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LBCC: Load Balanced and Congestion Controlled Routing Protocol for Wireless Multimedia Sensor Network

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Abstract

Wireless multimedia sensor networks consist of self organised nodes having the capability to sense and transmit multimedia information to the desired destination. These are a type of wireless sensor network to sense and transmit both scalar data as well as multimedia data which includes image, audio and video streams. It is being attracted by the research community because of its widespread applications and affordable cost for delay sensitive multimedia applications. The life of the nodes is a vital factor in routing protocols in this type of network. The life of the network can be increased by balancing the load in the network from source to destination as well as reducing congestion in the network. Congestion at a node occurs when the total rate of input to a sensor node exceeds the rate of output from that node. We propose a cross layer routing protocol "Load Balanced and Congestion Controlled Routing Protocol for Wireless Multimedia Sensor Network (LBCC)", which enhances the life time of the nodes and in turn enhances the aggregate life time of the network. This technique distributes the network load on the nodes evenly across the network and also avoids congestion at each node situated in the path from source to destination. The information provided by the MAC layer is used by the routing layer regarding the ongoing communications of neighbouring nodes in the direction of the destination. The energy consumption of the nodes is balanced by appropriately choosing its next hop. The forwarding nodes are used in such a fair manner that the network remains undivided and also the life of the network increases. The results obtained out of the simulation are quite encouraging as compared to existing protocols in this domain.

Keywords: Wireless Multimedia Sensor Network, Cross-layer routing protocol, Congestion control, Energy consumption, Load balancing, Network life.

INTRODUCTION

The term "wireless multimedia sensor network" comprises of units called nodes which are battery operated with limited power, to sense the physical phenomenon and also to capture the multimedia event information for subsequent processing and transmission to the desired destination. Usually they are deployed in remote locations where charging or replacing the battery is not possible. The development of low cost wireless sensor nodes equipped with camera devices lead to a new set of applications like video surveillance, battlefield intelligence and environmental monitoring, which are being focused by the research community. The requirement of Quality of Service (QoS) in multimedia communications introduces a great challenge because of stipulated bandwidth, unreliable channel and restricted energy level. So wireless multimedia sensor networks (WMSNs) [1, 2, 4] evolved as an extended topic in the field of wireless sensor networks (WSNs).

Usually load at any node is calculated as the number of packets created and the number of packets relayed over it by neighbour nodes. Because of high density of nodes, the sensing range of nodes overlaps and hence there is redundancy in event detection by the nodes. It leads to generation of higher traffic and in turn increases the rate of input at sensor nodes. The output rate decreases due to simultaneous transmission attempts by the nodes. Hence, input rate becomes more than output rate and data packets accumulate in its buffer causing congestion at a node which leads to buffer overflow and packet drops. Congestion at one node or part of the network spreads throughout the entire network and hampers the network performance. It leads to packet loss and also degradation of network throughput. Event tracking is also affected because the detected event characteristics could not be reliably delivered towards the sink node. Congestion also adversely increases energy consumption at nodes and partitioning of the network.

A possible solution to reduce the congestion could be to reduce load on the nodes and it can be achieved by decreasing the number of data packets generated or forwarded at any node. In event driven scenarios, the generation of data packets at a node is random in nature and also depends on the type of application. Hence the only alternative is to reduce the amount of data to be forwarded by the nodes and it is done by the routing algorithms. Congestion at any sensor node can be reduced by maintaining a high available buffer space for incoming packets. Hence load balancing technique is one of the possible solution to have maximum available buffer space at the sensor nodes to accommodate data packets.

