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A Holistic Approach to achieve Energy Efficiency in Delay Tolerant Mobile Ad-Hoc Network

Minimizing Superfluous Energy Consumption in the Opportunistic Network

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***Abstract*—Green networking is an important concern that currently acquires the attention in research. This paper explains an Energy aware cross layer optimization technique for Delay Tolerant Mobile Ad hoc Networks. Information sharing between Network Layer and Medium Access Control Layer has been utilized as an element to achieve the goal. Appropriate node selection strategy for data forwarding in Network Layer and minimizing idle listening by scanning the vicinity and discovering the knowledge of number of neighboring nodes in MAC Layer are the major factors considered for energy minimization. Energy Sensitive Routing Protocol (ESRP) minimizes ineffective energy utilization and Neighbor Table Responsive Asynchronous (NTRA) Energy Management MAC Protocol minimizes number of wake up slots based on the network status without losing network connectivity. Performance of the suggested cross layer approach is studied using NS-3 Simulator and observed that it outperforms the existing energy efficient schemes.**

***Keywords*—Cross Layer Optimization, Delay Tolerant Network, Mobile Ad Hoc Network, Data Delivery Predictability, Energy Efficiency, Idle Listening, Network Layer, Network Lifetime, MAC Layer.**

I. Introduction

The characteristics of Delay Tolerant Mobile Ad Hoc Network (DT-MANET) [1],[2],[3] is observed to be consisting of sparsely deployed nodes and the encounters among them are infrequent. Consequently, energy of the nodes gets more drained due to this sparse nature of the network. This paper analyses two major reasons of energy drain in DT-MANET. The idea of forwarding data from source to destination follows store-carry-forward method and so choosing an appropriate node for data forwarding saves energy consumption which is taken care by the protocols in Network Layer. Sparse network nodes spend most of its time listening to the network rather than transmitting or receiving the data and this idle listening duration can be minimized by the protocols in MAC Layer. We aim to minimize the energy consumption due to superfluous transmission and avoidable idle listening to the channel.

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This paper proposes a cross-layer protocol that incorporates an energy consumption aware routing protocol along with minimum idle listening sleep scheduling algorithms to provide energy constrained delivery of data in DT-MANET.

Rest of the paper is sectioned as follows. Section II explains the related work done in designing protocols for routing and duty cycling. Objective of this paper is given in Section III. Cross Layer Energy Optimization Protocol is explained in Section IV. Section V gives the Performance Evaluation of the proposed technique in comparison with the existing protocol.

II. Related Work

The energy management schemes of Delay Tolerant Mobile Ad Hoc Networks have been a focus in recent years. Numerous investigations have been carried out to resolve the issues identified to increase the node residual energy. Some of them are examined underneath.

Y.q.fei et al. in [4] proposed a cross-layer optimization design to minimize bit energy consumption by sharing control packets among physical layer and data link layer under retransmission delay constraints and packet loss rate. At the point when error happens in the transmitted packet, the ARQ initiator at the recipient transmits a retransmission request to the ARQ controller through a feedback channel and so the packet buffered will be retransmitted. At the physical layer, MQAM is supported focused around the Channel State Information. The authors have reasoned that by utilizing AMC and ARQ at cross layers, energy utilization can be minimized. Since DT-MANET is sporadic, as a replacement of selecting suitable ARQ and AMC it is obligatory to choose sleep scheduling and best node selection strategy.

In [5], authors elucidated the analysis of joint optimization of routing and scheduling issue in Wireless Mesh Networks in which hosts are furnished with directional transceivers. Spatial reuse TDMA scheme, to dynamically control power slot-by-slot which sets transmission rates according to the Signal-to-Interference-and Noise Ratio (SINR) been utilized to reduce power consumption. Bai, Yuebin, et al. In [6] considered the combined optimization of the physical, medium access control and network layer for energy optimization for Wireless sensor Network. Transmission Power between the nodes has been computed and fed to Network and MAC layer to decide routing and duty cycle scheduling. Comaniciu et al in [7] proposed a hierarchical cross layer energy optimization through joint adjustment of nodes transmitting powers and path selection. However energy efficiency is attained at the cost of a reasonable increment in intricacy.

