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Energy efficient cross layer approach for Wireless Ad-hoc Network

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Abstract

Wireless Ad-hoc or Sensor Network has wide range of applications. Sometimes it is not possible to replace batteries of Ad-hoc or Sensor nodes in as network is deployed in inaccessible area. Resource constrained nodes run on batteries with limited capacity. For long running of the ad-hoc or sensor network, energy consumption on each node and lifetime of overall network is a concern for these applications. To prolong lifetime of networks, use of energy efficient method is necessary and also a challenging task. The major limiting factor of current nodes is the amount of battery. These batteries have a lifetime of few months in case of sensor network and few hours for ad-hoc networks in active workloads or about two years for sensor networks and 1-2 days for ad-hoc network in idle time. In order to design network that have extremely long lifetimes, we presents a cross layer scheme that achieves the prolonged lifetime of a network by controlling radio transmission power level and rebroadcast times of Route-Request (RREQ) during path discovery. This scheme does not introduce any control packet. At Network layer, energy is extracted from physical layer and according to this energy level decisions have been taken at network layer either to immediately forward the packets or with some delay or drop them if the battery level is very low. At MAC layer it reduces energy consumption during 4-way handshaking. Proposed method is more efficient compared to standard AODV method. This is the reason that proposed method increases prolong lifetime of the network by 11.38 % compared to standard AODV method.

Keywords: Wireless ad-hoc network; cross-layer protocol; AODV protocol; energy efficiency

INTRODUCTION

Wireless Ad-hoc Network is a decentralized wireless network. This type of network doesn’t depend on existing infrastructure. Nodes in this type of network mutually cooperate with each other and for an ad-hoc network to complete specific goal. Some time node in this type of network is mobile. Wireless Sensor Network (WSN) is also special case of WAHN. Applications of mobile devices [1] have grown exponentially over the last few years. Mobile device include PDA’s, smart mobile phones, notebooks and laptops and all these devices are powered by batteries. In case of WSN, configuring sensor nodes in peer to peer topology allows them to form WSN in an ad-hoc manner. Applications of WSN use random deployment method as most of the time the area in which we want to deploy network is very difficult to access. Thus replacing batteries is not easy as physical access of sensor node is difficult. For this reason energy is the scarce and invaluable resource for WAHNs and WSNs [2]. Mobile devices also use energy even when they are in sleep mode, that’s why there is continuous drain of energy in mobile nodes. So in wireless communication network lifetime is the major issue, less is the variance of energy level higher is the lifetime of network. Thus it is increasing interest of researchers to prolong the lifetime of a network. This is also applicable to Wireless Sensor Networks (WSNs) as it is also a special case of Wireless Ad-hoc network. Optimization done for WAHN is also applicable to WSNs [3].

One way to control power consumption to employ power saving mechanism that will allow a node to go sleep mode when the wireless network interface is idle. But this is not suggested technique as they partition the network into parts [4-5]. So there must be some other methods that should be suggested in order to save the energy of mobile devices. Energy constraint is one of the crucial issues as far as wireless ad-hoc network is considered because every now and then replacing the battery is not an option. There are lots of methods that are available in the area of power conservation for multi-hop ad-hoc wireless network. Different methods are used to conserve energy but here, we are proposing a scheme of power saving that is used to increase the lifetime of the network by using cross layer design using AODV protocol. The main objective of this paper is to improve performance for wireless ad-hoc network by increasing the lifetime of a network as well as individual nodes.

BACKGROUND

In this section different concepts of wireless ad-hoc are focused that principally affect the working of wireless ad-hoc network. These concepts are necessary to design and implement proposed method ESM/ESAODV.

A. Distributed Coordinated Function (DCF)

The Distributed Coordination function (DCF) [6] is a protocol which uses carrier sensing along with a four way handshake in order to maximize the throughput while preventing packet collisions. A packet collision is the case when a node is receiving more than one packet but none of them has been correctly received.