The candidate solution is to adopt centralized routing algorithm that calculates the routing decision for a given sensor node and distribute it to the sensor nodes. When the topology changes, there is the need of re-computing the route and distributing among the sensor nodes. Hence, because of this sort of redundancy centralized routing algorithms are inappropriate for WSNs and WMSNs in particular. In case of distributed schemes [7], routing algorithms distribute the traffic load among the neighbour nodes evenly to maximise the available buffer space at each node in the entire network. In WMSNs the event occurs randomly and hence the traffic load and the available buffer at sensor nodes in the neighbourhood of nodes are dynamic in nature. This dynamism leads to unevenness of load during the time of routing. So distributing the load evenly without the support of the information of other layers (cross-layer) may result in non-uniform distribution of buffer level information in the neighbourhood. However sometimes there is the possibility of selecting a neighbour node having no available buffer space as the candidate next hop node during data transmission by the routing algorithms. In such situation there will be packet drop at the next hop sensor node which causes energy wastage. To reduce the possibility of such packet loss in the next hop nodes, the network layer takes help of the MAC layer to get the knowledge of the available buffer space of neighbouring nodes. Upon getting the knowledge of current availability of buffer space of neighbouring nodes, the sensor node decides the next hop accordingly to have an even distribution of load in the neighbourhood. In certain cases there is also a possibility that the information regarding the available buffer space of neighbour node is not the updated one and the sensor node will select the next hop node as per the rule which in fact may not be the ideal one to be selected as next hop node. This leads to drop of packets in the next hop node. So to avoid such situation we can have mutual understanding (handshaking) among the participating nodes before data transmission to confirm the status of available buffer space and readiness of nodes. If the there is no sufficient available buffer space at the next hop node, the idea of packet delivery to that node should not be done. Cross-layer optimization is one of the methods for the requirements and challenges of WMSNs [3] in order to meet the characteristic features of multimedia applications.

Our proposed protocol LBCC which is a cross-layer protocol that integrates routing and MAC (Medium Access Control) layers in wireless multimedia sensor networks to provide reliability by means of load balancing and congestion control.

LITERATURE SURVEY

The objective of routing protocols in wireless sensor networks and WMSN in particular is to find the optimal routes between the source and the sink node and use the same path for data communication. This objective may lead to uneven use of energy of the nodes because of uneven load distribution throughout the entire network. So now researchers focus to have a balanced energy uses among the nodes in order to increase the network life.

The authors in [15] have provided a detailed research challenges and issues pertaining to WMSN and the protocols associated with them.

In [8] the authors have proposed a protocol called Cross-Layer Balancing (CLB) routing to improve the life of the network by distributing the energy uses in the network. This protocol adopts a bottom-up approach and the routing layer makes use of the information provided by MAC layer in order to select the next hop node. During the first phase (initialization phase), sink node sends a request message to find the best route from every sensor node. In data transmission phase the MAC layer provides the information to the routing layer regarding the overhead communications around the neighbourhood. Because of this message, every node comes to know the frequency of participation of a node in data communication. Hence to have an even distribution of energy consumption, nodes select a node whose participation is less. However this protocol does not ensure the freshness of the optimal path at the time of data delivery and also overlooks the congestion aspect at each intermediate node.

In [9], the authors have discussed regarding the transmission energy uses and relay distance of each node over single hop. The trade off between more transmission energy over long hop distance and low transmission energy over short hop distance have been elaborated. For a network consisting of densely deployed nodes, energy uses can be optimized when every node finds the optimal distance among all the available neighbour nodes. However there is no discussion about the congestion issues at each hop during data transmission which may lead to delay and more power consumption and loss of data.

The authors in [10] proposed an approach which reduces the total energy consumption based on path selection and bit allocation. Data packets are transmitted to the node which behaves as a fusion point in the most suitable hops. However, it lacks in the allocation process of data bits within the nodes in the networks having limited queue lengths for congestion detection. Hence for heavily loaded traffic the approach may fail in reliability aspect.

Authors in [5] proposed cross-layer architecture based on impulse radio ultra wide band technology, designed to reliably deliver QoS to heterogeneous applications in WMSNs, by controlling interactions among different layers of the protocol stack according to applications requirements.

In [11], the authors have discussed to minimize energy uses and maximize life of nodes in the networks where locations of the nodes are predetermined and unchangeable. The authors have considered opportunistic routing concept in order to have optimized energy use which extends life of the networks.

The authors in [12], proposed Energy-Balanced Routing Protocol (EBRP) to send packets to move towards the sink node through the area of the network having dense energy so as to protect the nodes with relatively low residual energy. Also they have addressed the routing loop problem with enhanced mechanisms. However the technique fails to achieve the desired metrics like throughput and end-to-end delay which is of utmost importance in WMSNs.

In [13], the authors have proposed an improved protocol named as Delay Aware Energy Balanced Dynamic Routing Protocol (DA-EBDRP) over EBRP which has improved throughput, reduced delay and better network life. However this protocol incurs additional overhead because of finding a shortest path and alternate path and also for updating of the routes.