Miao, Guowang, et al in [8] proposed energy efficient cross layer design for wireless communication. Link-level transmission plans and network/MAC layer resource management strategies are their predominant focus. Zuo, Jing, et al. in [9] proposed an energy effective routing algorithm that shares the information of the Frame Error Rate (FER) in the physical layer, the number of retransmissions in the MAC layer and the number of relays in the Network Layer. Wang, Y. et al in [10] incorporates two stages, i.e., the asynchronous stage and the synchronous stage and developed a cross layer data delivery protocol.

Anyhow, the focuses of these papers disallow consideration for minimization of idle listening and ineffectual energy utilization. We have chosen the joint routing and scheduling strategy in our paper to concentrate on minimization of superfluous energy utilization. Some of the Routing and MAC protocols for Delay Tolerant Networks are discussed in the following section.

In [11] Vahdat et al. explains Epidemic Routing, where message delivery guarantees by means of random pair-wise exchange of messages. Lindgren et al in [12] proposed a procedure to forward data to all encountered nodes with higher *p*-value than itself to the specified destination. P-value is calculated utilizing history of encounters and transitivity. In [13] Medjiah, Samir et al proposed ORION protocol, just a single duplicate of the message is forwarded in the network contact by contact towards the end. ORION makes utilization of autoregressive moving average (ARMA) stochastic process for best contact expectation. Spyropoulos et al in [14] explains Spray and Wait protocol which operates as two phases. It “sprays” a number of duplicates into the network, and “waits” until one among them meets the destination. Hui, Pan et al in [15] proposed Bubble Rap protocol focused on the learning of human mobility in terms of social structures, and to utilize these structures as a part of the design for data forwarding algorithms.

In [16] Yongsheng et al proposed an Energy Efficient MAC protocol that categorize all the nodes in the network into Master and Slave nodes. Slave nodes follow energy conscious sleep/wake-up schedule whereas master nodes stay awake throughout and be conscious to receive beacons all the time. To be reasonable, a shift mechanism is utilized among the nodes to allot the master nodes. In [17] Wu, Shih-Lin et al proposed yet an alternate power saving MAC protocol for IEEE 802.11 ad hoc networks. It takes two properties for power saving mode. First, scheduling of data transmission for power saving nodes is carried out based on listening to ATIM frames. Second is to fine-tune the ATIM window size based on the network status. In [18] the authors proposed an asynchronous clock-based sleep scheduling protocols for DTN, in view of hierarchical arrangements of cyclic difference sets. In paper [19] proposed the thought of Hyper Quorum System (HQS) which is a continuation of Quorum-based Power Saving (QPS) scheme that takes into consideration arbitrary cycle length.

III. Objective And Contribution

The Objective of this paper is to present an energy effectual method of communication among the mobile nodes in DTMANET. To accomplish our objective, we have taken cross layer optimization design which incorporates Network Layer and MAC Layer into account. Data Forwarding is been restricted to nodes which are not capable of carrying or conveying the data to the destined node. To acquire this we have provided the node choice criterion based on the meta-data imparted among the mobile nodes. Since Idle Listening is one of the noteworthy issues which devours energy of a node in spasmodic network. The wake up slots in sleep/wake-up schedule can be maintained and minimized focused on the presence of the nodes in the vicinity.

Fig 1 given below exemplifies the cross layer optimization technique applied across Network, MAC and Physical Layer.

