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Hierarchical Multi Path Routing Protocol for Wireless Multimedia Sensor Networks

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Abstract: Wireless multimedia sensor network (WMSN) deals with transmitting multimedia traffic over a long range in multi-hop along multiple paths. This is so for achieving the objectives of Quality of Service (QoS). In clustered routing, the load on the cluster head nodes increase and the energy consumed at the cluster head nodes lead to energy depletion of that node which degrades the network performance. The proposed protocol focuses on QoS and energy efficiency in WMSN by considering the hierarchical deployment of heterogeneous nodes. This protocol makes use of hierarchical structure of powerful cluster head nodes and the optimized multiple paths to support reliable and energy efficient multimedia transmission in WMSN. The reliability and life of the network increases because of the fault tolerance and load balanced feature of the protocol. Simulation results describe a significant performance improvement in terms of energy consumption of the nodes and the QoS parameter.

Keywords: Wireless multimedia sensor network, Quality of service, Energy efficiency, Fault tolerance.

1. Introduction

Wireless Multimedia Sensor Network (WMSN) consists of multimedia sensor nodes which are capable of sensing events and transmit multimedia data which has widespread applications now days. The multimedia data transmission has a number of challenges like use of limited bandwidth, intolerance to delay for time critical applications, limited power supply and many more. WMSN bears special attention because of the routing constraints like resource management and transmission of the multimedia data to achieve the QoS parameters. Hence WMSN imposes much more limitations for designing the routing protocols. Existing protocols for WMSN hardly focus on these specific requirements and are also not optimized to improve the network performance keeping in mind the minimum energy consumption of the nodes. Cross layer optimization techniques has been observed as one of the methods to cater to the challenges of WMSN [1] and improve the network performance. However, here the focus is mainly on QoS requirements and efficient uses of energy of the nodes.

Due to the high density of the multimedia sensor nodes, redundancy of data needs to be addressed in order to improve on energy efficiency. Considering the architecture of WMSN, mostly two types are widely used namely flat architecture and hierarchical architecture as mentioned in Fig. 1.

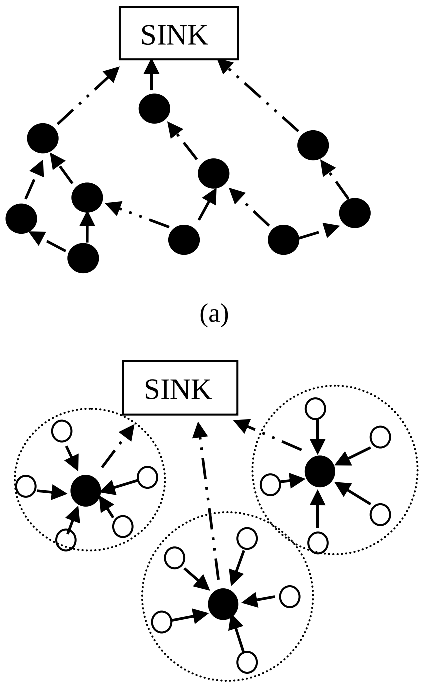
Flat architecture consists of homogeneous nodes to perform all sorts of task ranging from multimedia processing to data transmission towards the sink in a multi hop manner. In hierarchical (clustering) approach, the network is divided into clusters consisting of a group of sensor nodes termed as a cluster and one of them is selected as the cluster head. The sensed event information by the sensor nodes are transmitted to the cluster head node. The cluster head node processes, removes the redundant data items, aggregates and transmits to the sink node.

However the data packets from the cluster head nodes could be transmitted to the sink node through several available paths [2].

