"Performance and Scalability of OSPF in MANETs: Impact of Node Placement Strategies Using OPNET"

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***Abstract*—The research studies how different node position schemes affect Open Shortest Path First (OSPF) routing performance in Mobile Ad Hoc Networks (MANETs) using OPNET to assess scalability characteristics. Network performance in MANETs requires efficient adaptive routing since these networks operate under free infrastructure and dynamic node configurations. The OSPF protocol received modifications through MANET Designated Router extensions which improve its operation in mobile frameworks. The deployment arrangement of nodes as random, grid or circular formats directly affects OSPF routing performance along with control operations and the overall scalability capability in mobile ad hoc networks.**

The performance of OSPF through simulation with OPNET allows users to evaluate effects from deployment models and process node density together with mobility patterns and network size impacts on end-to-end delay and throughput measurements. OSPF in MANETs achieves improved scalability and stability when operated through structured random, grid and circular deployment models that both lower route update frequency and control message flooding rates. Random distribution methods enable networks to produce multiple connection types and flexible routing behavior thus improving network flexibility with growing network dimensions. The investigation proves the essential role of choosing appropriate node deployment methods for improving OSPF scalability within MANETs which can lead to better practical application outcomes in military operations and emergency response situations as well as mobile sensor networks.

***Index Terms*—Manets, OSPF Routing Protocol, scalability, OPNET Simulator.**

I. Introduction

A Mobile Ad Hoc Networks (MANETs) operate as decentralized networks which use mobile nodes that function without requiring either prior infrastructure or centralized administration for their communication purposes. The shifting network structure creates specific obstacles for routing protocols because these protocols need to function effectively under changing network topology and mobile node behavior. OSPF stands out among other network routing protocols with its superior data routing capabilities for extensive network environments. The original fixed network OSPF protocol now includes MANET Designated Router (MDR) modifications to enhance its functionality in mobile environments.

The performance results of OSPF routing depend heavily on the selection of node deployment model within MANETs. Network connectivity together with routing efficiency and scalability are powerfully influenced by the deployment strategies which consist of random, grid and clustered arrangements. Uncertain implementation of nodes disrupts network topology and connectivity which causes control operations to waste more resources and slow down overall performance. The use of grid or cluster-based deployment structures leads to foreseeable node placement patterns which creates better routing performance along with improved efficiency. The ability to scale up comes under strict scrutiny in MANETs because network size and node density tend to increase immediately. MANET performance decreases while congestion increases when a MANET contains more nodes because numerous control messages such as Link-State Advertisements (LSAs) accumulate. OSPF's scalability depends on node deployment models' effects which determine the ability to build resilient military and disaster response and mobile sensor network applications.

The research examines OSPF routing protocol efficiency in MANETs through an evaluation of different network deployment models running on the OPNET simulation platform. Our research utilizes different simulation models including multiple node densities and mobility behaviors and deployment methods in order to determine OSPF performance optimization.

II. Literature Review

The routing protocols that run in Mobile Ad Hoc Networks (MANETs) demonstrate performance changes based on the deployment models used in their networks. Various studies have researched how these models influence the scalability and efficiency of the Open Shortest Path First (OSPF) routing protocol.

The performance results from different deployment strategies such as random, grid and clustered deployment models vary significantly. Random placement of nodes without particular positioning results in irregular network connectivity along with excessive routing operations. Random network deployment leads to worsening network performance according to Gupta and Kumar [1] when the number of nodes rises while OSPF struggles to spread its control information correctly. The protocol scalability faces complications because end-to-end delays become longer and packet delivery performance deteriorates in such situations.

The grid-based models create better network connectivity enhancements with reduced control message overhead from routing protocols compared to other deployment approaches. Grid-based deployment systems benefit the OSPF protocol according to Younis et al. because they create regular node distributions which produce faster routing and reduced LSA advertisement flooding. The research indicates that the system of grid deployments leads to enhanced scalability benefits in expanded network infrastructures.