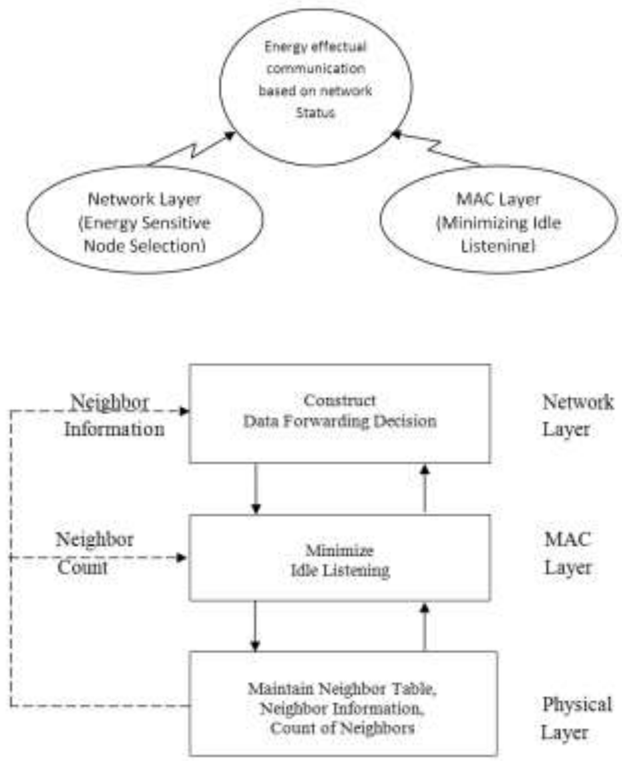

Fig1: Cross Layer Energy Optimization

IV. Cross Layer Energy Optimization Protocol

A. Network Model

In this paper a wireless multi-hop network is represented as a directed graph *G* (*V*, *E*), where $\{v_1, v_2, v_3 \ldots v_i, v_j \ldots\} \epsilon$ V is the set of mobile hosts and $\{e_1, e_2, e_3 \ldots e_i, e_j \ldots\} \epsilon E$ is the set of edges between the communicating hosts. The hosts are not closely deployed and so the network experiences frequent

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disconnections and the data delivery delay also exists. If host 'v_i' is within the transmission range of host 'v_j', then a bidirectional link exists between them. Suppose $E\{v_i,v_j\}= 1$, it means that v_i, v_j are in the transmission range and $E\{v_i, v_j\} = 0$ means that v_i, v_j are out of transmission range. Since the network is intermittently connected, the path between the nodes does not really exist at all the time. The contact duration between the hosts is also limited due to their mobility characteristics. Source nodes with the aid of intermediate hosts make the data reach the destination. We have assumed the network to be asynchronous therefore no clock synchronization is maintained. Following are the assumptions we made in our paper. Acknowledgement is sent back to the one-hop neighbour once the data is received. No acknowledgement is directly sent from the destination to the source. Data packets are buffered in the sender node until it receives the acknowledgement from the receiver node.

B. *Node Selection Strategy*

The main intention of node selection strategy is to adapt to the changes in the network status and not to generate false detections of misbehaving nodes and to isolate the nodes which do not forward the packets. The subsequent sections explain the node selection strategy [22] based on frequency of encounters, buffer occupancy and misbehaving nodes.

History of Encounters (E):

History of encounter is a parameter which was chosen to calculate the data delivery predictability based on the idea that a host visited a locality a number of times before, have improved chance of visiting the same location yet again in the future. Superfluous forwarding of data to the intermediate node which does not have the history of encounters with the destination node consumes the energy with no use. For predicting the possibility of data delivery between the source and the destination nodes, the factors to be considered are Data delivery surety, ageing and Transitivity

Data Delivery Surety and Ageing:

When two hosts are in the transmission range of one another, they exchange the contact records which is calculated up to that time and updated in its memory. Contact records comprise of data delivery surety information to predict the likelihood of the receiver host to receive the data. With this information the host decides forwarding the data to the encountered node or not. Calculation of Delivery Predictability [20] is done with Equation (1) as follows.

$$DP(A,B) = N * DP(A,B)_{old} * e^{-\Delta t} \qquad (1)$$

Where DP (A, B) - Delivery Predictability between the node A and B

N – Number of encounters

$DP(A, B)_{old}$ - Most up-to-date Delivery Predictability.

e - Mathematical constant which is approximately 2.718.

$\Delta t = (t2 - t1)$ – time gap between successive encounters of the same nodes.

Transitive Property:

The data delivery surety should satisfy transitive property too. Although any two nodes do not have communication range overlapping each other, transmission of data between them is possible if an intermediate node exists in the network which meets both the nodes frequently. Maintaining the contact record in the nodes achieves the transitive property.