Consider a node wants to send the data to another node then it will wait for random back off time which is always less than contention window. If at any point of time node senses that another node is using the channel, it will wait for timer until another node has finished. When this back off time has expired then it will sense the channel again. If the channel is free then it will wait for DIFS time and sense the channel again and if it found the channel still free, and then transmit the request to send RTS to the destination node If the destination node is not receiving any data from another node then it will respond to the source node by transmitting clear to send (CTS). After receiving CTS source node starts transmitting the data. After correct reception of data the destination will transmit acknowledgement (ACK) back to the sender. The SIFS is used as a wait time between RTS, CTS, DATA, ACK frames. The reason of short time period of SIFS than DIFS is that another node in the network will not incorrectly determine that channel is idle. So NAV is used in this case, it is the amount of time that the current node will need. Working is shown in figure 1 below.

B. Cross layer approach

The main use of the cross layer approach is that it exploits the dependencies and interactions between the layers of TCP/IP model to increase the performance in certain scenarios of wireless networking. This is illustrated in figure 2 (A-F) below.

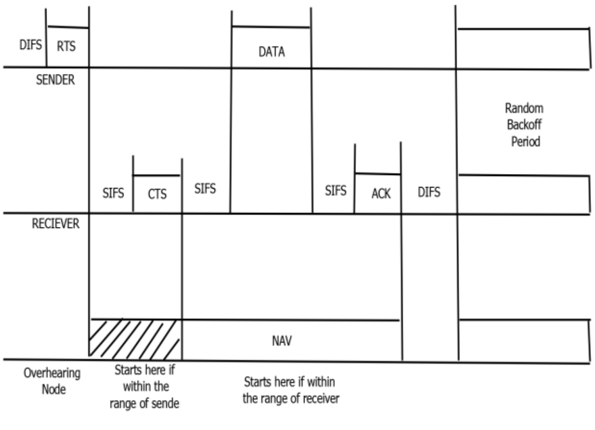

Figure 1: Distributed Coordinated Function

As wireless network characteristics are quite different from wire-line systems. Systems developers and researchers face different problems and challenges than in wire-line networks. Wireless channel characteristics generally affect all traditional TCP/IP layers fixing problems locally inside the layers. In wireless network there are certain challenges so traditional layered architecture that has served well for wired network are not suitable for wireless network. For increasing the performance of wireless systems it is better to share knowledge about layer state and conditions proved to be a promising paradigm for performance optimization in wireless systems. The cross-layered approach is more effective and energy efficient than in traditional approach. Cross layer approach minimizes transfer overheads by having data shared among layers [7]. In cross layer approach the protocol stack is treated as a system and not individual layers, independent of each other. The following interactions between the layers in cross layer approach are Network and MAC layer interaction, Network, MAC and link layer interaction, Transport, Network and MAC layer, Physical, MAC and routing layer, Transport and physical layer, Physical, MAC and routing layer, Transport and physical layer. Using these approaches of cross layer performance of wireless ad-hoc network can be achieved in terms of energy, throughput, end to end delay etc but our main focus on the improvement to network lifetime.

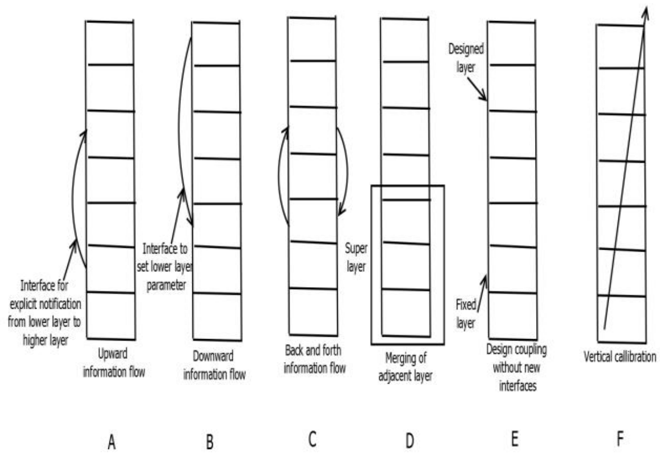

Figure 2: Different cross layer designs [8]

RELATED WORK

As energy management is considered it is one of the critical issues as energy resources are limited in wireless ad-hoc networks. Energy management schemes are very important to know when we are talking about energy conservation. So, in this section we have described some energy management techniques.

