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Review / Survey

Mobile Ad-Hoc Networks: A Classification System for Routing Protocols

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ABSTRACT

In a Mobile Ad-hoc Network (MANET), all nodes are mobile, interconnected in varying patterns, and each node acts as a router, actively participating in route discovery and maintenance for communication with other nodes in the network, with the network topology constantly changing due to node mobility. Routing and broadcasting have been primary areas of research interest since the inception of commercial MANETs. Routing ensures the successful delivery of data packets from source to target nodes, while broadcasting is vital for addressing a range of network issues, including routing problems. This paper introduces a classification system for routing protocols that expands beyond the traditional categorisation of proactive, reactive, and hybrid methods. It identifies eight distinct groups to encompass a broader range of routing methodologies, ensuring the inclusion of significant approaches that may have been overlooked in the conventional classification. Further, the paper classifies power-aware routing protocols and highlights various broadcasting schemes, providing a comprehensive overview of both topics. Finally, the paper explores mobility models, categorising them and highlighting simulation platforms ns-2 and ns-3.

Keywords: MANETs, Routing, Broadcasting, Mobility Models, Classification, Power-aware, NS Simulators.

INTRODUCTION

Whether a network is wireless or not, routing is an essential task. However, the characteristics of routing schemes vary across different network types [1]. Different routing models used in MANETs have goals such as forwarding data, generating, selecting, and maintaining routes. With this, nodes act as routers. A typical routing algorithm's main responsibility is to make sure packets reach their endpoints successfully. Finding a series of intermediary nodes that can transmit data from the start point to the endpoint is how this is accomplished. A routing table is kept by each node and has a list of the next intermediaries for each designated ending point to which a packet is to be sent. Since the eighties, many routing algorithms have been modelled, with the majority predicated on wired or infrastructure-based networks. Even though the ultimate purpose of the designers was to cater to more extensive networks, most of these protocols were mainly developed for minute-sized networks.

Broadcasting is a critical dissemination method in multi-hop ad hoc networks, irrespective of the specific paradigm such as MANET, VANET, etc. While a straightforward process, broadcasting has garnered substantial research interest due to its significant impact on network performance. The primary objective of broadcasting approaches is to optimize network reach. Also, the choice of mobility models and network simulators plays a crucial role in implementing and evaluating the performance of protocols developed for MANETs.

The rest of this paper is organized as follows: Section 2 is related to works on routing. Section 3 introduces the power-aware routing protocols. Section 4 provides broadcasting, while section 5 presents mobility models. Section 6 provides highlights on the NS-2 and NS-3 simulation platforms, while Section 7 concludes the paper.

LITERATURE REVIEW

Features Desired When Designing Routing Protocols

When creating a routing scheme for MANETs, additional desirable characteristics that must be taken into account are listed [1]:

Users should experience the highest quality service from their use of the protocol during communication. For instance, when it involves data like audio or video.

Since the nodes have limited battery power, appropriate mechanisms should be taken to preserve energy. A typical example is the use of sleeping mode.

The algorithms employed in the design of the protocol should be free of loops. This would reduce the loss of data and network bandwidth.

The protocol should function in a distributed fashion. This would provide a better quality of service and experience.

Security should be taken into consideration so nodes do not become vulnerable to passive and active attacks. Data encryption and deciphering should be done carefully.

To reduce the waste of resources, nodes should be provided with alternative paths. This would reduce the amount of time spent by nodes trying to find other paths when communication is altered abruptly.

Classifying Routing Protocols in MANETs

The study literature has seen the emergence of numerous routing protocols, which have, to some extent, considered these various features. Consequently, Figure 1 provides a detailed classification of these routing protocols.