The authors in [14], proposed BEAR to have an improved energy balancing and network life. There is the use of automata concept to have a fair trade-off between energy and distance. Selecting the next hop in BEAR is based on learning automata and is purely probabilistic in nature. Before data transmission, every node searches its neighbour table for a neighbour with highest probability and the energy level of the sender node is piggybacked to the original data packet to be forwarded to neighbour with highest probability. However the protocol fails to guarantee the packet delivery as it selects a node probabilistically which may be unreliable for WMSNs.

PROPOSED PROTOCOL

In the proposed routing scheme the selection of next hop node is subject to the position of the sink node and the next hop node in the neighbourhood. In greedy forwarding approach [16], the next hop node is selected based on the objective of maximizing advancement in the direction of sink node. It also ensures that at each hop the packet makes a forward direction movement and it is the closest node among all the nodes towards the sink node. The meaning of maximizing advancement towards the sink node is to determine a next hop node from the set of neighbour nodes, which is physically nearer to the sink node than that of the current node i.e. always we need to make sure that the packet does not move away from the sink node which may incur delay. The drawback of this strategy is that more than one node may select the same node as the next hop node which leads to creation of congestion at that node. Considering a situation as per Figure-1, the source nodes forward data packets to a node which is closest to the sink node. However, the packets could be sent to the other two nearby next hop nodes which also could transmit packets directly to the sink node. This mentioned situation near the sink may be replicated throughout the network leading to network wide congestion. In the proposed protocol, the next hop sensor node is selected dynamically as per the availability of buffer space of the neighbouring nodes which makes advancement in the direction of sink node. Recent buffer availability information of neighbour nodes can be determined by piggybacking procedure adopted in MAC layer protocol on periodical basis.

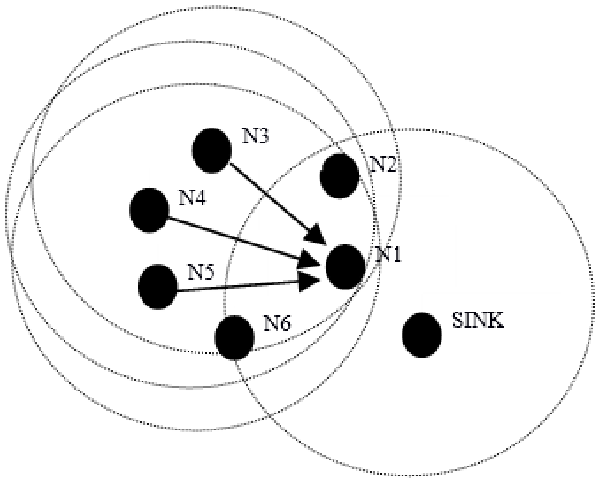

Figure 1: Greedy

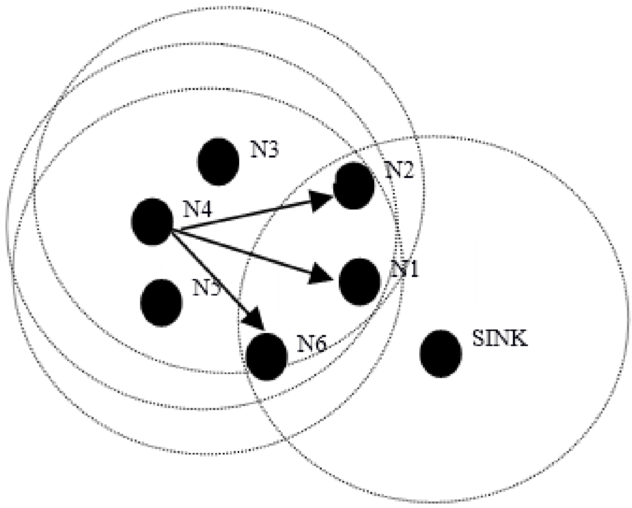

Figure 2: Load Balanced

We achieve the objective of balancing the load and reduce congestion by selecting a neighbour node having the maximum available buffer space to become the candidate next hop node. The objective is not only just to make a forward direction progress in the direction of sink node but also to have a trade off between forward movement and congestion at the selected next hop node. As per Figure 2, the source node divides the traffic load among the nodes in its neighbourhood to make advancement in the direction of sink node. In Figure 1, according to the greedy forwarding approach every node selects the same node as the next hop node which is closest to the sink and thereby that selected node loses its energy quickly and becomes a dead node. However in Figure 2, a node before selecting a next hop node which makes advancement towards the sink, it observes the available energy and buffer capacity of that node and selects the most optimal node based on the policy. This strategy divides the load among the neighbour nodes in the forwarding zone, so that none of the node is exhausted with power. The term forwarding zone refers to the region where the neighbour nodes are physically closer to the sink than that of the sending node.