The deployment of clusters allows OSPF to achieve higher performance through the local reception of control traffic. According to Heinzelman et al. [3], OSPF network scalability increases signficantly through the implementation of hierarchical clustering for routing update frequency reduction. Groups of organized nodes under cluster heads lessen the amount of OSPF control overhead while providing enhanced routing performance and stability in the network. OSPF faces significant scalability issues when operating in MANETs because node densities and mobilities rise. Ogier et al. [4] proposed the MANET Designated Router (MDR) as a solution to address OSPF scalability problems. Their research demonstrated MDR deployment as a solution to decrease the spread of LSA flooding thus increasing OSPF resistance in dense network environments.

The OPNET simulator serves as an important tool which enables researchers to assess OSPF performance within different node deployment configurations. Li and Prabhakaran employed OPNET to study OSPF network performance resulting in superior end-to-end delay and packet delivery success using grid and clustered topologies than random infrastructure choices [5]. The research outcomes demonstrated that correct placement of network nodes contributes to optimal functioning of OSPF within mobile ad hoc networks.

The research conducted by Zhang et al. [6] investigated deployment strategies that unite structured and random placement characteristics. Portions of their simulation showed that OSPF performance benefits from hybrid deployment strategies which allow scalable and efficient routing while achieving the best elements from structured and random approaches especially within dense and dynamic conditions.

Performances of OSPF routing in MANETs heavily depend on the selection of node deployment models according to existing research. The random placement approach introduces scalability and efficiency problems but grid and clustered deployment structures minimize network control costs and enhance connectivity network performance. The OPNET simulator demonstrates important findings about these network mechanisms which prove that effective deployment strategies must be implemented to improve OSPF scalability in dynamic network environments.

III. Routing Protocols in Manets

Efficient communication between mobile nodes depends on routing protocols within Mobile Ad Hoc Networks (MANETs) because of the nodes' constant positional changes. Routing protocols for MANETs need to adjust their operations as MANET topology shifts rapidly alongside changing network conditions. ARTs (Ad-hoc networks routing) contain three fundamental classes of routing protocols including proactive, reactive and hybrid networking models.

Proactive Routing Protocol

The routing protocols refresh their network parameters through periodic control signal exchanges even when no data needs transmission. These protocols build and sustain routing tables which contain paths leading to every node accessible within the network. Examples include:

1. **Destination-Sequenced Distance Vector (DSDV):** The protocol functions using tables while implementing distance vector routing algorithm logic. Each network device stores routing information about destination hosts through a table that shows their next hop location and distance to each destination. The update process in DSDV operates when changes occur within network topology and employs sequence numbers to stopn routing loops [7].
2. **Optimized Link State Routing (OLSR):** By using Multipoint Relays OLSR optimizes its control message flooding operation. Control messages travel through MPRs as their main function which helps lower transmission costs in the entire network system [8].

Reactive Routing Protocol

When routing protocols become active, they create network paths only upon demand thus reducing system control information traffic in the network. The route discovery process starts when a node requires to transfer data to a destination. Key examples include:

1. **Ad hoc On-Demand Distance Vector (AODV):** The route discovery mechanism inside AODV determines how to establish communication paths to destinations. RREQ messages trigger by AODV whenever no route exists then intermediate nodes answer with RREP messages in response. The technique establishes routes minimally to prevent additional expenses [9].
2. **Dynamic Source Routing (DSR):** With DSR nodes acquire automatic route detection abilities through route maintenance functionality. Each data packet contains complete route information through source routing. Due to its design the system does not require routing table maintenance thus cutting down control overhead [10].

Hybrid Routing Protocol

Network conditions determine how hybrid routing protocols use proactive and reactive protocol features to find maximum optimization. An example is:

1. **Zone Routing Protocol:** (ZRP) organizes the network into separate zones since proactive routing functions inside each zone whereas reactive routing manages inter-zone communications. The integration of proactive and reactive protocols in this approach enables selection between the overhead consequences of proactive routes and the benefits of demand-based reactive routes [11].

Performance Considerations

Manet performance depends heavily on selecting the appropriate routing protocol because it determines metrics including throughput and end-to-end delay and packet delivery ratio. The literature demonstrates that proactive protocols work best in networks featuring low mobility together with stable conditions yet reactive protocols deliver better outcomes in high-dynamic environments which undergo multiple topology changes. Adaptive routing protocols implement hybrid systems that offer mixed implementations between reactive and proactive protocols according to changing network conditions [12].

