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Energy Efficient Linked Supervisory Set based Routing (E^2LS^2R) scheme for wireless mesh networks

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Abstract
Wireless Mesh Networks (WMNs) include mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. In WMNs, routing problem is an important issue that draws attention. The main objective of this paper is to reduce packet loss and to conserve the energy of nodes taken to transmit the packet from the source to destination. Energy Efficient Linked Supervisory Set based Routing (E^2LS^2R) scheme is proposed for WMNs to conserve energy by considering the Residual Energy (RE) of the intermediate nodes. This scheme outperforms the Connected Dominating Set (CDS) based scheme in terms of Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), Throughput and energy consumed.

Keywords: Wireless Mesh Network (WMN), Residual Energy (RE), Linked Supervisory Set (LSS), Energy Efficient Linked Supervisory Set based Routing (E^2LS^2R)

1. Introduction

A Wireless Mesh Network (WMN) is a dynamically self-organized and self-configured network. The nodes in the network establish and maintain mesh connectivity among them. WMNs support fast and easy deployment.

In WMNs, particularly with fixed backbone, the nodes have unlimited energy. They provide low cost broadband internet access to wireless Local Area Networks (LANs) and network connections to both network operators and users [1].

Indeed, mesh technology has captured the interest of academic research and industry with its ability to satisfy both the requirements of Internet Service Providers (ISPs) and wireless users. Industry and academia place very high demands on WMNs and their advantages, such as the network range extension, resilience, fault tolerance and high bandwidth capabilities.

Some characteristics of WMNs include:

- Dynamic self-configuration and self-organization
- Adaptation
- Robustness
- Low-Cost
- Integration and interoperability

WMNs involve mesh routers and mesh clients. Mesh routers provide network access for both mesh and conventional clients. The integration of WMNs with other networks such as the internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc, can be accomplished by the gateway and bridging functions in the mesh routers. On the other hand, the mesh clients connect to the network over both mesh routers and other clients. In these networks, due to more number of nodes, security and manageability become issues. They offer redundant communication paths in a network. Whenever a link fails, the network automatically routes messages through alternate paths. Even in adverse conditions, devices in WMNs co-operate with each other in transmitting packets through the network.

Fig. 1 shows a sample mesh network architecture [2] that consists of nodes called Mesh Points (MPs) which only relay traffic but do not provide wireless coverage to Mobile Stations (MSs). These MPs use the services of WMNs to communicate with other MPs in the network. They can act as a Mesh Access Point (MAP) or Mesh Point Portal (MPP), whose aim is to integrate WMNs with various existing wireless networks such as cellular systems, Wireless Sensor Networks (WSNs),Wireless-Fidelity (Wi-Fi) [3] systems and Worldwide interoperability for Microwave Access (WiMAX)[4].

Due to increased energy consumption and its consequent environmental effects in a WLAN mesh network, energy efficiency has become a key factor to evaluate the performance of a communication network.

In WMNs, the resources of Wireless Access Networks (WANs) are for long periods of time underemployed, since only a few percentage of the capacity of these devices is effectively used and this leads to high energy waste [5]. Large amount of energy can be conserved by switching off unnecessary network elements.

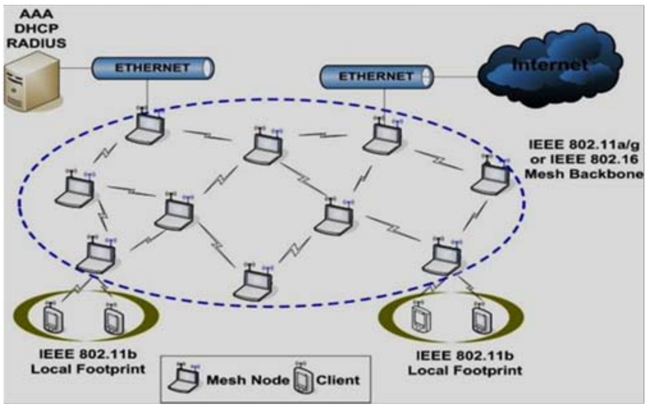

Fig. 1: Mesh Network Architecture

2. Routing Protocols in WMNs

Routing protocols in WMN can be classified into proactive and reactive protocols. Proactive protocols maintain routes between every pair of nodes all the time, while the reactive routing protocols build and maintain routes only on-demand.