In the case of repeated occurrences of events, the nodes along any path from the vicinity of occurrence of events to the sink are always engaged in transmission and reception leading to quick drain of battery power of those nodes and in turn network partitioning. To improve the overall energy of the network, the load around the network is diverged to maintain an average energy level of the nodes across the network and improve performance. The aim is to spread the packets spatially and divert the traffic in various directions of the entire network. The objective of balancing load across the network is achieved by considering the buffer occupancy levels simultaneously at each node locally. Because of dividing the traffic spatially, this method achieves improved performance with respect to packet drops and delay by utilizing available buffer space in less congested regions of the network.

Here we propose a cross layer routing scheme, which resolves the problem of congestion in WMSNs. It makes use of the information of available buffer space of possible next hop neighbour nodes to achieve a fair distribution of traffic load. However frequent change of next hop node for a single event also introduces additional overhead which is a limitation for resource constrained sensor nodes in WMSNs. To reduce this overhead, a threshold value for the difference in the buffer occupancy level between a set of next hop nodes is taken into consideration. When the difference is more than the threshold value, the algorithm selects another next hop node. Above all the next hop node is always selected from the set of nodes which makes an advancement of packets in the direction of the sink node**.** Each node dynamically balances the load among the next hop neighbour nodes to avoid congestion and forward the packets towards the sink node.

The positions of the nodes are assumed to be static in this configuration. Every node is well aware of its own position and position of the sink node. The calculation of congestion is always localized in one hop neighbourhood without requiring end-to-end or multi-hop measurement. For a node $S_i (1 \leq i \leq n)$ in WMSN which consists of $n (n \geq 1)$ nodes, node S_j is said to be in the forwarding zone (**FZ**) of node S_i if and only if node S_j has less Euclidian distance to the sink node than that of the node S_i has to the sink node. i.e.

$$S_j \in FZ(S_i) \leftrightarrow D(S_j, SINK) < D(S_i, SINK) \qquad (1)$$

where D refers to distance between the nodes.

Hence every node is aware of its neighbour nodes and also whether the neighbour node is in forwarding zone or not. Before data transmission in the routing layer, the MAC layer during handshaking procedure exchanges the current buffer occupancy level of the neighbour nodes and hence every node gets the current status of the neighbour nodes in its forwarding zone. At the time of data transmission a sending node selects the node having maximum available buffer occupancy level and energy level from its neighbours in the forwarding zone to become the candidate next hop node. This node is selected for the predetermined number of packet transmissions, keeping the buffer occupancy threshold (B_{Th}) and energy threshold (E_{Th}) in consideration. Subsequently the current status of the receiver node is updated by the acknowledgement packet received by the sending node from the receiving node on regular intervals. When either the available buffer occupancy level or available energy level or both decreases to a value less than the predetermined congestion level and node's energy level respectively, the sender node has to select the next eligible node from its neighbour list in the forwarding zone. The freshness of the neighbour list is obtained by updating the neighbour list from the information gathered from MAC layer handshaking messages. The nodes use a CSMA/CA based MAC protocol with RTS/CTS message exchanges. Before transmitting data, every sensor node sends one RTS message and receives the corresponding CTS message from the neighbour node. This enables to update the corresponding entry of the record in the neighbour table in the vicinity of the node which sends CTS message.

Every node dynamically adapts the transmission of packets to the nodes within its FZ and tries to balance load to avoid congestion in FZ. Every sensor node ensures that the level of congestion of neighbouring nodes fall within the predetermined threshold value instead of considering the end-to-end feedback from sink to source which is an expensive affairs. In this way, our protocol aims to avoid congestion and load imbalance in a WMSNs to increase the performance and energy efficiency of the network.

NETWORK MODEL

The proposed model has the following assumptions:

- The network consists of N number of sensor nodes deployed around the network.
- There exists only one sink node to collect the sensed information.
- Coordinates of the sensor nodes and the sink node are fixed and known to each other.
- The batteries of the nodes are not rechargeable.
- The nodes and the network are assumed to be reliable

in nature.