In flat architecture, all the nodes have equal roles and responsibilities for multimedia processing and transmission which leads to increased energy consumption and reduced network performance. The traffic around the sink node is also overloaded being the interface towards the sink node which hampers the efficiency of the network and introduces delay in communication. However, in hierarchical network the cluster head nodes aggregate the data to decrease number of packets transmitted and to have scheduling between the sensor nodes inside the cluster. The design of QoS protocols [3, 4] becomes the objective for assured delivery of the real-time multimedia data within bounded delay in WMSN. Most of the existing protocols are based on carrier sense multiple access (CSMA) [4] as well as time division multiple access (TDMA) [5] techniques. CSMA is suitable when the traffic load is light and the occurrence of collision and congestion probability is low. Whereas when the load is heavy like in WMSN, this method may lead to energy wastage and delay because of idle listening and collision. TDMA is suitable in case of multimedia applications having heavier traffic load. In this paper a hierarchical multipath routing protocol is proposed to have optimized routing decision and delivery with minimum energy utilization. It is a new multipath routing protocol for wireless multimedia sensor networks with increased throughput, high packet delivery ratio, and decreased end to end delay and energy consumption.

Generally in hierarchical routing, the cluster head directly communicates with the sink node. However, when the network spans over a large geographical area, the cluster head node may be far away from the sink node. In this case the cluster head node needs to consume more energy in order to deliver the packets to the sink node in one hop. Hence in large networks, the use of clustering method is not a feasible approach [2]. In order to overcome this we have another method where there exist multiple paths between the cluster head nodes and the sink node through intermediate cluster head nodes.

The proposed routing protocol creates clusters of multimedia sensor nodes with resource rich nodes as the cluster head node such that a strong connection is maintained with number of multiple paths among the cluster head nodes suitable for data transmission depending on received signal strength (RSS). In each cluster the powerful cluster head node



(a)

(b)

Figure.1 Architecture of WMSN: (a) flat architecture and (b) hierarchical architecture

performs aggregation of multimedia data in order to decrease the amount of data transmission to save energy along with bandwidth. QoS aware transmission and scheduling is done in the network both inside the clusters and across the cluster head nodes to achieve the objectives of WMSN.

The advantage of maintaining multiple paths between the cluster head nodes in the direction of the sink node leads to an even distribution of energy throughout the network and also addresses the fault tolerance issue. We have considered the resource rich nodes as cluster head nodes to improve upon the routing aspects because multimedia transmission consumes more energy than scalar data transmission. The multimedia sensor nodes need to transmit only within the cluster (one hop) which ensures less energy consumption within bounded delay and also with higher accuracy. Hence the QoS requirements are fulfilled both within the cluster and across the clusters.

The rest of the paper is organized as follows. Section 2 focuses on literature survey, section 3 describes the system model, section 4 explains the proposed protocol and algorithm, section 5 explains the life time analysis in relation to the proposed protocol, simulation and result analysis is discussed in section 6. Conclusion and future work is presented in Section 7.

2. Literature survey

Over the years several routing protocols have been developed addressing the issues and challenges for WMSNs. The authors in [6] have provided a detailed survey on these issues.

In [7] the authors discussed a protocol named DHCT which reduces interference within neighbouring paths by using some metric. This protocol also maintains number of links at the sink node in order to have disjointed paths. However, this protocol does not consider the QoS parameters as metric for routing and also there is nothing mentioned for the prioritization of traffic types.

The authors in MCRA [8] proposed multi constrained routing algorithm for delay and packet loss ratio along with balanced energy consumption. Here in this protocol sink node starts the route search process by flooding messages called interest messages. Nodes which receive these interest messages, select the path with minimum hop count to send its data packets. MCRA reduces the number of flooding by aggregating interest messages. But the routing decision mainly depends upon flooding the interest message from the sink node to the source nodes all around the network to find the path based on minimum hop count only. This protocol does not consider the QoS parameters of the link which can be computed from RSS.

Multipath multi priority (MPMP) [9] protocol proposes to find the optimum number of possible unique path. This protocol computes the distance between sensor nodes and the sink node to obtain the route and it does not consider other parameters like bandwidth and link which are important for multimedia delivery. Also it does not focus on heterogeneous traffic types.

The authors in [10] have proposed a cluster based QoS aware multipath routing in WMSNs. Here multiple paths are obtained based on cost factors like packet loss rate, node energy level and transmission delay. The path which achieves the routing requirement limitations effectively is selected for data transmission.

In [11] the authors proposed a cross layer routing protocol for heterogeneous and hierarchical networks of WMSNs. They have used a cost function in order to achieve QoS parameters of the protocol. However, the throughput obtained using this protocol is found to be low.