Reactive routing protocols perform better in terms of the Packet Delivery Ratio (PDR) and incur lower routing overhead, especially in the presence of high mobility in the mesh networks.

In WMN, transfer of data packets takes place to and from the Access Point (AP). Each node sends route requests to its neighbors. When the requests reach the different APs, they send back a route reply.

The sender node receives the route replies and decides the route and the AP to use based on different conditions. Since the transfer of data packets in ad-hoc networks is similar to this, the existing ad-hoc routing protocols like Distance Source Routing (DSR) and Ad-hoc On-Demand Routing (AODV) can be used. But these protocols assume some properties of ad-hoc networks that are no longer true for WMN.

Quality of Service Routing (QoSR) is a key function for the transmission and distribution of digitized information across networks. It has two main objectives - finding routes that satisfy the QoSR constraints and making efficient resource utilization [2].

Unfortunately, several factors can degrade performance. Packet loss because of overloaded incoming and outgoing message buffers and packet delay when residing in the large queue using invalid routes are prevalent. The complexity in QoS routing comes from multiple criteria, which makes the routing problem intractable.

A Dominating Set (DS) is a subset of nodes such that each node is either in DS or has a neighbor in DS. The Connected Dominating Set (CDS) is recommended to serve as a virtual backbone for a WMN to reduce routing overhead.There is a path between any two nodes in CDS that uses nodes that are in CDS.

The other characteristics include robustness to node failures and low stretch. CDS construction algorithms are mainly based on the Maximum Independent Set (MIS) [1,2,5]. CDS construction algorithms should be robust to security attacks and ensure survivable network functionality.

Energy conservation plays a vital role in WMNs. Energy based routing mechanism is used to calculate the remaining energy of a node and an efficient routing algorithm is used to find out the path.

3. Related Work

Some distributed CDS construction algorithms are proposed in [6]. A greedy algorithm called Simple Minimum Independent Set (S-MIS) proposed by Li et al, has two phases. In the first phase, the MIS construction algorithm is designed. The second phase includes the black-blue component, a connected component of the sub-graph induced only by black and blue nodes, in which connections between blue nodes are ignored. Black node is the dominator of the first phase and the blue node is the dominator of the second phase. In the second phase, a greedy algorithm is used to find some gray nodes adjacent to atleast two black nodes in different black-blue components.

A distributed algorithm is proposed in [7] to construct CDS using MIS in Unit Disk Graph (UDG). This technique requires large amount of message exchanges and transmission for the construction of spanning tree for CDS.

An algorithm to find Minimum Connected Dominating Set (MCDS) using dominating set in UDG is proposed in [2]. This algorithm is implemented in three phases. In the first phase, dominating sets are found. In the second phase, connectors are identified, connected by Steiner tree. In the third phase, MCDS is constructed. The network should adapt to the continuous topological changes due to deactivation of a node and exhaustion of battery. These changes are taken care by a local repair algorithm that reconstructs the MCDS.

A CDS protocol that consists of two phases is discussed in [8]. During the first phase, each node collects the two-hop neighboring information by exchanging messages with its one-hop neighbors. If a node finds that there is a direct link between any pair of its one-hop neighbors, it removes itself from the CDS. In the second stage, two additional rules are applied to further reduce the size of the CDS.

The marking process is proposed by Wu and Li[9]. The pruning process is improved and denoted by Rule-k. Based on the Rule-k, the size of the final constructed CDS is reduced. A hierarchical graph is constructed and then the essential nodes in the graph are determined. Once the essential nodes determination phase has ended, there are some redundant dominators, which are deleted by Rule-2.

A distributed algorithm is proposed for the construction of an MCDS [10]. This algorithm involves two steps. In the first step, each node broadcasts the entire set of IDs of its neighboring nodes to its neighbors and after receiving this adjacency information from all neighbors, it declares itself as the dominator if and only if it has two non-adjacent neighbors. These dominators form the initial CDS. In the second phase, a node is considered as locally redundant if it has either a neighbor with a larger ID which dominates all other neighbors or two adjacent neighbors with a larger ID which together dominate all other neighbors. The algorithm then removes all locally redundant nodes.

In a multi-hop ad-hoc network, power is conserved by choosing paths that minimize the total transmit energy [11]. This approach is extended by Chang and Tassiulas [13] to maximize the overall network lifetime by distributing energy fairly. In this protocol, nodes adjust their transmission power levels and select routes to optimize performance.