- The network application is event driven, i.e. Packet transmission is initiated when an event occurs.

Algorithm (Find Next Hop Node):

It is a distributed algorithm executed in each sensor node that is either a source node or an intermediate node except the sink node. The nodes are deployed as per the assumptions mentioned above. The objective of the algorithm is to select a candidate next hop node for data transmission when an event occurs around a node in order to deliver the packet as quickly as possible to the sink node.

1. Compute the set **FZ** for every node depending on the location of sensor node and the sink as in (1).
2. The recent status of the neighbour nodes are gathered from the handshaking messages exchanged between the nodes in the MAC layer. (The CTS packet also contains the most recent status of the node and accordingly all the nearby nodes update their respective entry for that node in their neighbour table).
3. Repeat steps 4 to 7 until there are no more packets to send.
4. For data transmission at each node, select a node from the set **FZ** having maximum available buffer occupancy level $B_{max}$and maximum energy level E_{max}as the next hop node.
   4.1. In case of more than one node satisfying the criteria, select a node randomly.
5. Transmit packets to the selected next hop node.
   5.1. After each transmission, the receiving node responds with the **ACK** (acknowledgement) packet which provides the updated status of the node (i.e. buffer and energy level) and this allows the nearby nodes to update the respective entry in their neighbour table for that selected node.
6. For a selected candidate neighbour node, if the current energy level $E \leq E_{Th}$or current buffer occupancy level$B \leq B_{Th}$, then select a different neighbour as in step 3.
7. Repeat the find next hop node procedure at each intermediate node along the path to the sink.

SIMULATION AND RESULT ANALYSIS

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

1. Delivery Ratio.
2. Delay.
3. Energy Consumed.
4. Throughput.

We evaluate the performance of LBCC, by comparing it with GPSR [6] via simulation using NS2. We have considered 5 different rates of data transmissions and 250 nodes are placed uniformly within a region of 1000 x 1000 square meters. For every scenario we have positioned the sink towards the extreme right top corner of the region. The average values of these five scenarios are considered for plotting the graph.

The sensing and transmitting range of the nodes are set to 60 meters and the channel capacity is set to 2Mbps. The traffic is considered to be of Constant Bit Rate (CBR). Table-1 summarizes the parameters used for simulation.

Table 1: Simulation Parameters

No. of Nodes	200
Topography Size	1000 X 1000 square meters
Transmission Radius	60 meters
MAC Layer	IEEE 802.11
Simulation Duration	1000 seconds
Traffic	CBR
Size of Data Packets	512 bits
Initial Energy	200 joules
Buffer Size	100 Kbits
Bandwidth	2MB
Rate of Transmission	2,3,4,5,6 packets per second

Average Packet Delivery Ratio:

Delivery ratio is defined as a ratio between numbers of received data packets and the number of transmitted data packets. The objective is to know the impact of congestion and load balancing in improving the packet delivery to the sink node.