IV. OSPF-V3 History

OSPFv3 represents an upgraded version of Open Shortest Path First that efficiently operates with Internet Protocol version 6 protocols to support larger IP address ranges. OSPFv3 development emerged as a response to growing IPv6 adoption since this new network protocol solved the issues in IPv4 address space while adding advanced capabilities.

1. Evolution of OSPF

Moy released the first version of OSPF as OSPFv1 through RFC 1131 during 1989 [13]. OSPF emerged as an AS internal routing protocol that gained primacy status as the IGP after its successful implementation due to its optimized scalability. The enhanced version of OSPFv2 received its definition in RFC 2328 in 1998 while delivering improvements including expanded network capabilities and route summarization as well as authentication features [14].

2. Need for OSPFv3

The late 1990s implementation of IPv6 required routing protocols to adapt their systems for IPv6 address support. The IETF developed OSPFv3 after finding that OSPFv2 exclusively worked with IPv4 networks. OSPFv3 pursued three primary objectives that involved supporting IPv6 routing alongside keeping link-state protocol features while enabling IPv4 and IPv6 networks to interoperate.

3. OSPFv3 Development and Standardization

The IETF OSPF Working Group established OSPFv3 as a result of its development process. OSPFv3 received its official specifications in RFC 5340 when the document became publicly available in July 2008. Specific operational principles for IPv6 networks together with OSPFv2 concept backward compatibility are included in the RFC which describes the protocol's configuration along with operation [15].

These are the critical features which OSPFv3 presents:

a) OSPFv3 manages IPv6 addressing natively which means it does not require address families thus resulting in an easier routing process.
b) Link-Local Addresses in OSPFv3 routers require the use of these specific addresses to establish communications that boost security measures and minimize address conflicts [16].
c) OSPFv3 features an upgraded packet structure which includes the IPv6 header for creating efficient route processing and update operations.
d) OSPFv3 provides stronger authentication services through built-in IPsec mechanisms in IPv6 than the various authentication methods present in the original OSPFv2 framework.

4. Adoption and Use Cases

The adoption of OSPFv3 spread widely throughout networks for IPv6 routing purposes after its original deployment. Multiple routing solutions now implement OSPFv3 because it constitutes an essential requirement for organizations converting their networks from IPv4 to IPv6. The successful deployment of OSPFv3 takes place in enterprise networks along with service provider networks and data centers because routing efficiency and network scalability matter highly to these environments. OSPFv3 represents a major development in routing protocol evolution that implements IPv6 support while keeping the fundamental features which established OSPF as successful. The future of Internet routing depends heavily on OSPFv3 because the industrial migration toward IPv6 continues.

V. Simulation Environment

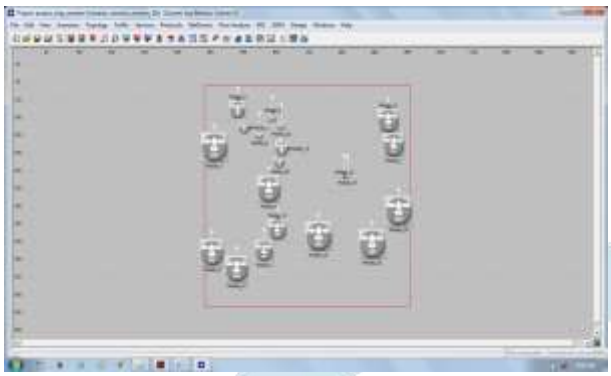
Networked framework or protocol validation can be carried out through mathematical modeling in addition to simulation and hybrid approaches incorporating simulation and mathematical modeling while test-bed emulation serves as another method [17]. When modeling calculations serve as the fastest methodology it leads to errors and impracticalities during analysis of complex multiple factor systems. Simulation effectively represents how modeling devices interact with each other by creating complete packet-by-packet descriptions of network operations. Hybrid modeling has become a common solution to handle simulation's computational needs because it combines mathematical models with simulation techniques to evaluate network conduct. Test-bed emulation requires deploying new frameworks alongside specific protocols to actual hardware-based equipment. Tests with real devices provide authentic network information yet tend to be expensive and may trigger unexpected engineering problems.