A. Energy management in ad-hoc network

In wireless ad-hoc network energy is the very scarce resource, so it is very necessary to use it efficiently while establishing communication patterns. Energy management is defined as the process of managing the resource and consumers of energy in a node or in a network as an entire for enhancing the lifetime of the network [9]. The main reasons for energy management in ad-hoc networks are; limited reserve of energy, lack of central administration, difficulties in replacing the batteries, constants on the battery source, selection of optional transmission power. Various energy efficient methods has been proposed in [10-13]

B. Classification of energy management schemes

Before improving the lifetime of the network we should understand capabilities of devices and limitation of energy resources of the nodes. First is the battery management schemes that deals with device management schemes, data link layer schemes and network layer schemes, second is transmission power management schemes that deals with data link layer, network layer and other higher layers and the third one is system power management schemes that deals with processor power management scheme and device management schemes. So energy management schemes can be further divided into; battery management schemes, transmission management schemes, system power management schemes.

There are basically three approaches by which we can minimize energy i.e. transmission power control approach, load distribution approach and sleep mode approach. In transmission power control approach the main objective is to find the route that minimizes the total transmission power between a source-destination pair. In load distribution approach energy usage of the mobile nodes are balanced by selecting the nodes with higher energy level rather the path with the shortest route. In this case the routes may become longer but packets are only transmitted through energy rich intermediate nodes. This kind of approach ensures longer lifetime of the node. Now, in sleep/power down approach the main focus is on inactive time of communication. In this method radio transmission subsystems are put in sleep state or turn it off in order to save energy.

This section presents the state of the art cross layer methods available in literature keeping energy efficiency in mind.

IEEE 802.11 specifies Physical and MAC layer for ad-hoc applications. On top of the MAC layer, designer of ad-hoc network (AHN) applications need to use Network layer. On top of Network layer an Application layer is needed as for most of the applications Transport layer is part of application layer. Each layer is responsible for specific roles and decisions need to be made by each layer. It provides simpler view of the functionalities to the above layers by hiding complexity of its own and layers beneath it. Generally, there is no interaction amongst layers in terms of information generated by one layer and being used by another layer. This scenario leads to inefficiency in AHNs. According to [8] layered architecture is not suitable for wireless networks and so for AHNs. Protocols need to be energy efficient as energy is utmost important for AHNs. In order to achieve energy efficiency we need to have exchange of information between layers and there is a need to introduce cross layer protocols. According to the literature, cross-layer design is demand of the day and it is needed specifically for interaction amongst any two of; Physical, MAC and Network layers. According to [8] sharing of information between non-adjacent layers or variables between any two layers is known as cross layer protocol. According to literature it is possible to have some sort of cross layer information exchange to improve performance for AHNs. Spectrum of cross-layer protocols are proposed in [14-17] with information exchange amongst more than one layers to achieve key design requirement of AHNs i.e. energy efficiency.

Transmission power adjustment method was proposed in [18] on the basis of number of neighbors. Threshold value of number of neighbors used to adjust transmission power. If current numbers of neighbors are lesser than threshold value of neighbors then transmission power is increased to increase number of neighbors else transmission power is decreased to decrease number of neighbors. This type of cross layer design demands for an interaction between MAC and Physical layer. This type of protocol improves performance only when density of the sensor nodes in wireless sensor network is high.

Method in [19] falls in to category of back and forth information exchange of cross layer model. It caters to the need of performance improvement of wireless network by information flow between Physical and MAC layers. Method proposed in [19] used QoS and neighbor density information to adjust transmission power at Physical layer. Method proposed in [18-19] creates a problem to neighboring nodes when the node sets its transmission power to high on the basis of its own observation of either QoS or neighbor density. Setting high transmission power creates interference to more neighboring nodes and prevent them sending information to other nodes.