Buffer Occupancy (B):

Buffer Occupancy [20] calculation in individual hosts are essential to identify the capacity of the hosts to receive the data packets. It is calculated using Equation (2).

$$BO_{new} = BO_{old} - Msg_{size} \qquad (2)$$

Where

BO_{new} – Current Buffer Occupancy

BO_{old} – Previous Buffer Occupancy

Msg_{size} – Message Size

Only if the receiver nodes Buffer space is greater than or equal to the receiving message size, it accepts the data. Otherwise transmission will not occur.

Detection and Isolation of the Misbehaving Nodes (M):

Number of acknowledgements received is used as a parameter for detecting the misbehaving nodes. We have assumed that the acknowledgement packet takes only one-hop transmission. Every time when the packets are forwarded to the next node, it is necessary to acknowledge the sender by the receiver that the packets are received successfully. Whenever the acknowledgement packet is received by the nodes, packet delivery confirmation counter is updated by 1. If the node is dropping the packet or it is not receiving the acknowledgement from the other nodes, then packet delivery confirmation counter will not be updated. This counter is refreshed for a regular period of time t_{rfresh}. When the node wants to forward the data, it first checks misbehaving character of the node. If the number of packets it received from other nodes for forwarding is equal to the number of acknowledgement packets it received for forwarding others data, it is concluded that the node is not dropping the data. If the number of packets received to forward to the other nodes N_{pr} is higher than the number of acknowledgements it received for forwarding others data N_{ar}, the node is said to be selfish node. The threshold for packet delivery confirmation factor varies with respect to the number of nodes present in the network. If the number of ack packet received is high, it is not selfish node. Selfish nodes have very less or even zero acknowledgements received.

$$N_{ack} = \frac{N_{ar}}{N_{pr}} \qquad (3)$$

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Cross Layer Optimization proposed Algorithm to minimize Energy Consumption

Choose H hosts or nodes

Speed Beacon Signal **ACC**

Moving Neighbors **MN**

Power Saver Slot **PSS**

Construct Forwarding Decision

Get Neighbor Information

Delivery Predictability **DP**

$$DP(A,B) = N * DP(A,B)_{old} * e^{-\Delta t}$$

Buffer Occupancy **BO**

$$BO_{new} = BO_{old} - Msg_{size}$$

The number of Ack received $\mathbf{N_{ack}}$

$$N_{ack} = \frac{N_{ar}}{N_{pr}}$$

if

{

DP ≥ 0.4 ;BO ≥ 256 bytes ;$\mathbf{N_{ack} \geq 0.8}$

}

Then Decision is

Encounter Node <= fit for forwarding

else

Encounter Node <= Unfit for forwarding

end if

Construct Sleep Scheduling

Get Moving Neighbor Count

For

Accelerometer reads > 0 m/s

Send **ACC**

Check MN

If MN = True then

PSS Scheme <= Inactive

else

PSS Scheme <= Active

end If

V. Neighbour Table Responsive Asynchronous (NTRA) Energy Management Mac Protocol

Design of an energy-efficient Media Access Control (MAC) protocol as in [21], [22], [23] which is well responsive to change in the network status without lose of connectivity is required to minimize futile energy consumption. In order to minimize the avoidable energy exploitation, predefined duty cycle is applied to schedule proper sleep/wake up patterns. In the power saving state, the nodes are required to wake up periodically based on the allotted sleep/wake up schedule to receive every beacon frame transmitted by other nodes. The nodes have to continue to be awakening throughout the announcement or ad hoc traffic indication message window (ATIM). During the ATIM window other nodes that are attempting to send its frames to it will announce ATIM frames. In order to receive those frames the nodes must remain awake during the ATIM window. If the node receives an ATIM frame, it must acknowledge the sender and stay conscious until the last part of the ATIM window so as to allow the sender node to send its data frame. The power saving technique puts burden on the sending node than on the receiving node. Each transmission of a beacon frame and idle listening during the entire ATIM window consumes power. The nodes must wake up and remain awaken for every Beacon frame and ATIM window, but transmission does not occur unless it receives an ATIM frame. The wake up time or the node entering into Power saving mode varies from one node to the other. So the chance of time drift 't' occurs among the mobile nodes is high.

