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Review on Routing Algorithms in Wireless Mesh Networks

K.P. Vijayakumar[1], P. Ganeshkumar[2] and M. Anandaraj[3]
[1,2,3]Department of IT, PSNA College of Engg. & Tech., Dindigul, TamilNadu, India
[1]kalkivijay@rediffmail.com

***Abstract*— Wireless mesh networks (WMNs) have emerged as a key technology for next-generation wireless networking. This paper focuses on a variety of routing protocols that are used in wireless mesh networks and identify the performance of these routing protocols. The performance is done with regards to load balancing, packet delivery ratio, congestion, network overhead, throughput and mobility of nodes.**

***Index Terms*—WMN, Routing Protocols, Proactive, Reactive and Hybrid**

I. INTRODUCTION

WIRELESS Mesh Networks (WMNs) are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity [1]. Wireless mesh networks offer advantages over other wireless networks; these include easy deployment, greater reliability, self-configuration, self healing, and scalability.

If WMNs are comprised of two types of nodes: Mesh routers and Mesh clients. Mesh routers have specific routing functions to support mesh networking. Mesh routers are not very mobile and they are considered as the mesh backbone for clients. Mesh routers have multiple wireless interfaces which can be built on either the same or different wireless access technologies. Mesh routers can be built based on dedicated computer systems such as Power PC and ARM (Advanced Risc Machines).Mesh clients have additional functions for mesh networking and can also work as routers. Mesh client has only one interface. Mesh clients have a higher variety of devices compared to mesh routers. They can be a laptop/desktop PC, pocket PC, PDA, IP phone, RFID reader, BACnet (building automation and control networks) controller [2].

Routing is an important factor to forward the data packet from source to destination node. The Wireless Mesh routing protocols can be divided into proactive routing, reactive routing and hybrid routing protocols.

In proactive routing protocols paths are established to all the destination nodes regardless of whether or not the routes are needed to transmit data. They are also called table-driven methods. Continuously evaluate routes to all reachable nodes and maintain consistent, up-to-date routing information. Thus the main advantage of proactive protocols is that nodes can quickly obtain route information and quickly establish a path. The proactive routing protocols [3] are Destination-Sequenced Distance-Vector Routing (DSDV), Cluster Head Gateway Switch Routing (CGSR) [6], Optimized Link State Routing Protocol (OLSR) and Scalable Routing using heat Protocols.

In reactive routing protocols, routes are established on demand. Reactive methods are also called on-demand methods. The route discovery process is initiated when the source node requires a route to a destination node. The discovery procedure terminates either when a route has been found or no route available after examination for all route permutations. In mobile networks active routes may be disconnected due to node mobility. In WMNs node mobility is very minimal, so reactive routing protocols have better scalability than proactive routing protocols. The reactive routing protocols [3] are Dynamic Source Routing (DSR) protocol, Adhoc On Demand Distance Vector (AODV) protocol, Link Quality Source Routing Algorithm (LQSR) protocol and Temporally Ordered Routing Algorithm (TORA).

Hybrid Routing Protocols combines the merits of proactive and reactive routing protocols by overcoming their demerits and find efficient routes, without much control overhead It employs diverse routing protocols in different part of the infrastructure WMNs i.e. reactive protocols for the ad hoc network area while proactive protocols are employed in wireless backbone [5].

Routing is an important factor to forward the data packet from source to destination node. To guarantee good performance, routing metrics must satisfy these general requirements are scalability, reliability, flexibility, throughput, load balancing, congestion control and efficiency. The routing metrics for mesh routing protocols are [5] Hop Count, Blocking Metrics, Expected Transmission Count (ETX), The Expected transmission time (ETT), The Weighed Cumulative ETT (WCETT) [4], MIC,EETT, WCETT-LB, ALARM, iA-WARE, Adv-iAWARE, Adv-ILA, LAETT.

The rest of the Paper is organized as follows. Section II describes proactive routing protocols include DSDV, CGSR, OLSR and Scalable Routing using heat Protocols. Section III describes reactive routing protocols include DSR, AODV, LQSR and TORA. Hybrid routing protocol is described in Section IV. We finally conclude this paper in section V.

