SCALABLE ENERGY EFFICIENT AD-HOC ON DEMAND DISTANCE VECTOR (SEE-AODV) ROUTING PROTOCOL IN WIRELESS MESH NETWORKS

Sikander Singh
Research Scholar, Department of Computer Science & Engineering, Punjab Engineering College (PEC), Deemed University, Sector-12, Chandigarh-160012 (India)
er_sikander@rediffmail.com,

Dr. Trilok Chand Aseri
Sr. Lecturer, Department of Computer Science & Engineering, Punjab Engineering College (PEC), Deemed University, Sector-12, Chandigarh-160012 (India)
a_trilok_chand@yahoo.com

ABSTRACT

A new routing protocol called Scalable Energy Efficient Ad-hoc on Demand Distance Vector (SEE-AODV) having good scalable properties and energy efficient than existing Ad hoc on Demand Distance (AODV) routing protocol in wireless mesh networks has been proposed in this paper. Wireless mesh networks (WMNs) consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. They provide network access for both mesh and conventional clients. Two techniques called Clustering and Blocking-Expanding Ring Search has been applied on existing AODV routing protocol to improve its scalability and energy efficiency problem. Results shows that, performance of SEE-AODV routing protocol is better than existing AODV routing protocol in wireless mesh networks. To show the efficiency of our proposed routing protocol, simulations have been done by using Network Simulator-2 (NS-2).

Keywords: Wireless mesh networks, Ad-hoc network, Routing, Distance vector.

1 INTRODUCTION

Wireless mesh network (WMN) [1] technologies have been actively researched and developed as key solutions to improve the performance and services of wireless personal area networks (WPANs), wireless local area networks (WLANs) and wireless metropolitan area networks (WMANs) for a variety of applications, such as voice, data and video. Compared with mobile ad hoc networks (MANETs), wireless sensor networks (WSNs) and infrastructure-based mobile cellular networks, WMNs are (i) quasi-static in network topology and architecture (ii) not resource constrained at mesh routers and (iii) easy and flexible to deploy. These technological advantages are especially appealing to the emerging market requirements on future wireless networks and services, such as flexible network architecture, easy deployment and self-configuration, low installation and maintenance costs and interoperable with the existing WPAN, WLAN and WMAN networks. Potential applications of WMNs include broadband home networking, community and neighborhood networking, enterprise networking, building automation and so on. These wide ranges of applications have different technical requirements and challenges in the design and deployment of mesh networking architectures, algorithms and protocols.

The objective of this work is to develop routing protocols for Wireless Mesh Networks and to analyze their performance by realizing different environments. The analysis has been done theoretically and through simulations using NS-2 (Network Simulator-2). Objectives of the work are:-

1. To simulate the proposed routing protocol, Scalable Energy Efficient-Ad-hoc on-demand Distance Vector (SEE-AODV) for wireless mesh networks.
2. Evaluation of routing protocols based on various parameters.
3. Comparison of proposed protocol with existing protocol.

2 RELATED WORK

Wireless mesh networks has recently gained a lot of popularity due to their rapid deployment and instant communication capabilities. These networks comprise of somewhat static multi-radio Mesh Routers [2], which essentially provide connectivity between the mobile single-radio Mesh Clients. Special routing protocols are employed which facilitate routing between the Mesh Routers as well as between the Mesh Routers and the Mobile Clients. AODV is a well known routing protocol that can discover routes on-the-fly in a mobile environment. However, as the protocol was actually developed for single-radio nodes, it frequently lacks the ability to exploit the potential offered by the Mesh Routers. There are hundreds of proposed routing protocols [3], many of them have been standardized by IETF and have been in use for many years. Some of those protocols have proven themselves in the Internet and are expected to continue to perform well for many years to come. In the ad-hoc networking arena, several classes of routing protocols have been proposed and carefully analyzed. The WMN companies [4] are using a variety of routing protocols to satisfy their needs. Furthermore proposed routing protocol takes advantage of the fixed nodes in WMNs. In this paper some enhancements are done to improve the existing AODV protocol so that it works well in wireless mesh networks having good scalability and energy efficient.