Authors in [12] proposed an energy efficient routing protocol considering particle swarm clustering approach and inter cluster routing algorithm for wireless sensor networks to achieve data transmission and conserve energy along with balancing load between various nodes. This protocol suffers from producing low throughput value.

Energy aware Data Gathering Protocol have been proposed in [13] on the basis of the double cluster heads in a cluster of nodes. After the selection of the main cluster head, a vice cluster head is selected based on the residual energy and average energy of nodes to perform data transmission. Hence the overall load on the main cluster head is reduced.

The authors in [14] proposed an energy efficient clustering algorithm for heterogeneous network and in this protocol cluster head selection is done based on the energy and communication cost. This increases the chance for a node to become the cluster head if its residual energy is higher. So the use of energy in the network is balanced.

In [15] the authors have shown an optimization approach using the Ant Colony Optimization (ACO) technique to transmit multimedia data with guaranteed QoS in WMSNs. However the authors have focused on performance metrics like throughput and packet delivery ratio. The novel technique needs further investigation with reference to other parameters. Our approach in this paper is a routing technique in WMSNs targeting the typical requirements of WMSNs.

3. The system model

The network is divided into clusters where each cluster consists of heterogeneous nodes and inside a cluster, the multimedia sensor nodes communicate with the *cluster head node* which is assumed to be a resource rich node and relay their sensed data to it. The *cluster head nodes* have more energy to perform both computation and communication tasks. The resource rich cluster head nodes are uniformly deployed throughout the networked environment and communicate with the sink node directly or in multi-hop manner depending on its position i.e. if the sink node is within the transmission range of the *cluster head node,* then that *cluster head node* communicates directly with the sink node. Otherwise the *cluster head node* communicates through other intermediate *cluster head nodes* in the direction of sink node in multi hop manner.

The proposed routing protocol considers the hop count and RSS of messages as a measure of distance between the nodes and the link quality respectively. In wireless networks RSS is calculated as:

$$RSS = \frac{P_r}{P_t} \tag{1}$$

where P_t and P_r are considered to be the transmission power and reception power respectively. The RSS value could be computed at each node which receives a signal containing the P_t of the sender node along with other desired information.

4. The proposed protocol

4.1 Assumptions and parameters

The network is assumed to be static in nature and consists of two types of nodes. The first types of nodes are the multimedia sensor nodes called *cluster member nodes* to detect the events and transmit to their respective *cluster head nodes*. The second types are the powerful (resource rich) nodes having adequately available battery energy to act as *cluster head nodes* and responsible for data processing and transmission to the sink node in one hop or multi hop manner depending on their deployment position. These resource rich nodes are deployed uniformly throughout the network and the multimedia sensor nodes are deployed randomly. Multipath routes are maintained among the *cluster head nodes* for transmission of multimedia packets [16] to provide reliable and efficient data transmission in the direction of sink node. Alternate paths are also maintained to address the fault tolerance issue and also in the case of packets with low priorities could be transmitted in other directions (alternate path) to maintain uniform consumption of energy across the network. Multipath routes are maintained to achieve the objectives like reliable data transmission, balanced energy consumption, load balancing among the nodes, dynamic and fault tolerant network along with reduced delay [2, 16-18].

The proposed protocol is a hierarchical routing protocol and there exist *cluster head nodes* in every cluster for data gathering and transmission to the sink node. Also there exist multiple paths between the *cluster head nodes* based on *hop count* and RSS. The parameters *hop count* and RSS are considered for the process of decision making while discovering the multiple routes. Two threshold values namely *higher threshold* (T_H) and *lower threshold* (T_L) are used (where $T_H > T_L$) to compare with the RSS. The T_H value is used to determine the *cluster head nodes* and *cluster member nodes*. The T_H value should be selected judiciously such that it should be neither very large nor very small. If it becomes a large value, then a node may not find any receiving node or only a few nodes in its neighbourhood so that, the size of the cluster would become small which leads to increasing the load on few of the cluster head nodes for providing service. Similarly if the TH value is too small, then the size of the cluster would become very large which may lead to overload the *cluster head nodes* with many number of *cluster member nodes* which leads to more interference.