A power-aware routing algorithm is presented for wireless networks with renewable energy sources [12]. The proposed algorithm is asymptotically optimal. The proposed routing algorithm uses a composite cost metric that includes transmission and reception power, non-uniform replenishment rates and Residual Energy (RE). It introduces a battery energy threshold scheme to decrease overhead.

A new mechanism that makes a trade-off between energy efficiency and the shortness of a selected path for forwarding data packets is propounded [13]. In other words, this mechanism tries to minimize the energy consumption and at the same time, maintain a good end-to-end delay and throughput performance. The existing on-demand DSR is extended and the resultant version takes the name, Extended Max-Min DSR (EMM-DSR).

A Spanning tree algorithm is proposed to select specific nodes as coordinators. These coordinators thereby form a CDS and let the other nodes go into low power mode thus saving energy [14]. According to this algorithm, a node becomes a coordinator if it has two neighbors that are not directly connected, or it has two neighbours that are indirectly connected through one or two intermediate nodes. The status change of a node from a non-coordinator to a coordinator is governed by the back-off delay such that nodes with less delay are entitled to have higher probability of becoming coordinators. The problem with this algorithm is that, it cannot form a CDS when there is a simultaneous change of two coordinators to non-coordinators.

The concept of zone and level are combined to construct CDS [15], the virtual backbone of a wireless network. Based on these ideas, they partition the wireless network into different zones. For each zone, a dominating tree is constructed and they are connected by inserting additional connectors at the zone borders to produce the final CDS.

The algorithm proposed by [16] is a centralized version of the distributed algorithm. It consists of three phases. The first phase finds an approximation to Minimum Dominating Set (MDS) which is essentially the set cover problem. The second phase constructs a spanning forest. Each tree component in the spanning forest is a union of stars centred at the nodes in the graph. The stars are generated by letting each dominate node pick up an arbitrary neighbor in the graph. The third phase expands the spanning forest to a spanning tree. All the internal nodes in the spanning tree form a CDS.

A distributed CDS algorithm that uses a unit-disk graph model is propounded [17]. It is also a two-phase protocol. In the first stage, the MIS of the given network topology is constructed in a distributed manner by repeated selection of the nodes with the highest number of local neighbors. The nodes in the MIS become the virtual backbone of the CDS. It considers the distance between any pair of its complementary subsets to be exactly two hops away, although nodes in the MIS are not connected. In the second stage, a localized search is performed to include additional nodes in CDS to connect the nodes in the MIS. Thus, the CDS protocols are distributed and decentralized; they generate a large number of messages. Also, the node mobility issue not addressed in these protocols indicates that, if the network topology changes, an entire CDS is to be reconstructed from the scratch.

An approximation algorithm that involves the construction of a spanning tree with a node which has maximum number of neighbors is discussed [18]. Initially, all the nodes are marked in white colour. The node with the maximum number of neighbors is marked black, added to the tree and its neighbors are colored gray. The gray colored nodes are added to the spanning tree. This process continues until all the nodes in the network are marked either gray or black and thus the black nodes in the network form the CDS. This algorithm involves more maintenance cost and does not deal with mobility.

A single phase distributed algorithm called Distributed Single Phase (DSP) is proposed for constructing a CDS [19]. In this algorithm, each node gets the information from its one-hop neighborhood, using which it makes a local decision whether to join the dominating set. Each node makes decision based on a key variable and strength which guarantees that the dominating set is connected when the algorithm converges. The rules for computing strength can be changed to accommodate different application needs like, including the ability to balance energy consumption among neighboring nodes.

4. Connected Dominating Set (CDS)

A subset of nodes in a graph, such that each node is either a member of the subset or atmost one hop away from an element of the subset forms a dominating set ‘S’. A DS is a subset of nodes such that each node is either in DS or has a neighbor in DS.

A CDS of ‘G’ is a dominating set ‘S’ in which all the elements are connected. The nodes in CDS are called dominators and the other nodes which are one hop away from CDS are dominates.

A WMN is treated as a graph G (V,E), where ‘V’ is the set of vertices and ‘E’ is the set of edges. A CDS of a graph is a set ‘D’ of vertices with two properties:

- ✓ Any node in ‘D’ can reach any other node in ‘D’ by a path that stays entirely within ‘D’. That is, ‘D’ induces a connected subgraph of ‘S’.
- ✓ Every vertex in ‘S’ either belongs to ‘D’ or is adjacent to a vertex in ‘D’. That is, ‘D’ is a dominating set of ‘G’.