3 SCALABLE ENERGY EFFICIENT AD-HOC ON DEMAND DISTANCE VECTOR ROUTING PROTOCOL (SEE-AODV)

In this paper to develop SEE-AODV Routing Protocol two techniques called Clustering and Blocking Expanding Ring Search have been applied to improve the performance of existing AODV routing protocol in wireless mesh networks. The performance of wireless mesh networks is highly dependent on routing protocol. AODV is a popular routing protocol for wireless networks. AODV is well suited for wireless mesh networks in that it has low processing & memory overhead and low network utilization. Additionally AODV provides loop freedom for all routes through the use of sequence numbers.

3.1 Design Goals

The design goal of SEE-AODV routing protocol is to improve the scaling potential of AODV and to make it energy efficient. The main feature of AODV-Clustering includes:-

(i) Gradualness

The protocol first works on AODV method, then gradually changes to a clustering route protocol. There are several considerations about it: First, there is central control node in mesh network; second, using this method can also allow AODV nodes coexisting with AODV-Clustering nodes; third, it can reduce the overhead caused by frequently changing of cluster.

(ii) Coexist with AODV

AODV is a widely accepted routing protocol. There are several implemented version of AODV reported. One of the important principles in designing AODV-Clustering is the coexistence with AODV; it means nodes which implement AODV protocol can work collaboratively with nodes that implement proposed protocol in the same network. To achieve this, keep all AODV route control packets and add some new control packets as needed. In fact AODV-Clustering let all nodes that haven't joined a cluster works on AODV method.

(iii) Route Discovery Mechanism

In AODV-Clustering, there are two route discovery mechanisms for the nodes which join the cluster. One is Blocking-ERS, it can increase the efficiency of the route discovery; the other is traditional RREQ flooding route discovery mechanism which extends from AODV. Normally Blocking-ERS is used first, if a suitable route can't be found before timeout, then traditional route discovery mechanism is used.

(iv) Local Route Repair

To reduce the number of lost data packets, when the route broke due to mobility, AODV-Clustering let the node upstream of the break link perform a local repair instead of issuing the RERR. If the local repair is successful, a RREP will be returned either by the destination or by a node with a valid route to the destination. In the event that a RREP is not returned, the local repair is not successful and a RERR message is sent to the source node.

3.2 AODV-Clustering Routing Scheme

(i) Route Discovery

At the beginning the status of all nodes is “unassigned”. Source node broadcast [5] RREQ message to find a route, destination node or intermediate node that has fresh route to destination reply with RREP message to source. On the way which RREP pass by, one or several nodes are selected as cluster head (CH) using a defined rule. CH node will broadcast CH message to its neighbours, the neighbour nodes which receive this broadcast will act differently according to its roles.

(a) For node whose status is “unassigned”, it will issue a Join Cluster Request to the broadcasting CH and can become an ordinary cluster member after receiving the acknowledgment from this CH. In AODV-Clustering, CH node can reach all his members by one hop, so the protocol's architecture is one level hierarchy.

(b) For node which is an ordinary cluster member, it will judge if the broadcast message sender is its original CH, if yes, no action needed; else, send Join Cluster Request to the CH and become gateway node after receiving acknowledgement from it. Being a gateway, it will send Gateway Message to all CH nodes which it connect directly, let them put its address in their Gateway Table.

(c) For node which is a gateway, it will check its Gateway Node Table whether there is an entry for this broadcasting CH node, if yes, no action needed; else, send Join Cluster Request to it and put its address into Gateway Node Table after receiving acknowledgement from it. Gateway nodes have two tables, one is Gateway Node Table which contains cluster head address which it connect directly, another is Joint Gateway Table, which contains address of the CH nodes which can be reached by 2 hops and also the nodes which help to reach these CHs which are called Joint Gateway.

(ii) Route Maintenance

AODV-Clustering extends many features from AODV for route maintenance, for example, use “hello” message to confirm the existence of neighbours, use RERR message to inform the nodes affected by the link breakage. In addition to it, AODV-Clustering adds some cluster related maintenance operations such as joining cluster, leaving cluster and changing its status.