Method proposed in [20] estimates transmission power of the sender based on information provided by all neighbor nodes. In this method sender sends beacon signal to all its neighboring nodes with maximum transmission power. Upon receipt of the beacon signal, all the neighboring nodes informs sender node about minimum required transmission power to be able to receive packet successfully. Upon receiving minimum transmission power requirement from all neighboring nodes, sender node sets it transmission power to the maximum of received values of minimum required transmission power from all the neighboring nodes. This method is also case of interaction between MAC and Physical layers. Method in [20] suffers from higher collision rate.

DESIGN AND IMPLEMENTATION

The objective of Energy Saving IEEE802.11 MAC layer (ESM) and Energy Saving Ad-hoc On-demand Distance Vector routing protocol (ESAODV) is to forward the packet with desired power level to another node by calculating distance which depends upon radio propagation model and through the nodes which are having higher energy at a given time respectively. The AODV is modified in such a way that if the energy of the node which is forwarding the packet within a multi-hop path reaches a level less than or equal to certain threshold percentage of its initial energy the node will ask the neighbor node to look for another path for such data packet. Since the nodes may die out of energy if they continuous sending and receiving packets. So the modified algorithm has introduced energy saving features.

A. Power data rate control in MAC layer

ESM proposed here is based on Transmission Power Control (TPC). In MAC layer a variable power data rate control is used change the transmission power between RTS–CTS and DATA-ACK packets. Simple idea behind this is that RTS-CTS are send with maximum transmission power level and lowest data rate but DATA-ACK packets are send with minimum transmission power level and highest data rate. To obtain minimum transmission power level received signal strength is used and received signal strength depends upon distance d between transmitter and receiver. The cross-over distance d_c is calculated from the (1) to decide which propagation model is used.

$$d_c = \frac{(4\pi * h_r * h_t)}{\lambda} \quad (1)$$

When d < dc, received signal strength ( ) is calculated from (2)

$$P_r(d) = \frac{P_t * G_t * G_r * \lambda^2}{(4\pi)^2 * d^2 * L} \quad (2)$$

And when d > dc, is calculated from (3)

$$P_r(d) = \frac{P_t * G_t * G_r * h_t^2 * h_r^2}{d^4 * L} \quad (3)$$

Now, after calculating Pr(d) from (2) or (3) depending upon radio propagation model, DATA-ACK packets are send by minimum transmission power level Pdesired which is calculated by (4)

$$P_{desired} = \left(\frac{P_t}{P_r(d)}\right) * RXThresh * C \quad (4)$$

Where, $P_{desired}$ = Desired transmission power level for DATA-ACK packet; P_t = Maximum transmitted power level;G_t = Transmitter gain (1.0 for all antennas); G_r = Receiver gain (1.0 for all antennas); d = Distance between transmitter and receiver; L= Path loss (L=1); h_t = Transmitter antenna height(1.5m); h_r = Receiver antenna height(1.5m); =wavelength; RXThresh = Minimum necessary received signal strength; C = Constant.

When control packets are sent with maximum transmission power and lowest data rate; this ensures that they are received across widest range because lowest data rate is having smaller receiver sensitivity. Benefit of having smaller receiver sensitivity is that any node can use it to provide collision free communication.

B. Rebroadcast time control mechanism

ESAODV proposed here is based on rebroadcast time control mechanism. It attempts to reduce the routing control overhead and processing requirement so as to minimize power utilization.

In On-demand routing protocols source floods RREQ packet to search for a path from source to destination. The destination node then responds by unicasting RREP back to the source to set up the route. This is route discovery procedure that comes to an end as soon as route is established. After route discovery phase, a route maintenance procedure maintains the continuity of the route.

In traditional AODV, residual battery level does not plays any role in forwarding the RREQ packets but in ESAODV routing decision are taken on the basis of residual battery energy to select the desirable route so that the variance of the network is less and routing overheads are reduced. When the intermediate nodes are involved in forwarding mechanism of RREQ packets from node to another, in between they also check for the duplicate RREQ packets. If duplicate RREQ packets are received they will discard those packets but, if they are not duplicate packets then nodes in the network will check for residual battery level and then they take the decisions accordingly mentioned below. First of all, divide the nodes according to the battery level.