Sleep/Wake-up scheduling has been initiated based on the format of Cyclic Block Design and Cyclic Difference Sets [24] in combinatorial theory. The cyclic difference set follows (v,k,λ) format where v is the total slot in the sleep/wake-up schedule, k is the active slot and λ is the possible overlapping slot. We considered (7, 3, 1) cyclic difference set and it is asynchronous. Fig 2 gives total, active and overlapping slot in the sleep/wake-up schedule in which slot 1, 2 and 4 are active and so it is shown with beacon signals.

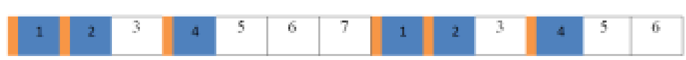

Fig 2: Sleep/Wake-up schedule with 7-slot, 4-active and at-least 1- overlapping slot.

To figure out whether there are contacts around to communicate with, a device needs to turn on its radio, send beacons, and listen for beacons sent by others. This strategy of communicating with other nodes is unreasonable concerning energy consumption, if the density of nodes encompassing is sparse. So for, existing energy aware MAC protocols reduces the number of idle listening slot up to (n+1) for (n^2+n+1) total slots. But, this work diminishes the idle listening slot further by considering the network status which is acquired from the

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neighbor table of the encountered nodes. For this we have framed a technique called Power Saver Slot (PSS) which is one among the idle listening active slot which switch to sleep mode based on the number of moving nodes in the vicinity of each node. This PSS mode has been introduced in the sleep/wake-up schedule keeping in mind that 'Nodes should avoid spending effort and energy on attempting to search for the contacts that will likely be too far away and no chance to reach in the near future

$$\text{No. of Wake-up slots} = \begin{cases} n+1, & \text{Movement of nodes detected in the vicinity} \\ \leq n+1, & \text{Movement of nodes not detected in the vicinity} \end{cases}$$

Here, let us make clear the term Vicinity. Nodes in vicinity imply that they are away from the coverage range however which can have the likelihood of reaching the coverage range of other nodes when it moves. Nodes ought to avoid spending effort and energy on attempting to exploit contacts that will probably be immobile in its vicinity. Velocity of the node or the movement of the node can be measured utilizing accelerometers [25]. Moving nodes broadcast its status along with the beacon signal. Details of the number of mobile nodes in the vicinity are imparted with all the encountered nodes. Nodes wake up and listen to the network only when the nodes are scanned moving in its vicinity. Once presence of mobile nodes are not detected in its vicinity the immediate next slot in the sleep/wakeup schedule goes to sleep mode irrespective of it being sleep mode or active mode by default. So applying PSS makes (7,3,1) sleep/wake up schedule to (7,2,1) and saves energy by reducing the number of idle listening slot.

According to the PSS scheme, only when a node receives the information that it has at least a moving neighbor, it wakes up for listening to the network. So the rate that a node wakes up depends on the number of mobile neighbors and in some cases smaller than (n+1) for (n^2+n+1) total slots

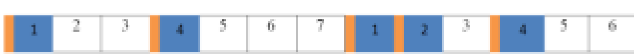

Fig 3: With Power Saver Slot. Slot 2 switches to sleep mode since no mobile node is detected by slot 1.

VI. SIMULATION RESULTS AND DISCUSSIONS.

The Simulation was carried out using NS-3 Simulator. Random walk mobility model has been used for the mobility pattern of the nodes. It is based on the thought that individuals characteristically move around in random ways which cannot be predicted. In this model, every node moves towards a new randomly chosen location. A random direction and speed is assigned to each node from a predefined range and nodes of a network are independent from one another. The maximum speed of the node is chosen to be 1.4 m/s. We have analyzed the performance of the proposed method with the existing techniques. The Simulation Scenario is given in Fig 4 in which nodes are sparsely deployed.