II. PROACTIVE ROUTING PROTOCOLS

A. Destination Sequenced Distance Vector

Destination Sequence Distance Vector (DSDV) protocol is based on Bellman – Ford routing algorithm where each node maintains a routing table that contains the shortest path to every possible destination in the network and number of hops to the destination as shown in Fig.1.The sequence numbers allows the node to distinguish stale routes from new ones and avoid routing loops. A new broadcast route contains

--Destination Address

--Number of hops to reach the destination

--Sequence number of the information about the destination and a new sequence number unique to broadcast.

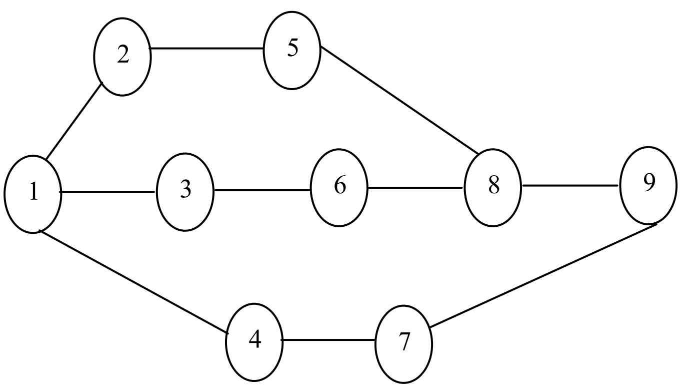

Fig. 1. DSDV Routing Protocol in Network

Updates in the routing tables are done periodically to maintain table consistency. The routing table consisting of Destination address, Next Node, Metric (Number of Hops) and Sequence number as shown in the Table I.

TABLE I
ROUTING TABLE AT NODE 1

Dest.	Next Hop	Metric (Hops)	Seq. No.
1	1	0	29
2	2	1	48
3	3	1	17
4	4	1	22
5	2	2	57
6	3	2	84
7	4	2	96
8	3	3	143
9	4	3	198

The table updates are two types: Full Dump and Incremental update. The first approach carries all available routing information and can require multiple Network Protocol Data Unit (NPDU). The next approach, which carries only the change in information since the last update.

B. Clusterhead Gateway Switched Routing

Clusterhead Gateway Switched Routing protocol uses DSDV as an underlying protocol. is a hierarchical routing algorithm. In CGSR, number of nodes are formed into clusters and each cluster uses a cluster head (CH) which control a group of wireless nodes and hence achieve a hierarchical framework for code separation among clusters, channel access, routing and bandwidth allocation. Once cluster is formed then distributed algorithm is invoked to elect a cluster head in every cluster as shown in Fig.2. Cluster head can be replaced frequently which affect the performance as nodes spend more time selecting a CH rather than relaying packets. To overcome this shortcoming, the Least Cluster Change (LCC) cluster algorithm is used. In LCC, CHs only change when tow CHs come into contact or one of the node moves out of range with all other CHs. In CGSR, each node maintains Cluster Member Table (CMT) and Routing Table to determine the nearest CH along the route to the destination and the next node required to reach destination CH.

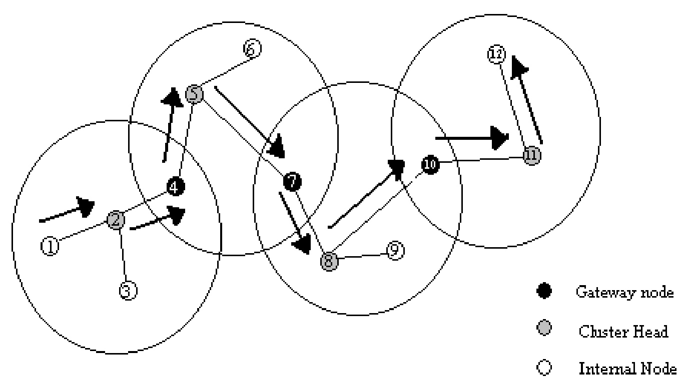

Fig. 2. Routing in CGSR form node 1 to 12

As shown in Fig. 2, when sending a packet, the source (node 1) transmits the packet to its clusterhead (node 2). From the clusterhead node 2, the packet is sent to the gateway node (node 4) that connecting to this clusterhead (node 2) and the next clusterhead (node 5).From the clusterhead node 5, the packet is sent to the gateway node (node 7) that connecting to this clusterhead (node 5) and next clusterhead (node 8) along the route to the destination (node 12). The gateway node (node 10) sends the packet to the next clusterhead (node 11), i.e. the destination cluster-head. The destination clusterhead (node 11) then transmits the packet to the destination (node 12).