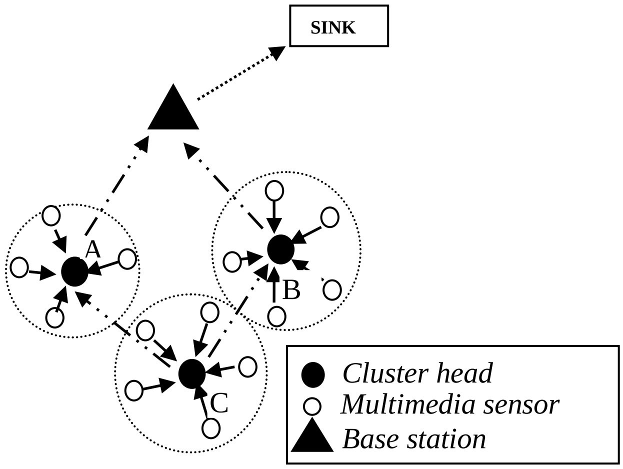


Figure.2 Clustered multipath WMSN

To establish links among the *cluster head nodes*, T_L value is used. Having high value of T_L may lead to poor network connectivity because this would prevent connecting the *cluster head nodes*. Similarly having a small T_L value also, the network may have low link quality between *cluster head nodes* leading to drop of packets.

4.2 Route setup

As per the algorithm (clustering) provided in the next subsection, initially the base station broadcasts *BS-Message* containing the transmitted power level as one of the parameters along with other usual parameters. The resource rich nodes upon receiving the *BS-Message,* compute the RSS value as per equation-1 and compare with the threshold value T_H. If the computed RSS value is more than T_H, then it responds with an acknowledgment message informing the base station itself as one of the up-link node and they are called *cluster head nodes* as shown in Fig. 2 (node A and B). Each *cluster head node* periodically broadcasts control messages called *CH-Message* which contains in addition to the transmission power, the *NODE-ID* of the sending *cluster head node* and the *hop count* mentioning the number of hops away from the base station. For each received *CH-Message,* RSS is again computed and compared with the threshold values T_H and T_L.

If the RSS value is more than T_H and the node is a multimedia sensor node, then the receiving node declares itself as a *cluster member node* and responds with an acknowledgment message which indicates its joining to that *cluster head node* as a member of that cluster. This means that the sender *cluster head node* is nearer and the link quality is too good to provide better communication. Nodes receiving more number of *CH-Message* from different *cluster head nodes,* having RSS value more than T_H, selects one with highest RSS value as its cluster head. The resource rich nodes which receive *CH-Message* with RSS value as same or more than T_L, declares itself as *cluster head nodes* and respond back to the sender with an acknowledgement to inform them as one of their parent node in the direction of the base station. Resource rich nodes receiving more than one worthy *CH-Message* from various *cluster head nodes,* stores all of them in its own routing table to maintain multiple paths towards the base station sorted on the RSS and hop count value. Multiple paths are used for back-up (alternate) paths and also for non critical type of traffic which may not require strict QoS requirements. If the RSS is less than T_L, then the message is simply ignored. The approach continues to build the network until all the nodes join the network and determine their roles i.e. *cluster head node* or *cluster member node*, and all possible paths are found.

For QoS requirement we need to have optimal route for data transmission of multimedia content and there should not be any path loop also. So to avoid path loop, each *cluster head node* upon receiving *CH-Message*, looks for the NODE-ID of the nodes joining the path to know whether it is already present or not. If a *cluster head node* finds its own NODE-ID in that existing path, then it looks for every given path whether it is a child for any participating node in this path. In case of path loop, the *cluster head node* ignores this and retains only the shortest path in its routing table.

The algorithm of cluster formation process is as follows:

Algorithm: Clustering

Step 1. Base station broadcasts *BS-Message*.