We have concentrated on Network Layer and MAC Layer which takes the Network status and Node Status as the inputs and reacts accordingly. The frequency of encountering between the nodes are calculated and updated along with the availability calculation of Buffer Space and the misbehaving characteristics of each node are considered as the criterion for selecting the nodes for carrying the data in the Network Layer.

Fig 4: Simulation Scenario with 20 sparsely deployed mobile nodes

Packet size, Buffer size, presence of misbehaving nodes and Node speed are the factors which affects the performance of the Routing Protocol. Hence we have analyzed the proposed Energy Sensitive routing protocol and studied its performance. Also we have compared the performance of the ESRP with the existing routing protocols for DT-MANETs in terms of Packet Delivery Ratio (PDR), Data Delivery Delay, Total Number of Transmissions and Total Energy Consumption. Table 1 gives the comparison of different routing protocols along with the proposed mechanism.

TABLE 1

Comparison of Routing protocols for Delay Tolerant Network

Parameters	Epidemic	Prophet	ORION	Spray & wait	Bubble Rap	ESRP
Packet Delivery Ratio	0.4	0.6	0.62	0.7	0.6	0.7
Data Delivery Delay (s)	5.9	5.7	5.8	5.9	6.2	5.7
Total No. of Transmission $(x\ 10^3)$	2.9	2.6	2.3	2.1	2.4	1.3
Total Energy Consumption (joule)	860	740	680	720	700	600

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The Impact of the Buffer Size

The performance of the proposed mechanism is analyzed with the buffer sizes varying from 200KB to 2MB. Bigger the size of the buffer size increases the capacity limit of every node and so the possibility of missing the packets due to lack of buffer occupancy is less. So we have analyzed the impact of buffer size on the performance of the network with varying node speed and number of nodes. The size of the network has been set to 500m x 500m in our simulation. The size of the Packet size is fixed constant and it is 20KB. Humans have the tendency to walk at about 1.4 m/s maximum. So the speed of the node is set to 1m/s and 1.4 m/s. For the analysis we have taken 20 nodes in the network and the transmission range of each node is 50m. The Energy Consumed when Transmitting and receiving the data is taken as 0.2818 J and 0.2053 J respectively. Energy consumed by idle mode is 0.1791 J. Constant Bit Rate is used as traffic model in our simulation.

Packet Delivery Ratio is the ratio of the packets that are successfully delivered to the destination to the packets that are sent out from the source.

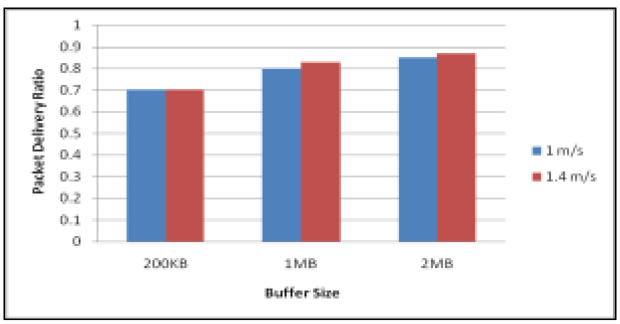

Fig 5: Buffer Size Vs Packet Delivery Ratio (for 2 different Node speed)

Increase in the speed of the mobile nodes, increases the PDR, since the nodes get the opportunity to encounter many numbers of nodes. But further increase in the speed creates the opportunity to miss the chance of forwarding the data. Since we have assumed mobile node users are pedestrians, the speed is limited to moderate level and the performance is good. Fig 5 gives the comparison of PDR for different buffer sizes with different node speed. The Data Delivery Delay comparison for different buffer size for different node speed is given in Fig 6.

Data Delivery Delay is the difference in the time that all the packets reached the destination successfully and the time at which it starts from the source node.