A Wireless Mesh Network is divided into multiple clusters for load control. A cluster head estimates traffic load in its cluster. As the estimated load gets higher, the cluster head increases the routing metrics of the routes passing through the cluster. Based on the routing metrics, user traffic takes an alternative route to avoid overloaded areas, and as a result, the WMN achieves global load balancing. The CGSR effectively balances the traffic load and outperforms the routing algorithm using the expected transmission time (ETT) as a routing metric [6].

C. Optimized Link State Routing

Optimized Link State Routing (OLSR) is a proactive routing protocol [7]. Each node broadcasts its link state information to all other nodes in the network. OLSR operation mainly consists of updating and maintaining information in 1- hop, 2 –hop neighbor table and routing table. OLSR uses hello messages for link state information. Multi Point Relays (MPR) is important aspect of the OLSR protocol. An MPR for a node N is a subset of neighbors of N which broadcast packets during the flooding process, instead of every neighbor of N flooding the network. When a node propagates a message, all of its neighbors are receive message. Only MPR which have not seen the message before again propagates the message. Therefore flooding overhead can be reduced.

OLSR uses three kinds of Control messages: Hello Messages, Topology control (TC) messages and Multiple Interface Declaration messages. HELLO messages are transmitted to all neighbors. These messages are used for neighbor sensing and MPR calculation. TC messages are the link state signaling done by OLSR. This messaging is optimized in several ways using MPRs. MID - Multiple Interface Declaration messages are transmitted by nodes running OLSR on more than one interface. These messages list all IP addresses used by a node.

D. Scalable Routing using HEAT Protocol

The HEAT algorithm is a fully distributed, proactive any cast routing algorithm. It is inspired by the properties of temperature fields .HEAT has two unique features [8]. First, the routing is decided based on length and robustness of the available path. Second, the field construction and maintenance mechanism of HEAT scales to the number of nodes and the number of gateways, as it only requires communication among neighboring nodes.

HEAT protocol assigns a temperature value to every node in the mesh network. New nodes are assigned a value of zero and gateway nodes are assigned a well-defined maximum value. This protocol determines the temperature of node based on

--Distances to the available gateways

--Robustness of the paths towards these gateways

That is, a path providing multiple alternative delivery opportunities along its way is preferred to a path over which packets cannot naturally be re-routed to an alternative path to one of the gateways. The Performance of the HEAT protocol [8] is better in wireless mesh networks in terms of packet delivery ratio than the OLSR and AODV.

III. REACTIVE ROUTING PROTOCOLS

A. Dynamic Source Routing

The Dynamic Source Routing protocol (DSR) is reactive routing protocol which is based on source routing. The protocols works in two phases: route discovery and route maintenance. When a node wants to send a data then DSR initiates route discovery. In route discovery, the source node looks at the route cache for destination route. If the route exists then send the data. Otherwise it broadcast the Route Request Packet (RREQ) to its neighbors until it reaches the destination as shown in the Fig. 3(a). The RREQ Packet contains the source address, destination address, route id and a route record as shown in the Fig. 3(b). When the request reaches destination, a route reply (RREP) is sent back to the source node via the recorded route which has the minimum number of hops as shown in the Fig. 3(c). In route maintenance, the route error packets are generated at a node during fatal transmission problem.