Here, Bi denotes initial battery level of node i.

- Normal level (Bi > 20%): When the node i's battery power level is more than 20% then it is in normal level and the RREQ packet is immediately forwarded by the AODV protocol.
- Warning level (10% ≤ Bi ≤ 20%): When the node i's battery power level is between 10% and 20% then the node is in warning battery level. In this case, RREQ packet is forwarded after some delay. As delay is uniformly distributed from 0 to 10ms, so it is calculated from (5).

$$delay = \left(\frac{1}{Residual\ energy}\right) * 0.01 \quad (5)$$

Introducing delay means we are giving lower priority to the node to forward the RREP packet. So the energy is balanced in the network by forwarding RREQ packet by the node that has relatively high battery energy of the intermediate nodes.

- Danger level (Bi <10%): When the node i's battery level is less than 10% then it is in danger level. When RREQ packet reaches to this node then it will drop the packet in order to save the energy of that node.

C. Algorithm for MAC layer design

Step 1: *Broadcast the RTS–CTS packet with maximum transmission level Pt from source node to another.*

Step 2: *Node receiving CTS packet will calculate desired power level from (4).*

Step 3: *Now send the DATA-ACK packet with desired transmission level .*

D. Algorithm for Network layer Design

Step 1: *Receive a RREQ packet*

Step 2: *if duplicate RREQ then*

Drop the RREQ packet

Step 3: *if (Bi <10%) then*

Drop the RREQ packet

Step 4: *else if* $(10\% \leq Bi \leq 20\%)$

$T_{RREQ} = T_{RREQ} + d$

endif

Where d is the dynamic delay that is added and calculated from (5)

SIMULATION RESULTS

In this section different simulations comparing the performance of traditional MAC/AODV and ESM/ESAODV under different parameters are focussed. All the simulations are done using network simulator tool NS-2. No of simulations are run to illustrate performance gain in ESM/ESAODV over MAC/AODV. All the results are plotted on the graphs by using GNUPLOT.

To evaluate the performance and energy efficiency of traditional MAC/AODV and ESM/ESAODV NS2 are used for simulations. Simulation parameters are listed in table 1 below. Set up consists of 30 nodes in 600*600 square area. Maximum range of each node is assumes as 250m and initial energy of each node is 50J. We use two ray ground because it is more realistic. The length of the simulation time is 100secs. There are Constant Bit Rate (CBR) traffics introduced between the different nodes which are not directly connected to each other. Below is the list of parameters used in this paper to simulate the work.

In this section, simulation results of AODV/MAC and ESM/ESAODV shows the performance and energy efficiency. The metrics are residual energy of nodes, simulation time, throughput, percentage of RREQ dropped, percentage of RREQ forwarded and percentage of RREQ received.

Table I: Simulation parameters

Parameters	**Values**
Network size (m^2)	600 x 600 m^2
Number of nodes	30
Traffic Type	CBR
Number of CBR	5
Packet size	512 Bytes
Propagation model	Two Ray Ground Model
Routing protocol	AODV
Simulation time	100 s
Pt(W)	0.2818
Transmission range(m)	250 m
Initial energy(joules)	50 J
RXThreshold(W)	$3.652*10^{-10}$ W

A. Node's residual energy

In figure 3, remaining energy of individual node is plotted at the end of the simulation. In traditional AODV/MAC energy of many nodes is completely used and becoming zero than that of ESM/ESAODV. The lifetime of these nodes have drastically improved and remaining energy is much more in ESM/ESAODV as compared to traditional MAC/AODV, so the nodes in ESM/ESAODV can be further used till their energy becomes zero.