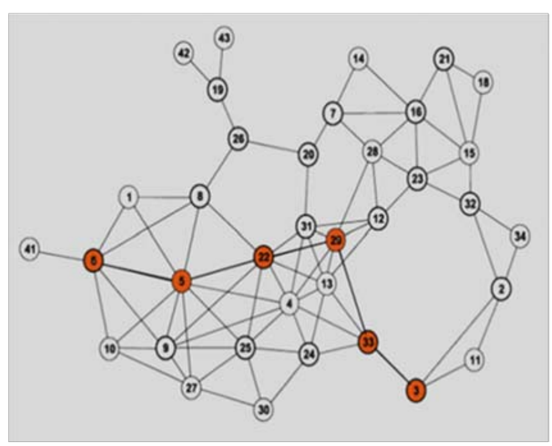

Fig. 2: Connected Dominating Set (CDS)

To minimize the number of hops, the smallest CDS is chosen as the backbone and every node is adjacent to this virtual backbone. Once data is received by a dominator, it is relayed through the MCDS towards the sink by minimum hop communication. Since the nodes have equal transmission range, the CDS should to be determined for UDG. The problem is known to be NP-hard and requires heuristics for the determination of the CDS [20].

CDS based routing includes dominating nodes. For instance, as shown in Fig. 2, if '6' is the source node and '3' is the destination node, the routing 6->8->22->29->33->3 is CDS routing, and the routing 6->8->22->31->29->33->3 is not because node 31 is not a dominating node.

5. Energy Efficient Linked Supervisory Set based Routing (E^2LS^2R) Scheme

In this paper, Energy Efficient Linked Supervisory Set based Routing (E^2LS^2R) Scheme is proposed. The backbone is selected based on the Residual Energy (RE) of the nodes.

The Residual Energy (RE_i) of all the nodes in the network is recorded after each transmission. RE is obtained by subtracting the energy consumed from the energy available before starting commencing transmission. The Priority (P_i) of node 'i' is assigned based on the amount of RE. Based on the priority, the node is selected and added to the backbone. Vertices with RE less than the threshold (τ) cannot be a member in a CDS.

The CDS of the original graph is found. To reduce the size of CDS obtained, the graph is pruned based on the RE.

6. Implementation

In this section, the results obtained after simulation using ns2 are discussed. The PHY layer performance metrics and the simulation parameters for the implementations are shown in Table 1.

Table 1: Simulation parameters

Parameters	Values
Area of Simulation	500 x 500
Number of nodes	20
Routing protocol	AODV
MAC	802.11
Antenna Model	Omni-directional
Transmission speed	1.2Mbps
Bandwidth	20MB
RE Threshold (τ)	0.5 J

Packet Delivery Ratio (PDR), Throughput, Packet Loss Ratio and the energy consumed are compared with the existing CDS based scheme. Table 2 shows the performance comparison of both the schemes.

CDS based scheme yields 1.03 times less PDR when compared to the proposed E^2LS^2R scheme (Fig. 3).

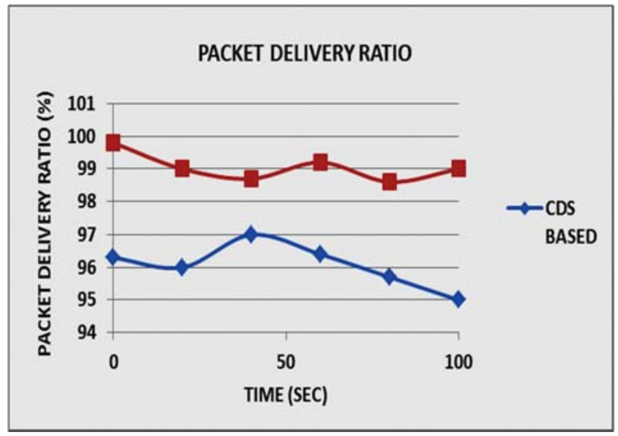

Fig. 3: Packet Delivery Ratio (PDR)

E^2LS^2R scheme yields 1.23 times more Throughput when compared to the CDS based scheme (Fig. 4).

