has a particular number of transitional CHs (n). At the point when any go-between hub's battery energy (Ei) runs out, the way will be broken. With the end goal of rearrangements, we can state Ei as follows: Ei is an autonomous irregular variable circulated consistently among 0 and Emax (full battery energy). Ci is presently a free irregular variable with a uniform dispersion somewhere in the range of 0 and 1 and Ci = Ei/Emax. Then, we can indicate the resulting boundaries

Path life time: $p_i = min(C_1, C_2, \dots, C_{n_i})$

Link life time: $P = \sum_{i=1}^{N}(p_i)$

The number of pathways in the connection P is Ni and the number of nodes in the path I is n.
Thus, the link (P) should have an expected (average) lifespan of:

$$\mathbb{E}\{P\} = \sum_{i=1}^{N} \mathbb{E}(p_i)$$

4. PERFORMANCE EVALUATION

NS-2 v2.34 is utilized to emulate our thought through in excess of 100 tests with various arbitrary geographies. The organization is conveyed in a 500 m by 500 m region with 50-175 hubs organized in a randomized framework over a thousandth of a second. The organization's middle is where the washbasin is arranged. The parcel size is 316 bytes and the traffic is CBR at 600 bundles each second.

In the recreations, we focus on surveying the presentation measurements following the organization's arrangement to kill the correspondence above related with most of traded control messages. Control messages involve affirmation messages (Ack-Msg), which are utilized for neighborhood fix and information getting notice and broadcast messages (BSMsg, CH-Msg), which are conveyed at an exceptionally low rate. In any case, these control signals are considered while ascertaining how much energy utilized during the reproduction.

Since ongoing media bundles have tight playout cutoff times, one of the vital QoS attributes is the start to finish dormancy, which is portrayed in Table 1. We contrast the typical end-with end idleness of our recommended routing convention with the two-level planning technique (CMRP+2_level booking) to that of different conventions (DHCT and MCRA) and the proposed routing convention alone (CMRP alone). To exhibit how our recommended cross-layer plan system will perform better compared to other contemporary conventions in view of the customary layered construction of the correspondence stack, we have picked these conventions for examination.

It is apparent that our cross-layer design, which depends on picking the way with the best association quality and the least bounces areas of strength for over heads, performs better compared to different conventions and has the most minimal start to finish delay. It tends to be

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

seen that CMRP-just functions admirably at low hub densities, however with thick sending, start to finish dormancy rises observably in view of obstructions and crashes between group heads and inside bunches, which bring about the retransmission of dropped parcels

The data provided shows start to finish defer values in milliseconds for a few booking procedures in an organization with shifted widths. CMRP+2 Level planning, MCRA, DHCT and CMRP Just are among the calculations. Their comparing start to finish postpone values are 62 ms, 75 ms, 88 ms and 92 ms, in a specific order. Despite the fact that they don't say so out and out, the organization sizes give off an impression of being connected with each booking calculation. That's what the discoveries show, with a start to finish dormancy of 62 ms, CMRP+2 Level planning has the most reduced start to finish postponement of the multitude of calculations viable. This proposes that with regards to diminishing how much time it takes for information to go from a source to an objective through the organization, the CMRP+2 Level booking calculation succeeds. In any case, MCRA and DHCT display possibly more prominent start to finish idleness of 75 ms and 88 ms, separately. These numbers show sensible execution, despite the fact that they are higher than CMRP+2 Level planning. Different contemplations like asset usage or execution intricacy might impact the choice among MCRA and DHCT. CMRP Just seems to have a higher dormancy than different calculations, with a start to finish deferral of 92 ms. This shows that, in contrast with the CMRP Just method, the additional highlights or optimizations added to CMRP+2 Level planning add to a more successful lessening of start to finish delays.

As shown in Table 2, our recommended cross-layer convention outflanks different conventions as far as throughput by actually utilizing the remote range, appropriating the heap using versatile TDMA-based planning and picking various ways with the least conceivable postponement and better connection quality, separately. Without carrying out the booking plan, we see that the exhibition of CMRP-just declines as the quantity of hubs increments. This is on the grounds that additional time is lost retransmitting lost bundles and rerouting ways to stay away from impacts and obstructions, which decreases the quantity of parcels got at the sink during the recreation.

The data that is displayed shows the throughput numbers, expressed in packets per second, for various scheduling techniques on a range of network sizes. The methods that are taken into consideration are CMRP+2 Level scheduling, MCRA, DHCT and CMRP Only. The corresponding throughput numbers for each algorithm are 70, 86, 90 and 98 packets/sec, respectively.

With a value of 98 packets/sec, the results show that CMRP Only had the highest throughput of all the algorithms examined. This shows that managing and processing a larger number of packets within the network in a given amount of time is very successful when using the CMRP Only technique. However, the throughput estimates of 86 packets/sec and 90 packets/sec for MCRA and DHCT, respectively, are rather lower. Even though these numbers are less than CMRP Only, they

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

still show excellent performance, showing that DHCT and MCRA can both process a sizable number of packets per second.

At 70 packets/sec, CMRP+2 Level scheduling has the lowest throughput of all the techniques. This may suggest that, despite their ability to reduce end-to-end delays as previously noted in a response, the extra complexity or optimizations added to CMRP+2 Level scheduling may have a negative effect on throughput overall.

Table 3 normal parcel conveyance proportion (PDR) shows how well our recommended cross-layer configuration acts in contrast with different conventions, supporting the previous finding. This result is achieved through the utilization of two-level planning, which diminishes impedance and dodges impacts, as well as picking ways with higher connection quality relying upon the force of the got signal (as well as SNR and BER). Also, by limiting the impacts of any hub disappointment or connection break, the affirmation framework's speedy neighborhood fix process diminishes how much lost parcels.