The Optimized Network Engineering Tools (OPNET) functions as a dominant industrial and academic commercial discrete event simulator [17]. OPNET implements object-oriented principles through its hierarchical modeling structure which makes network behavior emulation possible. A network model in OPNET includes diverse node models made up of processes and transmitters alongside receivers. A process model within OPNET designs a simulated node behavior through a state transition diagram that shows lifecycles notable events and conditions. OPNET provides an extensive collection of predefined network devices and protocols that contains routers and switches with both fixed and mobile wireless workstations. OPNET extends the C programming language with state transition diagrams to offer users the Porto-C language which specifically aids process model creation and implementation. Users possess the capability to expand the functionality of current OPNET models through C++ coding. Users can inspect flows of packets and study mobile node movements by using the debugging tool known as the OPNET Debugger (ODB) integrated within the platform.

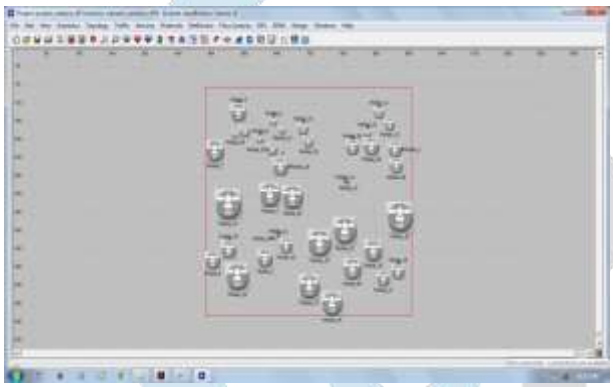
The main purpose of this simulation evaluation is to examine OSPF routing protocol performance while utilizing different node placements which include Grid, Random and Random Movement. Users can organize the nodes in multiple patterns before allowing their autonomous movement. OPNET version 14.5 enables wireless network simulation scalability through its software platform in conducting the tests.

The simulation model explores a zone with dimensions of 500 m × 500 m where both the number of nodes and their speed and pause time remain static but the source and destination nodes can change in quantity. Figures display the placement of nodes in the three network models with both 20 and 40 nodes intended for use in small to medium scenarios.

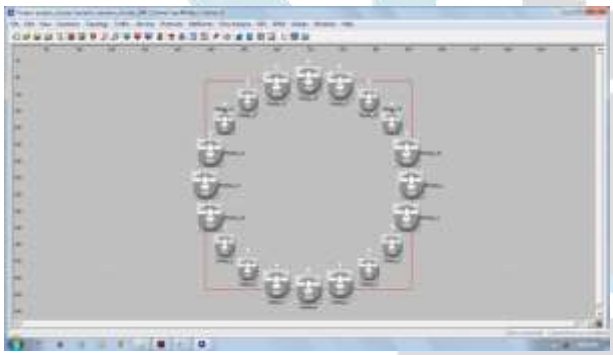
[1] Random Method (20 Nodes):



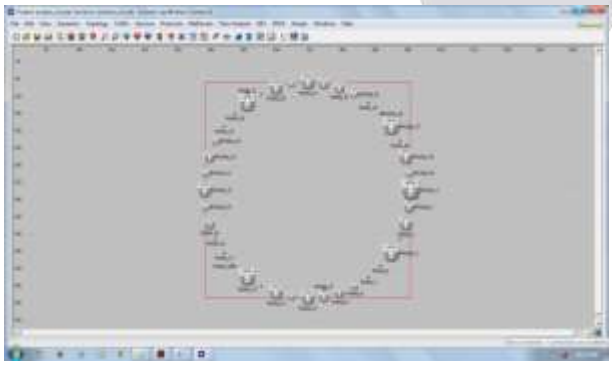
[2] Random Method (40 Nodes):