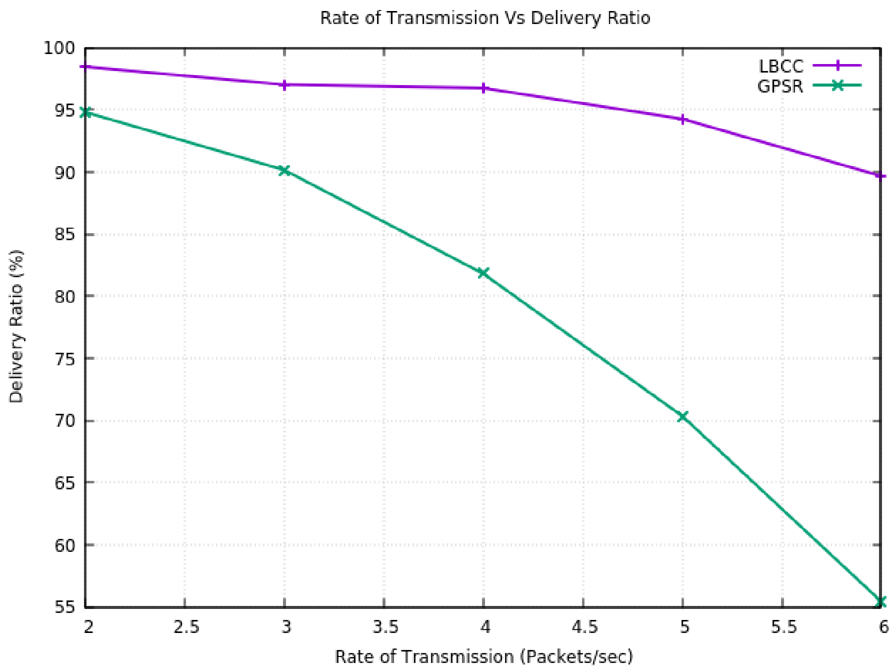

Figure 3: Rate of Transmission VS Average Packet Delivery Ratio

Figure 3 presents a comparison of the routing protocols with respect to packet delivery ratio for the protocols LBCC and GPSR. It is observed that LBCC achieves higher packet delivery ratio as compared to GPSR protocol. LBCC increases the packet delivery ratio because of its dynamic utilization of storage space of available alternate nodes. This dynamism provides a positive movement of packets in the direction of sink node in a balanced manner. The reason for this difference of performance between GPSR and LBCC is the difference of data packet loss rates at the next hop node. GPSR always selects a node that makes maximum movement in the direction of sink node in a greedy manner as the next hop node. This approach selects a single sensor node as the next hop node by more than one sensor nodes (Figure 1) and this selected node is prone to have less available buffer space. Packet loss rate of GPSR leads to buffer overflow because of low buffer available levels at the next hop nodes. As compared to GPSR, LBCC selects a node which makes maximum movement in the direction of the sink node among the sensor nodes having the maximum available buffer space. This fact ensures that every node achieves equal distribution in the buffer occupancy levels of its neighbours to have more availability of buffer space. Maintaining this equal distribution improves the probability of a node to select a next hop node with higher available buffer space. When the load increases, LBCC uses more nodes as next hop nodes to increase the number of possible contending nodes. As we increase the number of data packets it does not affect the next hop node selection in GPSR and the performance of LBCC improves over GPSR.

Average End to End Delay:

Delay is defined as the time taken by a packet to move from the source to the sink node. It emphasizes on the QoS parameter in WMSN. Here we compare the routing protocols (LBCC and GPSR) in terms of average end to end delay of packets delivered successfully to the sink as shown in Figure 4. It is observed that in case of lightly loaded situation, LBCC divides its load within a small number of neighbours in the forward zone. This reduces the number of nodes contending in its neighbourhood as compared to the heavily loaded situation. However, multiple sensor nodes select the same sensor node as the next hop node in GPSR protocol which selects less number of nodes as next hop node. Because of this fact the number of contending nodes is less than that of LBCC. Moreover because of this less number of contending nodes, more number of packets gets accumulated in these next hop nodes to have an adverse impact on the delay performance. It is also observed that when the traffic load increases, LBCC involves more number of neighbour nodes in its forward zone leading to have more number of contenders. However, in the case of GPSR protocol it remains constant irrespective of traffic load because of its static nature. So when the load increases, LBCC performs better as compared to GPSR protocol. Hence LBCC gets the advantage of spreading and load balancing technique.