(a) Joining Cluster

The nodes whose status is “unassigned” will join the cluster after receiving the CH Broadcasting Message. To reduce overhead, no periodic CH Broadcasting is used. Instead, a “on demand” method is used for new nodes to join cluster: when the node whose status is “unassigned” broadcast RREQ to its neighbours, a specific mark is set in RREQ, the mark will inform neighbouring CHs to let him join the cluster. Using this way, unassigned node that newly comes will have a chance to join the nearby cluster when it has data to send.

(b) Leaving Cluster

If the ordinary cluster member finds its CH node unreachable, it will change its status to unassigned. This means the node leaving the cluster. CH node should change its status to unassigned when it has no cluster members.

(c) Changing Cluster

In AODV-Clustering, the change of cluster is not occurred immediately. When the node leave the cluster, its status become “unassigned”, it works on AODV method until new CH node appear nearby and it has a chance to join the cluster.

3.3 Route Discovery Approaches in Wireless Mesh Networks

In Wireless mesh networks, nodes cooperating for delivery of a successful packet form a communication channel consisting of a source, a destination and possibly a number of intermediate nodes with fixed base station. In this paper some inefficient elements have been found in well known reactive protocols AODV and propose a new approach for rebroadcasting in Expanding Ring Search. This leads to the Blocking-ERS scheme, as we call it, which demonstrates improvement in energy efficiency at the expense of route discovery time in comparison to conventional route search method.

3.3.1 Blocking-ERS

An alternative ERS scheme has been proposed to support reactive protocols such as DSR (Distance Source Routing) and AODV and it is called Blocking Expanding Ring Search. The Blocking-ERS integrates, instead of TTL sequences, a newly adopted control packet, stop instruction and a hop number (H) to reduce the energy consumption during route discovery stage. The basic route discovery structure of Blocking-ERS is similar to that of conventional TTL sequence-based ERS. One of the differences from TTL sequence-based ERS is that the Blocking-ERS does not resume its route search procedure from the source node every time when a rebroadcast is required. The rebroadcast can be initialized by any appropriate intermediate nodes. An intermediate node that performs a rebroadcast on behalf of the source node acts as a relay or an agent node. Fig. 1 shows an example of Blocking ERS approach in which the rebroadcasts are initialized by and begins from a relay node M in rebroadcast round 2 and another relay node N in round 3 and so on. In Fig. 1 the source node broadcasts a RREQ including a hop number (H) with an initial value of 1. Suppose that a neighbour M receives the RREQ with H=1 and the first ring was made. If no route node is found, that is, no node has the requested route information to the destination node, the nodes in the first ring rebroadcast the RREQ with an increased hop number, for example RREQ with H=2 is rebroadcast in this case The ring is expanded once again just like the normal expanding ring search in AODV except with an extended waiting time.

The waiting time can be defined as

Waiting Time = 2 × Hop Number

The nodes in Blocking-ERS receiving RREQs need to wait for a period of 2H, i.e. 2×their hop-number unit time before they decide to rebroadcast, where the ‘unit time’ is the amount of time taken for a packet to be delivered from one node to one-hop neighbouring node.

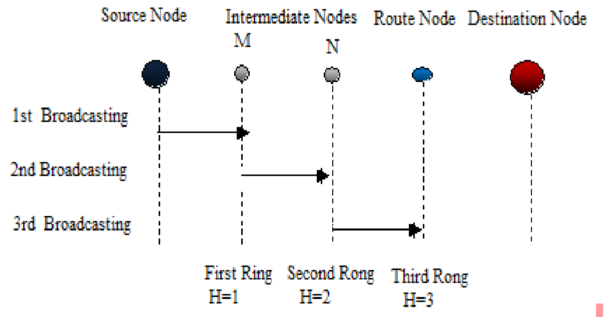

Figure 1: Blocking-ERS

(A) Energy Consumption

Energy consumption during the transmission of RREQs can be saved by using the Blocking-ERS scheme. Let the amount of energy consumption on each node for one broadcast is the same unit energy consumption, denoted by UnitEnergy. Assume that each action of broadcasting a RREP, RREQ or 'stop instruction' consumes the same amount of 1 UnitEnergy. This can be easily shown by the difference of the energy consumption between the conventional TTL sequence-based ERS and the Blocking-ERS scheme.