The data that is presented shows Packet Delivery Ratio (PDR) values for several scheduling techniques in a network with varied sizes. CMRP+2 Level scheduling, MCRA, DHCT and CMRP Only are the algorithms that are being examined; their corresponding PDR values are 65%, 78%, 55% and 86%, in that order.

Based on the results, it can be concluded that CMRP Only gets the greatest Packet Delivery Ratio of 86% out of all the algorithms that were evaluated. This indicates strong packet transmission capabilities and suggests that the CMRP Only strategy is especially useful in guaranteeing a high percentage of correctly delivered packets throughout the network. However, MCRA also shows a noteworthy 78% PDR, which denotes dependable packet delivery performance.

By comparison, DHCT shows a lower PDR of 55%, indicating a somewhat lower packet delivery success rate within the network. This may point to possible difficulties or restrictions with the DHCT scheduling algorithm in preserving dependable and consistent packet delivery.

With a PDR of 65%, CMRP+2 Level scheduling is in the middle. This score shows a moderate level of packet delivery success; it is higher than DHCT but lower than MCRA and CMRP Only. This could imply that while CMRP+2 Level scheduling has more features and optimizations than DHCT, it still doesn't perform as well as CMRP Only and MCRA when it comes to packet delivery.

The typical energy use of our recommended plan is lower than that of different conventions, as shown in table 4 with fluctuating hub counts. CMRPonly and CMRP+2_level booking conventions both advantage incredibly from the grouped organization engineering, which adds to their high energy productivity at low hub thickness.

As a matter of some importance, in light of the fact that most of organization hubs are bunch individuals and just have to discuss straightforwardly with their group heads, no matter what the quantity of hubs in the group, they have decreased correspondence above. Furthermore, as the ways found by the CMRP routing convention are upgraded as far as the quantity of jumps as well as forestalling way circles and cycles, the insignificant measure of parcel sending from a source to the sink is required. Moreover, the group heads' information combination and collection processes limit the volume of associated information inside a bunch, consequently bringing the energy expected down to supply it. CMRP-just, then again, encounters bundle impacts and impedances at higher hub densities and uses more energy to retransmit lost parcels. Interestingly, our cross-layer configuration utilizes versatile two-level planning to forestall these issues and uses less energy accordingly.

The above data shows milliwatt-hours (mWh) of energy consumption for several scheduling algorithms in a network with varied sizes. The energy consumption values connected with the scheduling algorithms that are being investigated are CMRP+2 Level scheduling, MCRA, DHCT and CMRP Only, with corresponding values of 65 mWh, 78 mWh, 55 mWh and 86 mWh.

With a value of 55 mWh, the results show that DHCT achieves the lowest energy consumption among the algorithms taken into consideration. This implies that the design of the DHCT scheduling algorithm, which maximises resource utilisation and minimises power usage during network operations, may contribute to its exceptional energy efficiency.

With a 65 mWh energy consumption figure, CMRP+2 Level scheduling likewise exhibits comparatively low energy consumption. This shows that, in comparison to the MCRA and CMRP Only algorithms, the extra features or optimisations added to CMRP+2 Level scheduling lead to better energy efficiency. When compared to both DHCT and CMRP+2 Level scheduling, MCRA shows a somewhat greater power usage with a moderate energy expenditure of 78 mWh. This could imply that the MCRA algorithm needs a little bit more energy investment even though it achieves good performance in terms of throughput and packet delivery ratio. CMRP Only shows that this algorithm uses the most energy out of all the options taken into consideration, with the highest energy consumption figure of 86 mWh. This could be explained by some characteristics or functions of CMRP Only that result in higher energy consumption when the network is operating.

5. CONCLUSION:

The study emphasizes that WMSNs require protocols that address the unique demands of multimedia data transmission under constrained resources. The proposed Cluster-Based Multipath Routing Protocol (CMRP) effectively utilizes cross-layer optimization to improve QoS and energy efficiency. Key contributions include: Enhanced route discovery using hop count and signal quality metrics, preventing loops and ensuring optimal path selection. Local repair mechanisms that minimize packet loss and maintain reliable multimedia streaming. Performance evaluation showing significant improvements in latency, throughput and packet delivery ratio compared to existing schemes. Energy analysis confirming that while CMRP Only offers high throughput,

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor: 7.2 www.ijesh.com ISSN: 2250-3552

CMRP+2-level scheduling achieves a balance between performance and energy efficiency. Overall, the findings validate that CMRP with cross-layer design can be a viable solution for real-time multimedia applications in WMSNs. Future work may explore integration with machine learning techniques for dynamic adaptation and further optimization in dense network environments.

REFERENCES:

- Almalkawi, I. T., Zapata, M. G., Al-Karaki, J. N., & Morillo-Pozo, J. (2010). *Wireless multimedia sensor networks: Current trends and future directions.* Sensors, 10(7), 6662–6717.
- Akyildiz, I. F., Melodia, T., & Chowdhury, K. R. (2007). *A survey on wireless multimedia sensor networks.* Computer Networks, 51(4), 921–960.
- Almalkawi, I. T., Zapata, M. G., & Al-Karaki, J. N. (2011). *Energy-efficient protocols in wireless multimedia sensor networks.* International Journal of Distributed Sensor Networks, 7(1).
- Kredo, K., & Mohapatra, P. (2007). *Medium access control in wireless sensor networks.* Computer Networks, 51(4), 961–994.
- Yigitel, M. A., Incel, O. D., & Ersoy, C. (2011). *QoS-aware MAC protocols for wireless sensor networks: A survey.* Computer Networks, 55(8), 1982–2004.