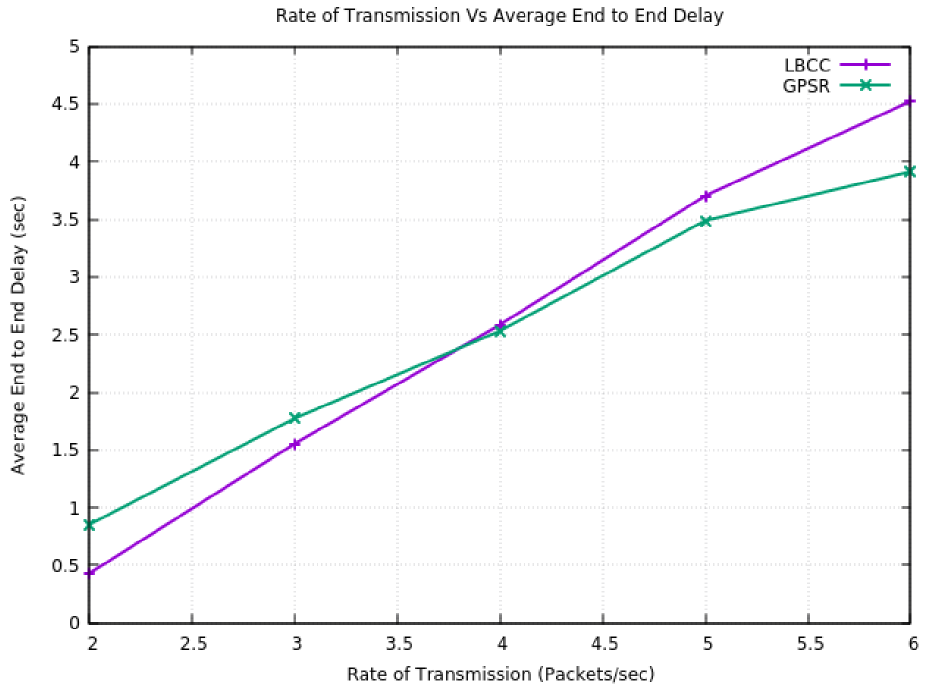

Figure 4: Rate of Transmission Vs Average End to End Delay

Energy Consumption:

The average energy consumption of nodes is compared for both the routing protocols (LBCC and GPSR) as shown in the Figure 5. It is observed that the energy consumption decreases as the load increases. When the traffic load increases, LBCC involves more number of sensor nodes by spreading the packets all around where as in case of GPSR protocol, this number remains constant. Hence the difference of energy consumption between the protocols reduces when the load increases. As per the observation it is concluded that energy consumption at the nodes for LBCC is less than GPSR (for higher traffic load cases) and this is because in LBCC the load is spread all across the network and none of the nodes are over used by balancing the load at each node. Hence LBCC makes use of node energy efficiently than that of GPSR.