(i) One route case: - First consider only the energy consumption along the route from the source to the route node. The energy consumption for the TTL based ERS and for the Blocking-ERS can be described by the following formula (Eq. (1) and Eq. (2)) respectively, where Hr is the hop number of the route node.

$$E_{TTL-ERS} = H_r + \sum_{i=1}^{Hr} i(UnitEnergy) \quad (1)$$

$$E_{Blocking-ERS} = 3H_r (UnitEnergy) \quad (2)$$

The difference of the amount of energy consumption is more visible from Fig. 2 where the amounts of energy consumption by the two ERS approaches are plotted against the number of rings. The Blocking-ERS curve is below the TTL based ERS curve after ring 3. As it is clear from Fig. 2, the difference of the amount of energy consumption between these two mechanisms becomes larger as the distance increases between the source and the route node.

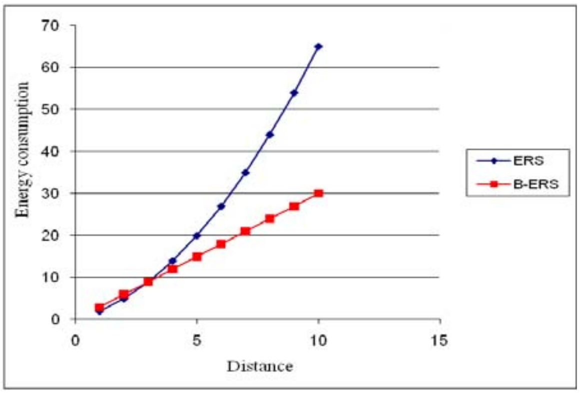

Figure 2: Comparison of energy consumption for one route (Energy is measured in Joule, and Distance in number of hops)

(ii) General case: - Now consider the general case. For the Blocking-ERS, the energy consumption during the route discovery process can be considered as the total energy consumption in three stages: (a) searching for the route node (b) return RREP and (c) sending the 'stop instruction'. For the conventional TTL based ERS, the energy consumption during the route discovery process includes that in two stages: (a) searching for the route node and (b) return RREP. The energy consumed for "(b) returning a RREP" is Hr UnitEnergy for both routing schemes and Hr UnitEnergy is consumed for the Blocking-ERS stage '(c) sending the stop instruction'. In the stage of '(a) searching for the route node', the energy consumption is different for the two methods. Each ring contains different number of nodes that rebroadcast to form the next ring. Let n_i be the number of nodes in ring i and the hop number of the route node be Hr.

In the Blocking-ERS, the energy consumed in each ring is as below: -

Ring i	Energy Consumed
0	1
1	n_1
H_{r-1}	n_{hr-1}

In the TTL based ERS, the energy consumed in each ring is as follows: -

Ring i	Energy Consumed
0	1
1	$1 + n_1$
H_{r-1}	$1 + n_1 + n_2 + \cdots + n_{hr-1}$

Therefore, the total energy consumption by the Blocking- ERS is given by Eq. (3)

$$E_{Blocking-ERS} = 2(1 + \sum_{i=1}^{H_r} n_i) + E_{RREP} (UnitEnergy) \quad (3)$$

Similarly, the total energy consumption by the conventional TTL sequence based ERS is given by Eq. (4)

$$E_{TTL-ERS} = H_r + \sum_{i=1}^{H_r} \sum_{j=1}^{i} n_j + E_{RREP} (UnitEnergy) \quad (4)$$

The difference between the $E_{Blocking-ERS}$ and $E_{TTL-ERS}$ is given by Eq. (5)

$$E_{Saved} = H_r - 2 + \sum_{i=1}^{H_r-1} ((\sum_{j=1}^{i} n_j) - 2_{n_i})(UnitEnergy) \quad (5)$$

Clearly, when $n_i = 1$, for $i = 1, \cdots, H_r$. The above formulas represent the energy consumption for a single route. This indicates that the energy consumption saving achieved by the Blocking-ERS for a single route is the minimum amount of energy saving.