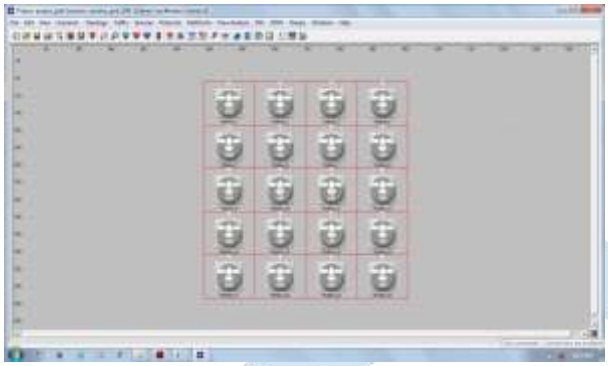
[3] Circular Method (20 Nodes):



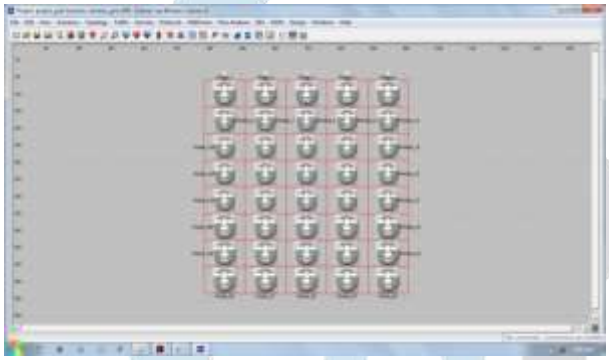
[4] Circular Method (40 Nodes):



[5] Grid Method (20 Nodes):



[6] Grid Method (40 Nodes):

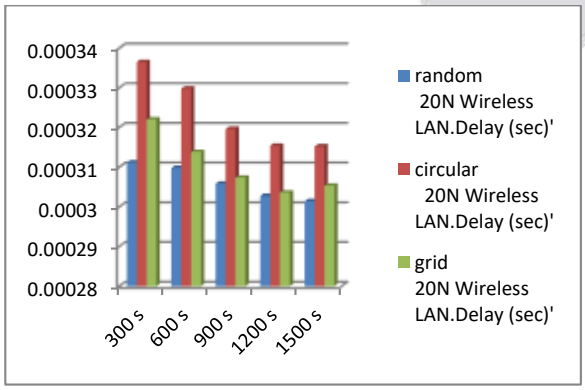


Area	50m x 50m
Nodes	20,40
Nodes Placement	Random, Grid, Circular
Mobility Model	Random Way Point
Node Transmission Power	0.005
Operational mode	802.11b
Data rate	11Mbps
Simulation time	300,600,900,1200,1500 sec
Defacto values set	MANET

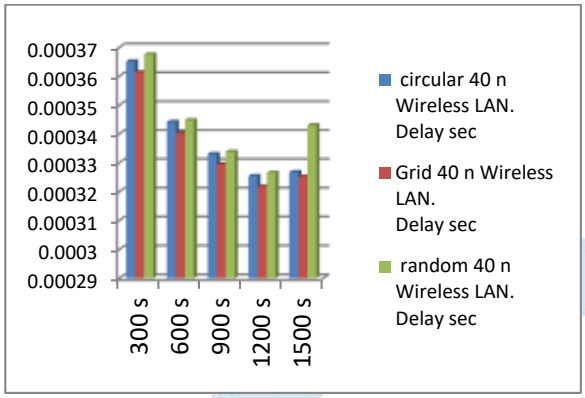
VI. RESULTS & DISCUSSION

1. **Average End-to-End Delay:** The average end-to-end delay measures the time taken for a packet to traverse from the source to the application layer at the destination. Figure illustrates how the average end-to-end delay varies with changes in the simulation time of mobile nodes.