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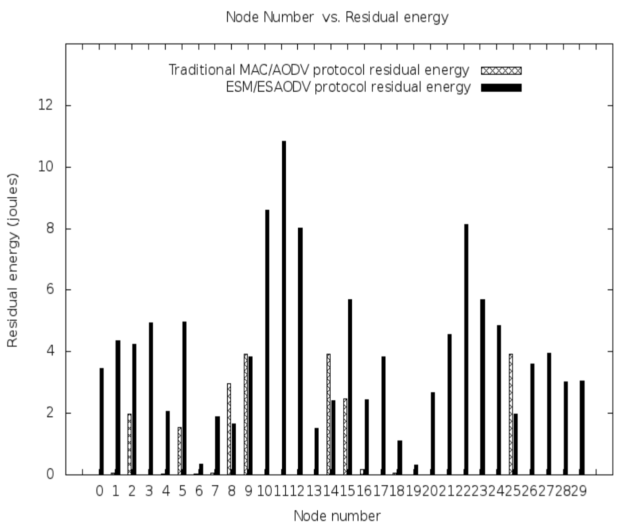

Figure 3: Node no. vs. Residual energy

B. Network life time

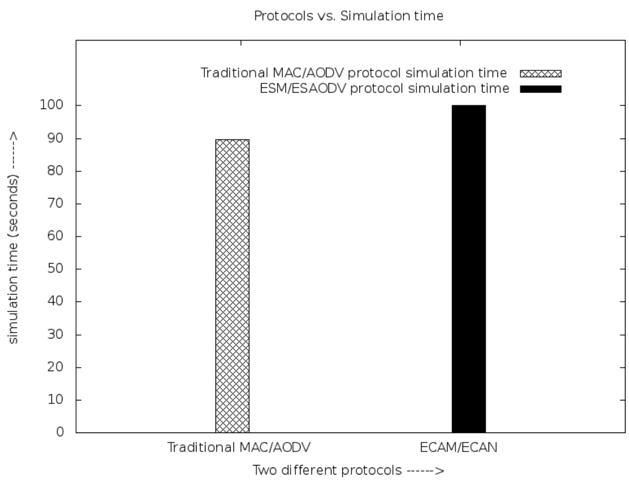

Figure 4: Protocol vs. simulation time

In our proposed algorithm network life time is the primary objective. As the lifetime of almost all the nodes has been improved, consequently the life time of the network has been increased in ESM/ESAODV as compared to traditional MAC/AODV. In traditional MAC/AODV the network is getting collapsed in 89.7 seconds whereas in ESM/ESAODV is lasting upto 99.9 seconds. So there is improvement of 11.38% in the life time of the network as shown in figure. 4.

C. Percentage of RREQ dropped

Our main is to drop the number of RREQ packets forwarded because forwarding the duplicate RREQ creates overhead in the network and every time receiving the duplicate RREQ packets in the network consumes higher energy in receiving mode. Consequently, if we are dropping duplicate RREQ packets then it will results in energy conservation of individual nodes. In the figure 5; percentage of RREQ dropped in ESM/ESAODV has been increased to 56.99% from 0% in traditional MAC/AODV protocol due to low residual battery energy level. So ESM/ESAODV is much more energy-efficient as compared to traditional MAC/AODV.

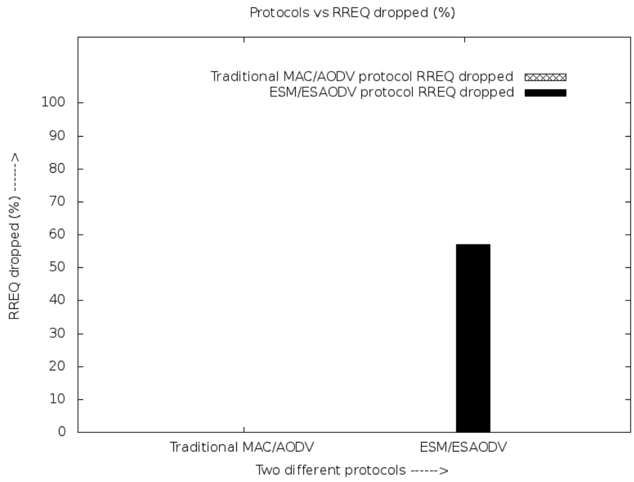

Figure 5: Protocol vs. RREQ dropped (%)