(B) Time Delay

Consider the time delay for the route discovery period, during which from the RREQ is broadcasted for the first time, transmitted from the source node to the route node possibly via flooding. That is the total time taken from when the source node broadcasts the first RREQ for the first time until after a Route Node is found and the source node receive the RREP from the Route Node. Let the UnitTime be the one-hop transmission time, which is the time taken for a RREQ from a broadcasting node to one of its neighbour nodes. In case of TTL sequence based ERS suppose H = 3, that is the route node is 3 hops distant from the source node. The total time includes the time when TTL = 1, 2 and 3. The final TTL number equals to the hop number of the route node. This gives the following formula of total time delay for the TTL sequence-based ERS (Eq. 6): -

$$T_{TTL-ERS} = 2\sum_{i=1}^{H_r} i(UnitTime) \qquad (6)$$

Now consider the time delay in the Blocking-ERS. The total time includes the time for three stages: (a) searching for the route node, (b) returning the RREP and (c) broadcasting the 'stop instruction'. For stage (a), the time consists of the time to for broadcasting and the waiting time. The broadcasting time for 1 hop distance is 1 UnitTime. The waiting time depends on the hop number of the node. The route node is 3 hops distant from the source node. Each node needs to wait for 2H before rebroadcasting. At ring 1, the node waits for 2 × 1 = 2 UnitTime, and at ring 2, the node waits for 2 × 2 = 4 UnitTime, and at ring 3, the node waits for 2 × 3 = 6, so the total waiting time for the '(a) stage of searching for the route node' is 2 + 4 + 6 = 12, and the total time for stage (a) is 12+Hr = 12+3 = 15. The time for stage (b) and (c) are Hr and this gives 2Hr = 2×3 = 6. Therefore, the total time for the route discovery and flooding control is 15 + 6 = 21 UnitTime. Mathematical formula is presented below, where H_r represents the hop number of a route node.

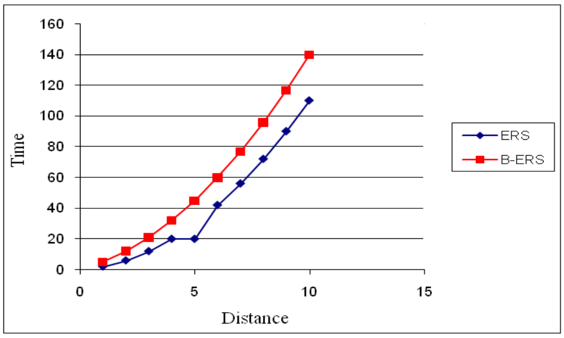

Figure 3: Comparison of the time delay (Time is measured in millisec, and Distance in number of hops)

The formula of the time delay in the Blocking-ERS is given by Eq. (7): -

$$T_{Blocking-ERS} = 3H_r + 2\sum_{i=1}^{H_r} i(UnitTime) \qquad (7)$$

Compare this to the TTL sequence based ERS as given in Eq. (8): -

$$T_{TTL-ERS} = 2\sum_{i=1}^{H_r} i(UnitTime) \qquad (8)$$

It is clear that the difference between the two is 3Hr three times of the hop serial number of the route node, depending only on the distance between the source node to the Route node. The time delay in both approaches is compared in Fig. 3 As illustrated the Blocking-ERS takes slightly more time than the conventional TTL sequence-based ERS for the route discovery process.

4 PERFORMANCE EVALUATION

To evaluate the performance of SEE-AODV routing protocol (AODV-Clustering with Blocking-ERS technique), the simulation is done by using NS-2 [6]. The performance of SEE-AODV routing protocol is evaluated by comparing it with existing AODV routing protocol in the same conditions.

There is evaluation of three performance metrics: -

(i) Packet Delivery Fraction: - This is the fraction of the data packets generated by the sources that are delivered successfully to the destination. This evaluates the ability of the protocol to discover routes.

(ii) Routing Load: - This is a ratio of control packet overhead to data packet overhead, measured by the number of route control packets sent per data packet. The transmission at each hop along the route was counted as one transmission in the calculation.

(iii) Average Route Acquisition Latency: - This is the average delay between the sending of a route request packet by a source for discovering a route to a destination and the receipt of the first corresponding route reply. If there is a fresh route already, 0 was used for calculating the latency.