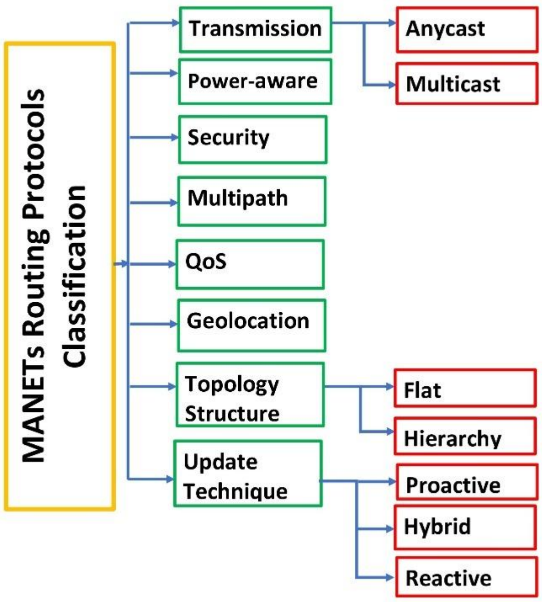

Figure 1. Classification of MANET Routing Protocols

Update Technique

In addition to hybrid routing protocols, routing protocols are categorised into proactive/table-driven, reactive, or on-demand categories. This classification is rooted in the mechanism governing the updating of information within the protocols' framework. Alternatively, the proactive ones are called distance-vector or link-state routing protocols [2]. This name finds its origin in traditional link-state protocols designed for traditional wired networks.

Essentially, each node must maintain a list of all open paths [3]. This topological information, which could be periodic or event-based, is distributed throughout the network to maintain a consistent view. Event updates occur when the network structure changes, while periodic updates happen at set intervals. The record includes routes to inactive nodes. These protocols create control traffic for the update of stale routes entered into the routing table. In settings where the nodes' mobility is extremely high, the overhead incurred to establish this kind of protocol is extremely expensive as a result of changes in topology and wide networks. This streamlined approach greatly enhances the ease of route selection from the routing table [4].

In this domain, notable protocols encompass Vector Routing Protocol (VRP), Destination Sequence Distance Vector (DSDV), Proactive Source Routing Protocol (PSR), Optimized Link State Routing (OLSR), Wireless Routing Protocol (WRP), Global State Routing (GSR), Source-Tree Adaptive Routing (STAR), and Landmark Ad Hoc Routing (LANMAR).

Reactive routing protocols construct routes only when they are needed by the nodes and links, as opposed to holding a route between every pair of nodes. Source-initiated or on-demand routing protocols are other names for reactive routing protocols. A source node initiates a route discovery process when it requires a route to a destination [5]. The network is flooded with route request (RREQ) packets. When the source node receives a route reply (RREP) message, it means a route has been established. This scheme only requires a small amount of bandwidth for the maintenance of routing tables at every node, as the route remains open until it becomes undesirable or impassable. By eliminating pointless modifications to routing information, this is ensured. These protocols are linked to an increase in latency, which results in communication delays. Some well-known examples include Source Routing for Roofnet (SrcRR), Ad hoc On-Demand Distance Vector (AODV), Signal Stability Routing (SSR), Dynamic Source Routing (DSR), Relative Distance Micro-Discovery Ad hoc Routing (RDMAR), Dynamic MANET On-Demand Routing (DYMO), Temporally Ordered Routing Algorithm (TORA), Interference-Aware Load-Balancing Routing (IALBR), Associativity-Based Routing (ABR), and Flow Oriented Routing Protocol (FORP).

Proactive and reactive routing strategies are combined in hybrid routing protocols by taking the most desired features characteristic of both protocols to enhance the competence of the routing mechanism [5]. This approach is obtained by using route discovery for nodes that are not near each other and maintaining routes for nodes that are close to each other. The primary advantage of employing hybrid protocols is to enhance the network's expandability. To achieve this, a backbone is created with nodes that are close to each other. Thus, the overhead incurred during the route discovery process is drastically reduced.

Hybrid protocols are commonly based on zones. For some, clusters or trees are used instead of zones. The protocols typically divide the entire network into two zonal areas, which may or may not overlap depending on the algorithm used by the hybrid protocol for the creation and maintenance of the zones. Each node has its own local and outside zones where proactive and reactive routing is employed, respectively. Thus, each node establishes and maintains paths to the various destinations found within and outside the zones. The following properties are characteristic of an ideal hybrid protocol.

Adaptive: Various target outputs can be met if the protocol is capable of automatically regulating the spectrum and variables under various network settings, which can be achieved by clearly mapping the parameters of hybridization against the appropriate performance metrics.