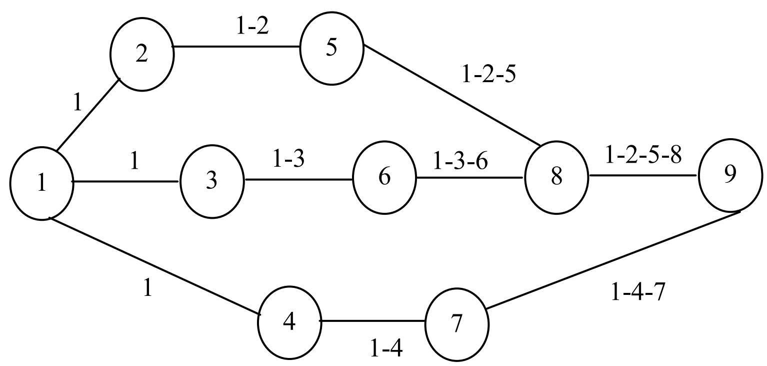

Fig. 3(a). Broadcast Route Request from source node 1 to destination node 9

SID	DID	Route Record	Route ID

Fig. 3(b). Route Request packet header

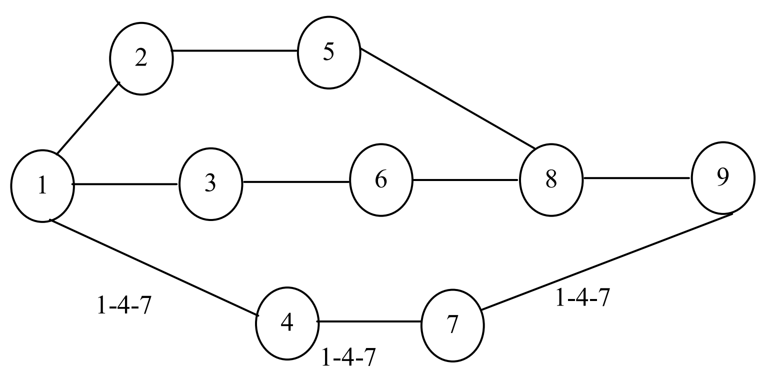

Fig. 3(c). Route Reply from destination node 9 to source node 1

The modifications in DSR protocol [9], in which congestion in the network is controlled and throughput is increased by reducing the number of route request packets.

B. Ad hoc On Demand Distance Vector Routing

Ad hoc On Demand distance Vector Routing (AODV) protocol is reactive protocol which is built over the DSDV. AODV is pure on demand route acquisition algorithm. When a node wants to send a data then that node looks at the route cache for destination route. If the route exists then send the data. Otherwise it broadcast the Route Request Packet to its neighbors until it reaches the destination as shown in the Fig. 4(a). The Route Request Packet contains the source address, destination address, source sequence number, broadcast id and the most recent sequence number of source and destination node.

When the request reaches destination, a route reply (RREP) is sent back to the source node via the route from which the destination receive first copy of the RREQ as shown in the Fig. 4(b). Hence the AODV finds route which is fastest and shortest.

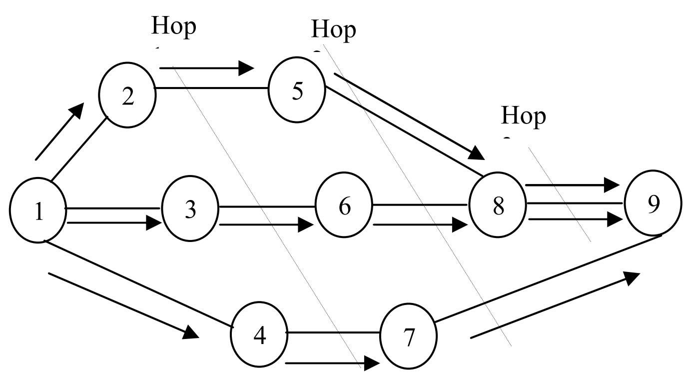

Fig. 4 (a). Broadcast Route Request from source node 1 to destination node 9

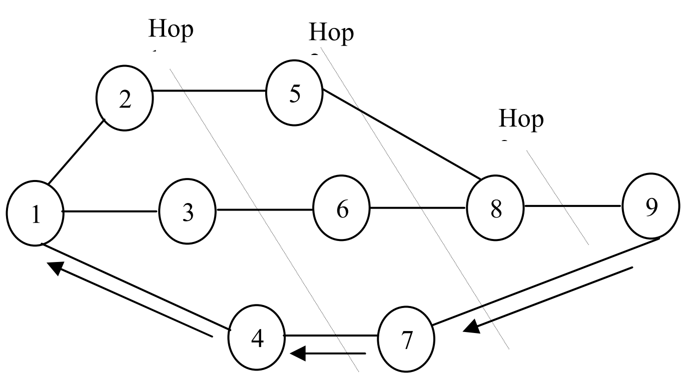

Fig. 4(b). Route Reply from destination node 9 to source node 1

The ad hoc on-demand distance vector (AODV) with DF (AODV-DF) [10] can significantly reduce routing overhead and increases the performance by reduce the number of route request (RREQ) packets broadcast by using a restricted directional flooding technique.