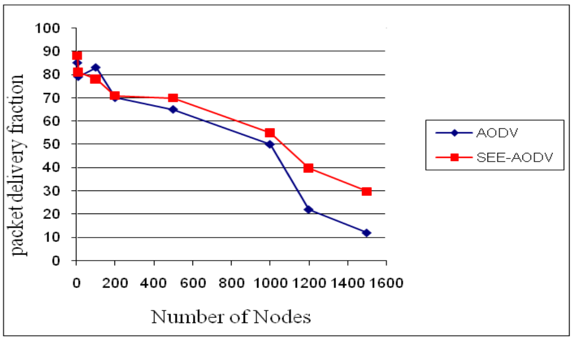

Figure 4: AODV, SEE-AODV packet delivery

fraction

As shown in Fig. 4 the packet delivery fraction obtained using SEE-AODV is almost identical to that obtained using AODV when node numbers are small. However, when there are larger numbers of nodes (i.e., more than 200), SEE-AODV performed better. This suggests that SEE-AODV is highly effective in discovering and maintaining routes for delivery of data packets.

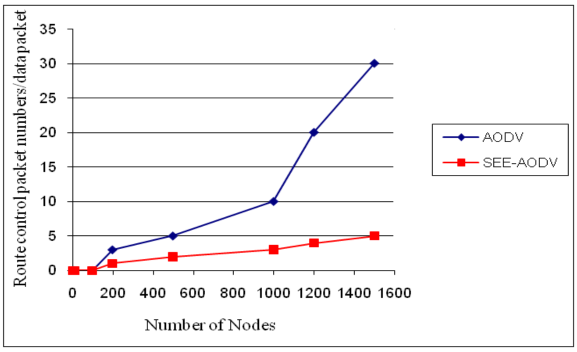

Figure 5: AODV, SEE-AODV Routing Load

Fig. 5 shows the routing load comparison of these two protocols. Routing load is measured by numbers of route control packets sent per data packets. For AODV, route control packets include RREQ, RREP, RERR and Hello messages, for SEE-AODV cluster related messages such as CH Broadcast Message, Join Cluster Request, Join Cluster ACK, and Gateway message are also included. It is clear from Fig. 5, routing load of SEE-AODV was significantly lower than AODV when there are large numbers of nodes in network. So SEE-AODV became a hierarchical protocol gradually, hierarchical routing greatly increases the scalability of routing in wireless networks by increasing the robustness of routes.

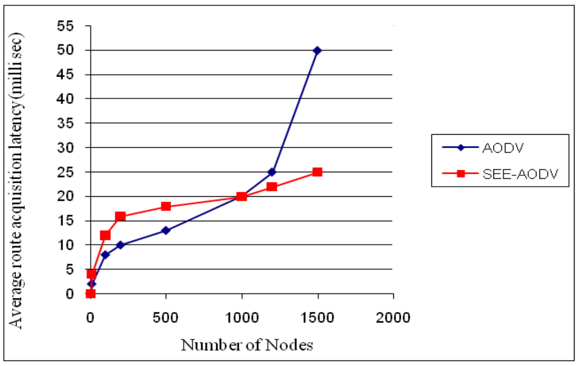

Figure 6: AODV, SEE-AODV Average Route Acquisition Latency

Fig. 6 shows the Average Route Acquisition Latency of the two protocols. SEE- AODV performed better than AODV in more "stressful" situations (i.e. larger number of nodes, more load), this is greatly contributed to the Blocking-ERS technique of AODV-Clustering and reduction of the RREQ flooding.

5 CONCLUSION AND FUTURE WORK

In this paper Scalable Energy Efficient AODV (SEE-AODV) routing protocol has been introduced to solve the scalability problem of AODV by applying Clustering and to make it energy efficient by using Blocking-ERS techniques in wireless mesh networks. The performance is studied by simulations based on NS-2. The result shows, that SEE-AODV protocol achieves better scalability than existing AODV while keeping the merits of it. The analysis demonstrates a substantial improvement in energy consumption that can be achieved by the Blocking-ERS at a margin cost of slightly longer time.

There are some limitations still in SEE-AODV routing protocol, such as during discovery of a route the technique used in this protocol slightly takes more time than existing conventional one, so it need further study to improve this drawback.

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