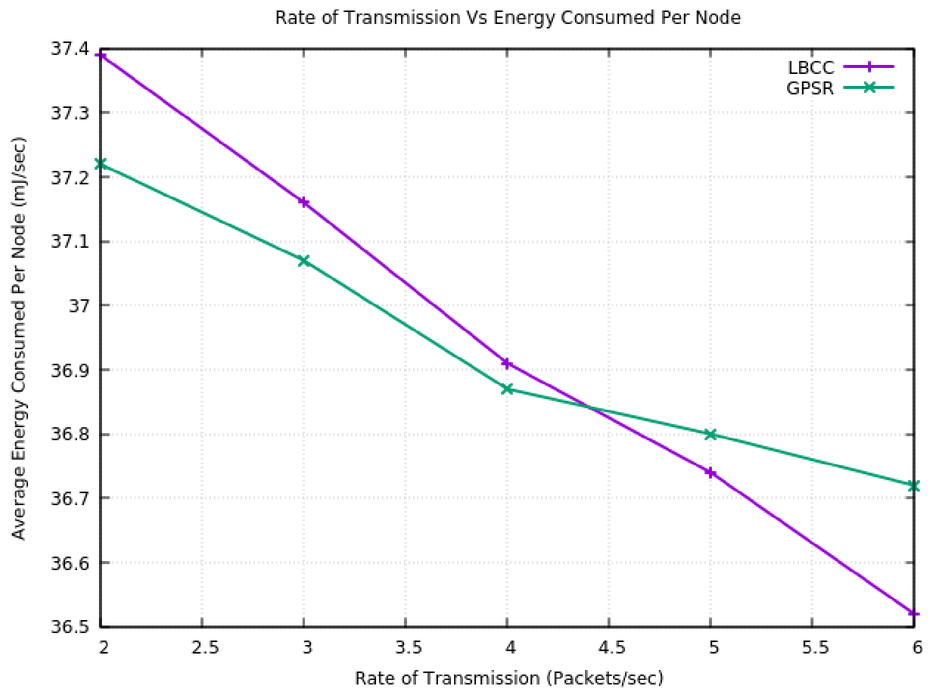

Figure 5: Rate of Transmission Vs. Average Energy Consumed Per Node

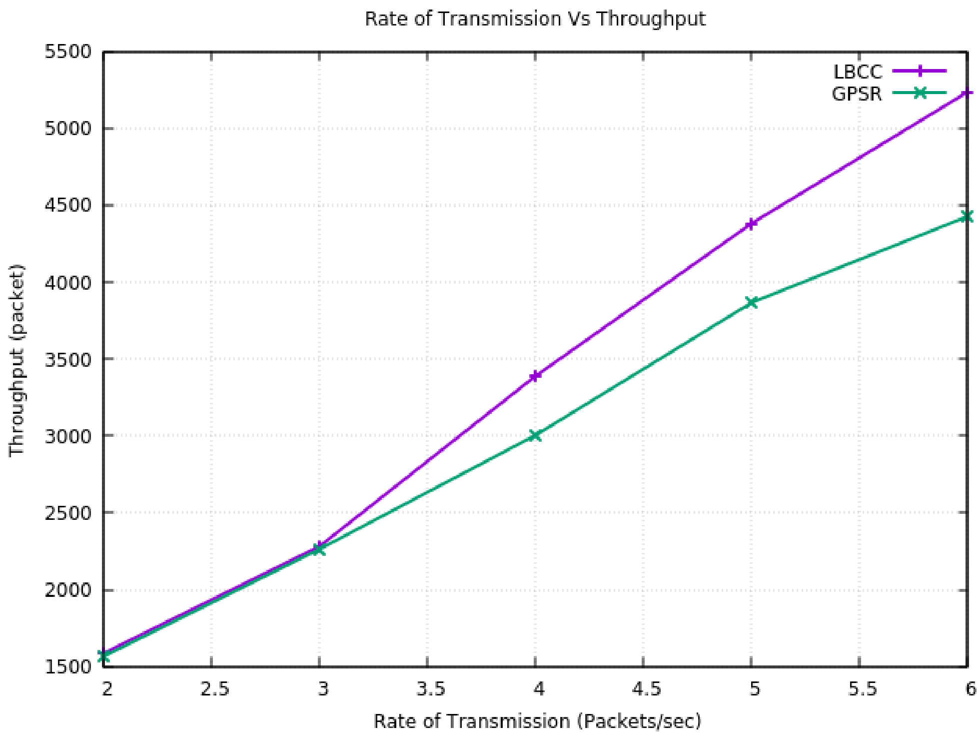

Figure 6: Rate of Transmission Vs. Throughput

Throughput:

Throughput refers to the number of packets received successfully. We have compared the protocols LBCC with GPSR to observe the performance with respect to throughput as shown in Figure 6. The obtained result confirms the acceptability of the proposed protocol LBCC, as it has a higher throughput value over GPSR. For lightly loaded traffic, the performance gap is not that remarkable. However as the load increases LBCC outperform GPSR. It is because for high transmission rate the load is spread across the entire network leading to balance the load and hence packet drop is reduced in case of LBCC. But as GPSR chooses a single node as the next hop node (greedy), it leads to buffer overflow and packet drops.

CONCLUSION

To address the congestion and QoS parameters in WMSNs, here we propose a protocol which avoids congestion at each node and balances the energy level of the nodes throughout the network to balance the load. The proposed protocol has an improved performance in terms of average packet delivery ratio and reduced end to end delay along with reduced energy uses and increased throughput.

Congestion is one of the reasons of packet loss in WMSNs which has an adverse effect in reliable data delivery. When an event occurs, many sensor nodes detect the same event and send packet streams towards the sink node and it may lead to congestion in the network. However, protocols considering shortest path from source to destination increases the possibility of congestion because of selecting a sensor node most of the time as a next hop node. This happens because of unbalanced load distribution in the network. Here our proposed protocol is a cross-layer protocol named 'LBCC', whose objective is to improve the reliability by avoiding congestion and adopting distributed approach in WMSNs. The main idea is the effective use of buffer levels of the neighbouring sensor nodes in the selection of next hop node for packet delivery. It uses a simple reporting procedure which involves piggybacking the information of buffer space availability to monitor the status of neighbour nodes in the MAC layer. The load distribution within the neighbour nodes is achieved by considering their available buffer space and energy levels in order to decide the next hop node. LBCC transmits data packets from the source node in more than one path spreading throughout the network which finally converges at the sink node. It partitions a data frame and delivers these small chunks of packets in more than one direction by providing load balance in the direction of the sink node.

The performance of this protocol is compared with GPSR protocol which does not involve any load balancing technique. The observed result reveals that LBCC provides better performance and also delivers more packets to the sink node with lower average end to end delay as compared to GPSR protocol. Moreover, LBCC has better energy efficiency in a highly loaded traffic scenario as compared to GPSR protocol.

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