A. Delay for 20 Nodes:

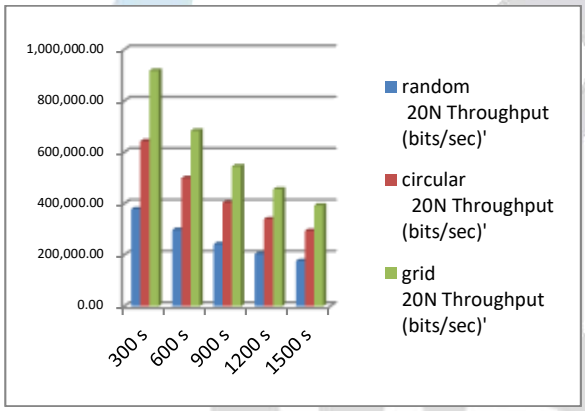


B. Delay For 40 Nodes:

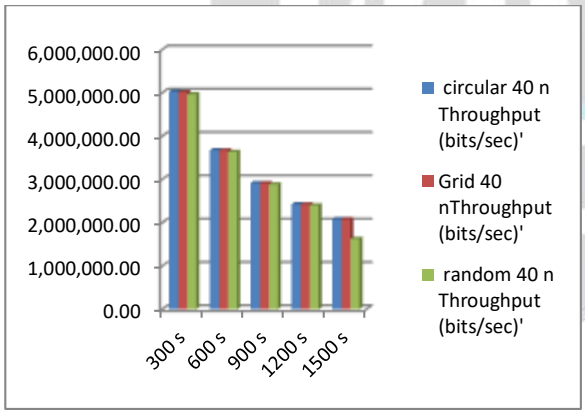


2. **Throughput:** Throughput is defined as the total amount of data received by the receiver R from the sender, divided by the time taken to receive the last packet. Figure demonstrates the variation in throughput with changes in simulation time for both 20 nodes and 40 nodes.

C. Throughput For 20 Nodes:



D. Throughput For 40 Nodes:



VII. Replica of above Scenario in Cisco Packet TRACKER:

Three routing approaches named Static and Dynamic and D-Overload are put into practice during this project. the administrator configures all network paths as part of Static routing because it relies on manual prespecified forwarding information. The static routing configuration includes four nodes numbered from 0 to 4 together with two switches and two routers. All the devices remain connected by using copper straight cables. The project consists of two switches named Switch0 and Switch1 which correspond to all four nodes starting at node0 through node4. The network uses Router0 as well as Router1 devices connected through a serial Data Terminal Equipment cable.

The data transmission from Switch1 starts at 0.949 seconds yet Switch0 begins its data transmission at 0.954 seconds. The configuration enables rapid communication as well as quick data transfers among all linked devices. The network deployment consists of router 0 linking with switch0 and nodes 0,1,2,4 while router1 connects with switch 1 and node3. Routers use dynamic routing as an automatic approach for developing routes by sharing network updates between devices to make routing adjustments. The configuration includes four nodes numbered 0 to 4 which connect to two switches together with two routers. Copper straight cables serve as the interconnection components between all devices. The network elements include switch0 and switch1 as well as node identifiers ranging from node0 through node4. The routers are named Router0 and Router1 while they connect through a serial DTE cable.

The time when Switch1 starts packet transmission begins at 1.50 seconds while Switch 0 begins its packet transmission at 2.34 seconds. The establishment of this system allows connected devices to share information with maximum speed and efficiency. Both the router 0 connects to switch0 as well as nodes0,1,2,4 and router1 links to switch 1 and node3. An excess of data traffic or requests will overwhelm hardware or software equipment which leads to reduced performance and possible system collapse (D-Overload). The D-OVERLODE routing configuration includes four nodes starting from 0 to 4 while using two switches and two routers. The connected devices share an interconnection established through copper straight cables. Both switches maintain the names switch0 and switch1 and the nodes retrieve designations between node0 through node4. A serial DTE cable connects router0 and router1 which are the names of these routers. The packet transmission from switch1 starts at 5.45 seconds followed by switch0 starting its packet transmission at 5.78 seconds. The setup promotes an effective transfer of information and data between the joining devices. The router 0 establishes connections between switch0 and nodes0 through 2 and 4 while router 1 operates through switch 1 to reach node3.

VIII. CONCLUSION:

Multiple node configurations serve as a basis for performance evaluation of OSPF, it shows maximum efficiency when operating in random networking conditions in Cisco Packet Tracker and also in opnet. Future investigation will analyze OSPF performance throughout different environments combined with mobile models under IPV16.

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