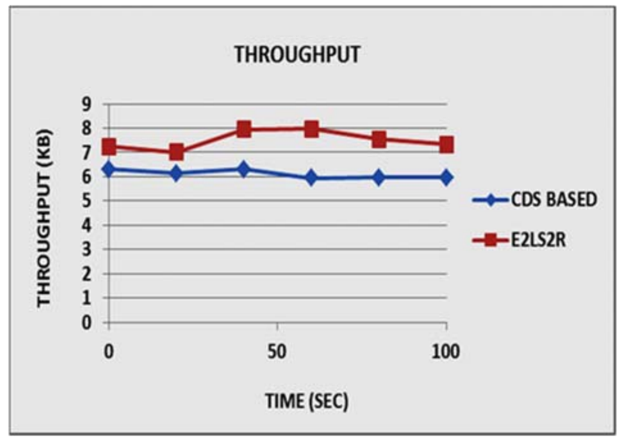

Fig. 4: Throughput

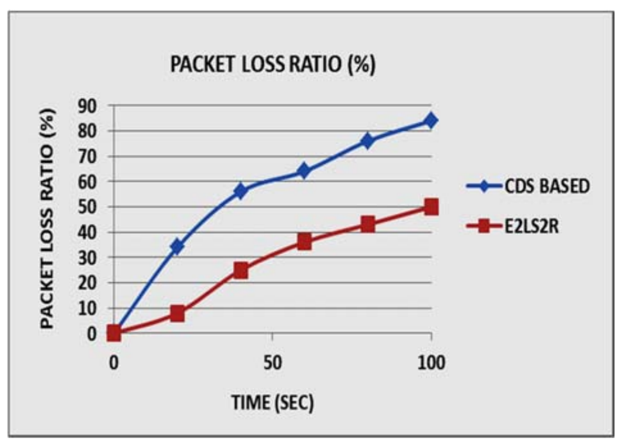

Fig. 5: Packet Loss Ratio

Similarly, CDS involves more 1.94 times more PLR when compared to the E^2LS^2R scheme (Fig. 5).

E^2LS^2R scheme involves 1.06 times less energy when compared to CDS based scheme (Fig. 6).

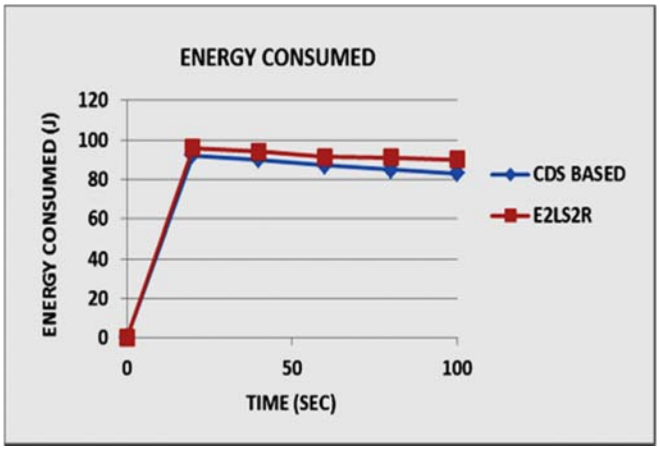

Fig. 6 Energy Consumed

Table 2: Performance comparison

Time (sec)	Packet Delivery Ratio (%)		Throughput (KB) × 10^3		Packet Loss Ratio (%)		Energy Consumed (J)	
	CDS BASED	E^2LS^2R	CDS BASED	E^2LS^2R	CDS BASED	E^2LS^2R	CDS BASED	E^2LS^2R
0	96.3	99.8	6.3	7.25	0	0	0	0
20	96	99	6.13	7.00	34	8	92	96
40	97	98.7	6.3	7.95	56	25	90	94
60	96.4	99.2	5.95	7.96	64	36	87	91.4
80	95.7	98.6	5.97	7.54	76	43	85	91
100	95	99	5.96	7.32	84	50	83	90
Average	**96.07**	**99.05**	**6.10**	**7.50**	**52.33**	**27**	**72.83**	**77.07**
Performance improvement		**1.03**		**1.23**		**1.94**		**1.06**

7. Conclusion

In this paper, an energy based routing scheme is proposed for WMNs. The network lifetime is increased as the virtual backbone of WMN is built from nodes with high energy reserve. The scheme outperforms the existing system in terms of PDR, PLR, throughput and amount of energy consumed.

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