Step 2. The resource rich nodes receiving *BS-Message* computes the RSS value.
If RSS $\geq T_H$
  Declare itself as *cluster head node.*
  Transmit acknowledgement message to the base station and set *hop count* to 1.
  Broadcast a *CH-Message.*
Else Ignore the *BS-Message.*

Step 3. Every node receiving *CH-Message* computes the RSS value.
If RSS $\geq T_H$, and the node is a multimedia sensor node
  Declare itself as a *cluster member node* and reply acknowledgement to the parent.
Else Ignore the *CH-Message*.
If RSS $\geq T_L$ and it is a resource rich node
  Check for path loop
    If there is no path loop
      Declare itself as a *cluster head node.*
      Maintain a record in the routing table and update *hop count*.
      Broadcast *CH-Message*.
    Else Ignore the *CH-Message.*
Else Ignore the *CH-Message.*

Step 4. Repeat Step 3 and 4 until all the nodes join the network to establish the path.

4.3 Scheduling and data transmission

Once the network is established and the respective roles of the nodes are decided, data transmission occurs as per the schedule among the nodes. There are two levels of scheduling considered for data transmission. The first level involves scheduling among the *cluster member nodes* and the second level involves scheduling among the *cluster head nodes*.

Due to the inherent characteristics of collision free medium access, TDMA schedule is preferred to access multimedia channel for QoS requirements under high traffic load conditions. In the first level scheduling, each *cluster head node* schedules the data transmissions among its *cluster member nodes* to provide high priority to the nodes which demand for higher QoS and also to avoid collision and interference. First level scheduling starts with the *cluster head nodes* by transmitting a broadcast message requesting their *cluster member nodes* inside its own cluster to send their QoS requirements for the traffic through a message called *Request Message*. Upon getting the response from the fellow *cluster member nodes* the *cluster head node* prepares a schedule for data transmission by the *cluster member nodes* and communicates it to the members of the cluster through a message called *Allocation Message.* This enables multimedia and delay intolerant data to be transmitted quickly with higher priority than the less priority data. The *cluster member nodes* transmit their data packets during the assigned time slots only. In order to conserve energy, the *cluster member nodes* turn off their respective transceiver (sleep mode) until their time slot approaches or to the end of an ongoing transmission in its periphery (in case of passive receivers). The *cluster head nodes* keep on sending *Request Messages* periodically to their respective *cluster member nodes* to provide their updated QoS requirements. The interval of time for scheduling operation in a cluster depends on the application requirements.

5. Life time analysis

There exist a link (L) between every *cluster head node* and base station for effective communication. However there are multiple paths between them and each path in that link may have $n\ (n \geq 0)$ number of intermediate *cluster head node*s. The path is said to be an effective path as long as the energy E_i of each *cluster head nodes* along that path are sufficient enough to participate in communication process. The energy E_i of that *cluster head node* can be considered as a random variable in the range of initial energy to the minimum threshold energy.

Let $c_1, c_2, \dots c_n$ be n independent and identical distributed random cost variables where c_i follows an exponential distribution with mean value of 1.
The probability density function is given by

$$f_{c_i}(c_i) = \begin{Bmatrix} e^{-c_i}, c_i \geq 0 \\ 0, otherwise \end{Bmatrix} \quad (2)$$

So the life time of any path is the minimum of all c_i
We can now define

$$\mathrm{X} = \min(c_1, c_2, \dots, c_n) \quad (3)$$

Let $F_X(x)$ be the cumulative distribution function. Then

$$\begin{aligned} F_X(x) &= P(X \leq x) \\ &= 1 - P(X > x) \\ &= 1 - P(c_1 > x, c_2 > x, \dots c_n > x) \\ &= 1 - (P(c_1 > x).P(c_2 > x) \dots P(c_n > x)) \\ &= 1 - \prod_{i=1}^{n} P(c_i > x) \\ &= 1 - e^{-nx} \end{aligned} \quad (4)$$

Hence the density function is given by

$$f_X(x) = \begin{Bmatrix} ne^{-nx}, n \geq 0 \\ 0, otherwise \end{Bmatrix} \quad (5)$$

which is also an exponential distribution.