C. Link Quality Source Routing

Link Quality Source Routing (LQSR) is a reactive protocol for wireless mesh networks developed by Microsoft Research Group [11]. LQSR is source routed link state protocol derived from DSR for improving link quality metrics and other related metrics. The metrics are hop count, round trip latency (RTT), packet pair latency and Expected Transmission Count (ETX).To improve the link quality, and LQSR uses link cache instead of route cache. When a node wants to send a data then that node looks at the link cache for destination route. If the route exists then send the data. Otherwise it broadcast the Route Request Packet to its neighbors until it reaches the destination. When a node receives a route request (RREQ) packet [3], it will add link quality metric for the link over which packet had arrived. When a Source node receives route reply (RREP) packet, it includes link quality information and node information. LQSR sends Hello message to its neighbors for link state information which is used to measure the link quality at each node for the link on which this message was received. All these messages are based on piggybacked approach.

D. Temporally Ordered Routing Algorithm

The Temporally Ordered Routing Algorithm (TORA) is a loop free, highly adaptive, efficient and scalable distributed routing algorithm for wireless networks. TORA uses destination oriented routing information that is already available at each node. Nodes only need to know their one-hop neighborhood. By the information of the neighbor TORA builds independently local routing information for each destination node. TORA also exhibits multipath routing capability. Directed Acyclic Graph (DAG) is maintained by each node to every destination. When source node wants to send data to destination node then it broadcasts a Query packet which containing the destination address as shown in the Fig. 5(a).

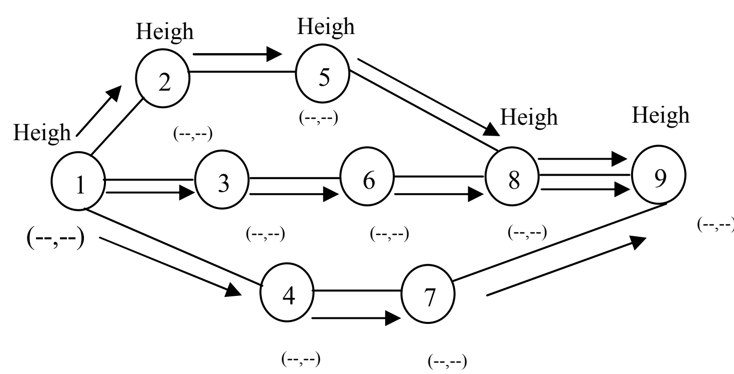

Fig. 5 (a). Propagation of Query message

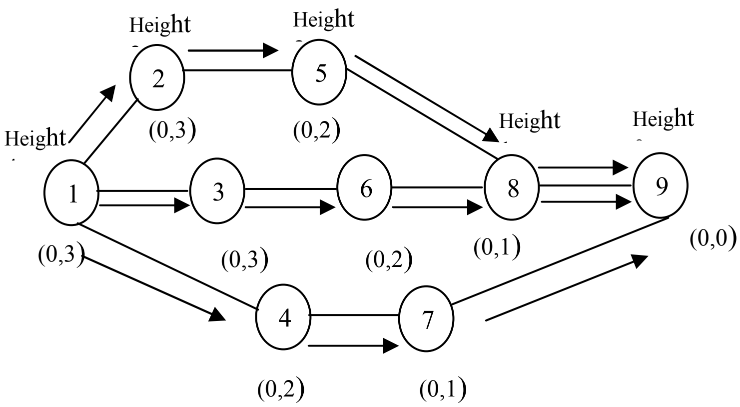

Fig. 5(b). Node's height updated as a result of update message

Destination node responds with an Update message as shown in Fig. 5(b). The average end to end delay for TORA is fair and performs better under high mobility simulations than DSDV [12] since DSDV is not on demand protocol.

IV. HYBRID PROTOCOL

Zone Based Routing Protocol (ZRP) is a hybrid protocol, which take advantage of best of proactive and reactive protocols. A node's local neighborhood is known as a routing zone. A node's routing zone is defined as the set of nodes whose minimum distance in hops form the node is no greater than the zone radius. To construct a routing zone, the node has to identify all its neighbors first which are one hop away and can be reached directly. The neighbor discovery process is managed by the Neighbor Discovery Protocol (NDP). ZRP [13] uses two routing methods: Intra Zone Routing Protocol (IARP) and Inter Zone Routing Protocol (IERP).The IARP is responsible for maintaining routes to all destinations in the routing zone proactively. The IERP is responsible for discovering and maintaining the routes to nodes beyond the routing zone reactively.