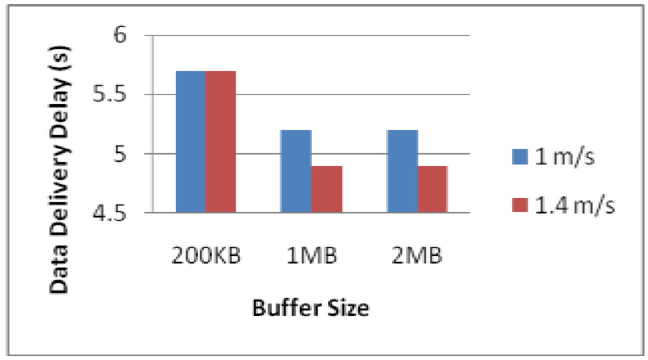

Fig 6: Buffer Size Vs Data Delivery Delay (for 2 different Node speed)

Fig 7 and 8 gives the comparison of Energy consumption comparison with and without Power Saver Slot.

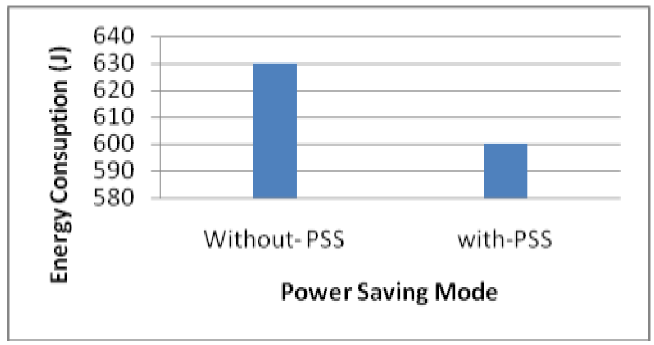

Fig 7: Power saving mode Vs Energy consumption

Total power consumption can be saved further when Power Saver Slot is used along with Quorum Based Asynchronous Power saving Protocols. This protocol performs well if the speed of the mobile node is moderate.

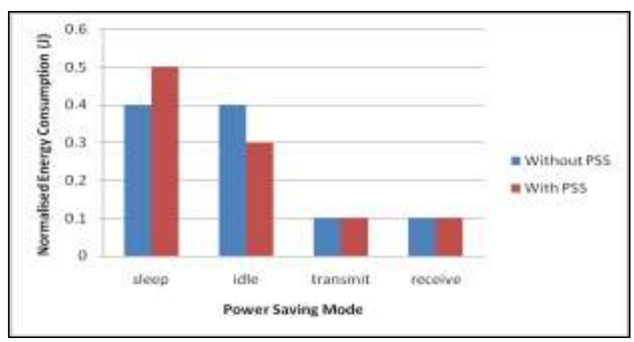

Fig 8: Power Saving Mode Vs Normalized Energy Consumption

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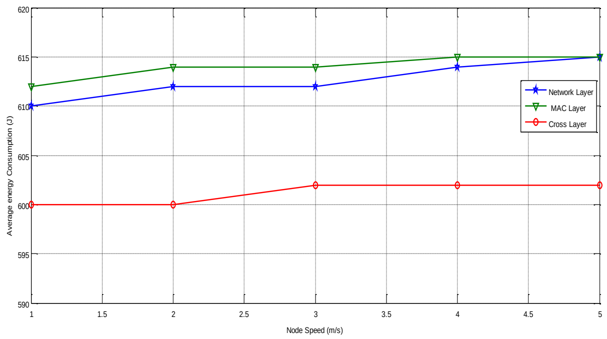

Fig 9: Node Speed Vs Average Energy Consumption

Figure 9 shows the Average Power consumption Vs Node Speed for 3 different Cases viz., applying Energy Minimization technique only in Network Layer, only in MAC Layer and in joint Network and MAC Layer (Cross Layer) approach.

CONCLUSION

Cross Layer Design Optimizes the performance of the network than the layered approach. In this paper we have concentrated and introduced an energy optimization technique by joint consideration of network and MAC layer. Factors which lessen the network life time are identified and they are minimized by avoiding unnecessary forwarding of data and minimization of idle listening. For the proposed strategy, parameters like Packet Delivery Ratio, Data Delivery Delay, Total Power Consumption and Total Number of transmissions are analyzed. The output shows that the proposed technique outperforms the existing techniques. We have focused on our future work to include physical layer issues in the cross layer design which further minimize the energy consumption.

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