Table 1. Simulation parameters

No. of sensor nodes	200
No. of cluster head nodes	5
Topography size	1000 X 1000 sq. meters
Sensor node transmission radius	60 meters
MAC layer	IEEE 802.11
Simulation duration	1000 seconds
Traffic type	CBR
Size of data packets	512 bits
Initial energy	200 joules
Bandwidth	2MB
Rate of Transmission	100,150,200,250 and 300 packets per second

The average (expected) path life time with this probability exponential distribution function is

$$AVG = \frac{1}{n} \quad (6)$$

and the average link life time (link consisting of m number of paths) is

$$AVG\{L\} = \frac{m}{n} \quad (7)$$

6. Simulation and result analysis

The following metrics for performance evaluation have been considered and compared with the existing protocol.

End to end delay.
Packet delivery ratio.
Average energy consumed.
Number of packet drops.

We evaluate the performance of our protocol "Hierarchical Multi Path Routing (HMPR) Protocol for Wireless Multimedia Sensor Networks" by comparing it with CBMRP [19] via simulation using NS2. Table-1 summarizes the parameters used for simulation.

Fig. 3 describes the comparison of the proposed protocol (HMPR) with the protocol (CBMRP) for the metric end to end delay. It is observed from the figure that the protocol HMPR has a substantial improvement in terms of end to end delay because of its reduced number of transmissions due to clustering and also the availability of *cluster head node* and multiple paths in the direction of the sink node. It is also observed that as we increase the traffic load the end to end delay increases in a linear fashion and maintains a steady order.

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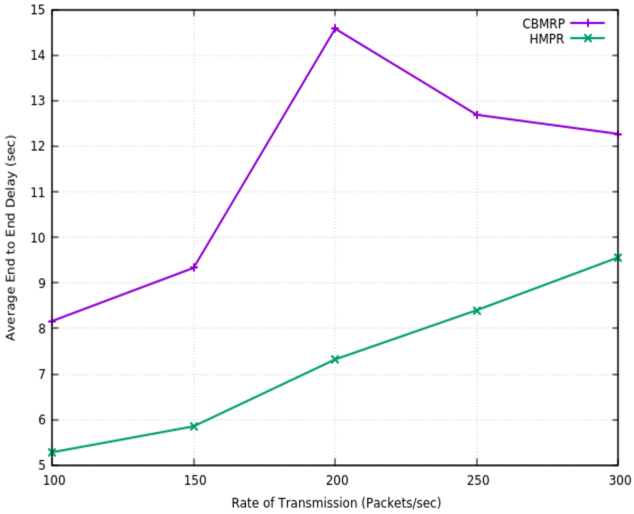