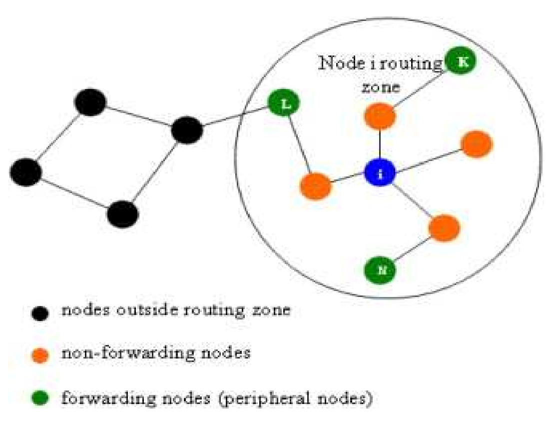

Fig. 6. Zone Routing Protocol

The selected hop distance is 2; thus, the peripheral nodes are located 2 hops away from node i. The routing zone of node i contain 1-hop and 2-hop neighbors as shown in the Fig. 6.

V. CONCLUSION

Routing Protocol is an important component of communication in Wireless Mesh Networks. In this paper, we have presented theoretical details of Proactive routing protocols like DSDV, CGSR, and OLSR and Scalable Routing using heat Protocols. We have also presented theoretical details of reactive routing protocols like DSR, AODV, LQSR and TORA protocols and hybrid protocol such as ZRP. The variety of routing protocols for wireless mesh networks are compared using metrics as shown in Table II. So we can select an effective protocol, depending up on the network and other conditions. This paper aims to provide a straightforward guide to the researcher for those who are interested to carry out their research in the field of WMN.

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Table II: Comparison of Routing Protocols for Wireless Mesh Networks

Routing Protocols	Type of Protocol	Routing Metrics	Mobility	Loop Free	Scalability	Reliability	Load Balancing	Congestion control	Throughput	Location aware
DSDV [14]	Proactive	Shortest Path	Yes	Yes	No	Yes	No	No	Decreases with mobility	No
CGSR [6]	Proactive	Shortest Path via CH	Yes	Yes	Yes	Yes	Yes	Yes	Decreases with mobility	No
OLSR [7]	Proactive	Shortest Path	Yes	Yes	No	Yes	No	No	Better compared to DSDV	No
Scalable Routing [8]	Proactive	Hop count	Yes	Yes	Yes	Yes	No	No	Yes	No
DSR [9]	On demand	Shortest Path	Yes	Yes	No	Yes	No	Yes	Decreases with mobility	No
AODV [10]	On demand	Fast and Shortest path	Yes	Yes	No	Yes	No	Yes	Decreases with mobility	No
LQSR [11]	On demand	Hop Count, RTT, ETX	Yes	Yes	No	Yes	Yes	Yes	Yes	No
TORA [12]	On demand	Hop count	Yes	Yes	Yes	Yes	No	No	Better compared to DSDV	No
ZRP [13]	Hybrid	Shortest path (zone)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

K.P. Vijayakumar received his B.E. degree in Information Technology from Madurai Kamaraj University (India) in 2003, his M.E. degree in Computer Science and Engineering from Anna University Chennai (India) in 2007, and doing Ph.D. degree in Information and Communication Engineering at Anna University, Chennai. He has been working as an Associate Professor in the Department of Information Technology at PSNA College of Engineering and Technology, India since June 2003. His research interests include computer networks, particularly in network optimization, Wireless network and ADHOC Network.

Dr. P. Ganeshkumar is a Professor in the Department of Information Technology at PSNA College of Engineering and Technology, India since December 2002. He received his B.E degree in Electrical and Electronic Engineering from Madurai Kamaraj University, India in 2001, his M.E. degree in Computer Science and Engineering from the Bharathiyar University (India), and his Ph.D. in Information and Communication Engineering at Anna University, Chennai. His research interests include ADHOC Network, Wireless Networks and Distributed Systems.

M. Anandaraj received his B.E. degree in Computer Science and Engineering from Madurai Kamaraj University (India) in 2003, his M.E. degree in Computer and Communication from Anna University Chennai (India) in 2007, and doing Ph.D. degree in Information and Communication Engineering at Anna University, Chennai. He has been working as an Associate Professor in the Department of Information Technology at PSNA College of Engineering and Technology, India since June 2003. His research interests include computer networks, particularly in network optimization, multicast algorithm design, network game theory and network coding.