D. Percentage of RREQ forwarded

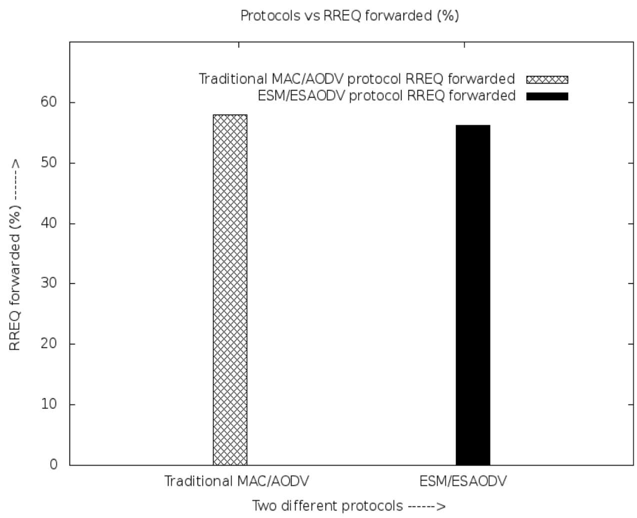

Figure 6: Protocol vs. RREQ forwarded (%)

When we are dropping RREQ packets then we are limiting the duplicate forwarding of RREQ. So less is the RREQ packets forwarding less is the consumption in transmitting mode that leads to higher energy conservation of the whole network. In the figure 6; percentage of RREQ forwarded in ESM/ESAODV has been decreased to 56.10% from 57.9% in traditional MAC/AODV protocol.

E. Percentage of RREQ received

Figure 7; shows that percentage of RREQ received in ESM/ESAODV is 39.723% which is half than that of traditional MAC/AODV which is 97.907%. Lower is the percentage of duplicate RREQ received lesser is the energy consumption in receiving mode that leads to energy conservation of the whole network.

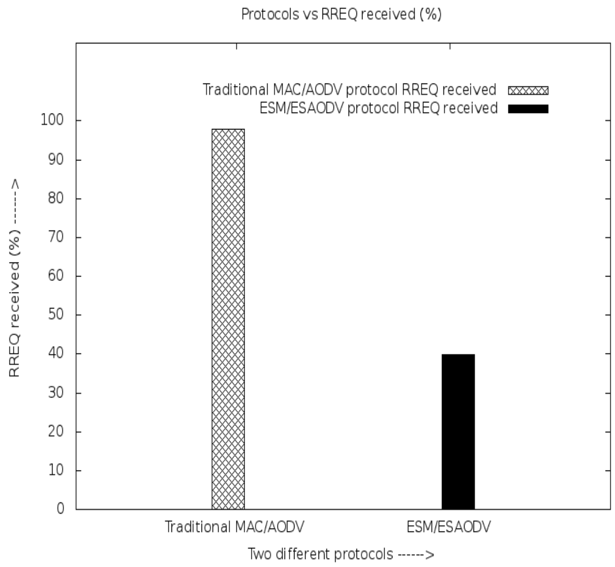

Figure 7: Protocol vs. RREQ received (%)

CONCLUSION AND FUTURE WORK

In all the evaluation metrics ESM/ESAODV is showing better simulation results as compared to traditional MAC/AODV by having a trade-off with network throughput. As all the evaluation metrics are giving better results so consequently we can say that ESM/ESAODV is an energy efficient protocol than traditional MAC/AODV. Improved algorithm prolongs node's lifetime and in turn prolong network lifetime. This algorithm reduces energy consumption in MAC layer during 4-way handshaking. In this method, Route Request forwarding decision takes place on the basis of residual battery level. So it also contributes to less energy consumption.

Still a lot of analysis can be done to evaluate the performance of ESM/ESAODV as all the parameters are not considered. We can analyze the performance by having more number of nodes with many more source and destination. Nodes were static during simulation so further experiments can be done by introducing mobility in the nodes.

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