Figure.3 Rate vs. average end-to-end delay

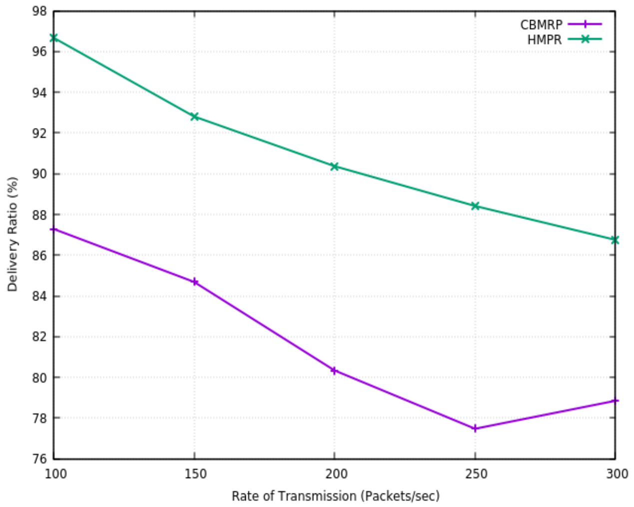

Figure.4 Rate vs. packet delivery ratio

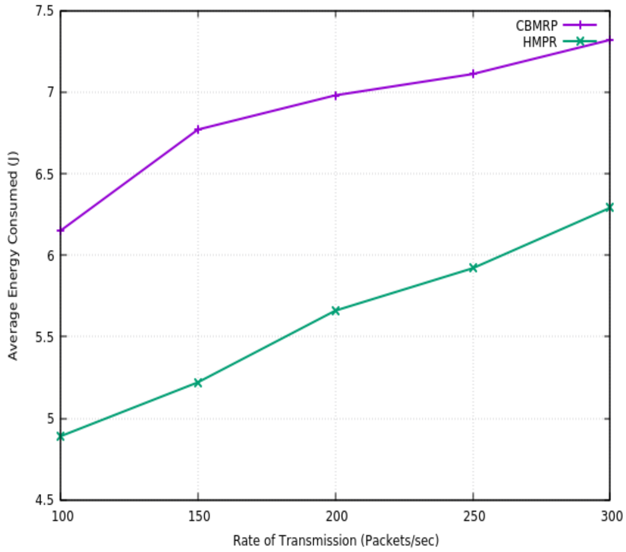

Figure.5 Rate vs. average energy consumed

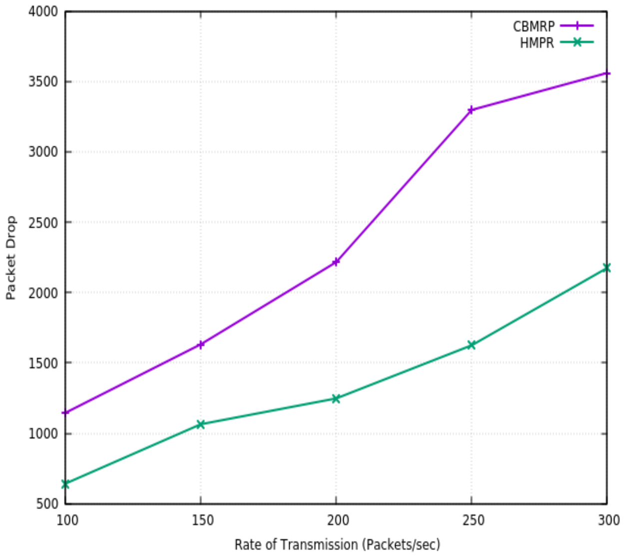

Figure.6 Rate vs. number of dropped packets

Packet delivery ratio is defined as the ratio between numbers of received data packets and the number of transmitted data packets.

The comparison of the HMPR protocol with CBMRP protocol revels that HMPR achieves more packet delivery ratio and hence out performs over the protocol CBMRP as shown in Fig. 4. This happens due to the TDMA scheduling inside the cluster and availability of multiple paths between the cluster head nodes.

The average energy consumption of nodes is compared for both the routing protocols (HMPR and CBMRP) as shown in the Fig. 5. It is observed that the energy consumption increases as the load increases. However it is apparent from the figure that, on an average HMPR consumes less energy as compared to CBMRP. This reduction of energy occurs because of the numbers of transmission are less in HMPR due to non overlapping scheduling and also it is in line with the life time analysis as mentioned in section 5. As per the observation it is concluded that energy consumption at the nodes for HMPR is less than CBMRP. Hence HMPR makes use of node energy efficiently than that of CBMRP.

Fig. 6 compares the protocol HMPR with CBMRP for the number of dropped packets over the time period of simulation duration. It is observed that, in HMPR the numbers of packets dropped are quite less as compared to CBMRP. This reduction also improves upon the energy consumption at the nodes as shown in Fig. 6.

Hence it is concluded that the proposed protocol HMPR outperforms in all respect.

7. Conclusion and future work

In this paper it has been shown that the energy consumption in WMSN can be improved by using hierarchical routing which also maintains multiple paths to route packets from the source to the destination in multi hop manner. The multiple paths are maintained by the cluster head nodes in the direction of the sink node. The results are quite encouraging to see that the performance of the protocol increases as compared to similar protocols. In this protocol the energy consumption decreases and hence the life of the node increases. It is evident from the simulation results that the protocol HMPR performs better than the protocol CBMRP in terms of delay, packet delivery ratio, energy consumed and also number of dropped packets. Hence the objective of QoS have been achieved in the proposed protocol HMPR along with increased life of the network.

As a matter of future work this approach may be further extended to have a second layer of clusters involving only the cluster head nodes to achieve the objectives and also making the nodes dynamic to observe the behaviour of the protocol under varying conditions.

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