Efficient: The efficiency of the hybrid protocol is much lower if it uses a single component rather than several components that are integrated.

Simplicity: Unnecessary overheads are avoided if the protocol is designed to be simple and lightweight.

Examples of hybrid routing protocols are the Distributed Spanning Tree (DST) protocol, Sharp Hybrid Adaptive Routing Protocol (SHARP), Link Reliability-Based Hybrid Routing (LRHR), and Hybrid Routing Protocol for Large Scale MANETS (HRPLS).

Topology Structure

The second classification of routing protocols involves the network's structure, leading to two distinct types: flat and hierarchical [1]. The proactive, reactive, and hybrid protocols discussed earlier operate in a flat topology. However, as the network grows larger, flat routing protocols incur increased overhead. Moreover, rapid changes in network topology can disrupt active routes and lead to more frequent route searches. To address these challenges, hierarchical routing protocols were proposed.

Hierarchical routing protocols reduce the size and overhead of the network by organising it into multiple levels. Clustering techniques are employed to establish the hierarchy of nodes [5]. Each cluster may consist of one or several clusters and gateways.

In Figure 2, a node z can belong to a cluster, and its address can be represented as y.z. If there are multiple levels of hierarchy, cluster y might be part of a larger cluster x, resulting in the node's address being x.y.z. As illustrated in Figure 3, various protocols showcase diverse cluster physical attributes, where certain clusters appear disjointed while others may exhibit overlapping characteristics.

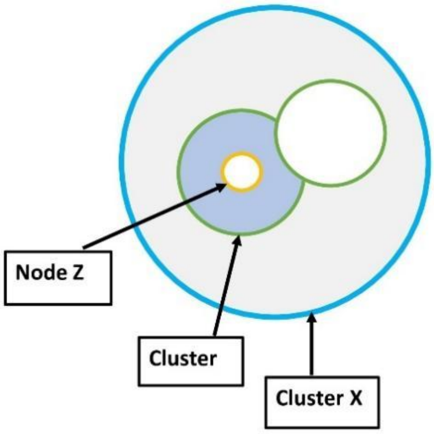

Figure 2. Hierarchical Addressing

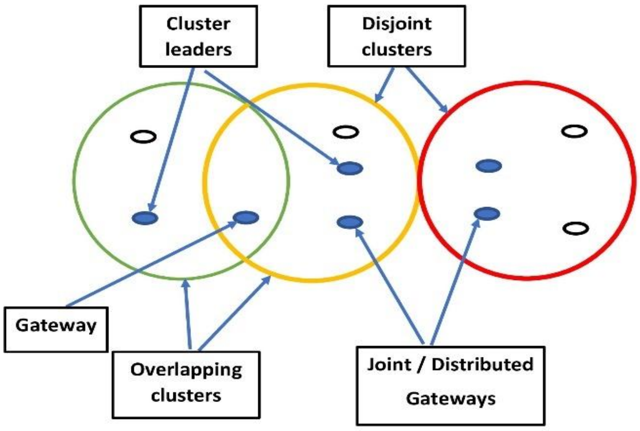

Figure 3. Cluster Topologies

The hierarchy's topmost nodes provide specialised services, which boost the network's effectiveness. Cluster Gateway Switch Routing (CGSR), Fisheye State Routing (FSR), DSR Over AODV (DOA), Cluster-Based Routing Protocol (CBRP), Augmented Tree-based Routing (ATR), Order-one MANET Routing Protocol (OORP), and Hierarchical State Routing (HSR) are examples of hierarchical routing protocols that exhibit different characteristics [1].

Geolocation

The next group of routing protocols consists of geolocation-aware routing protocols. Utilising geographic location data, these protocols optimise routing by commonly relying on GPS coordinates or other reference points as their source of coordinates [1]. By using geolocation information, these protocols eliminate the need to search for destinations throughout the entire network. Instead, upon establishing the recipient node's coordinates, messages are directed towards its location, necessitating each node's access to its own and all other network geographic coordinates. This interaction introduces heightened routing complexities stemming from information exchange concerning coordinates. Well-known examples of geolocation-aware protocols include Location Aided Routing (LAR), Scalable Location Updates Routing Protocol (SLURP), Grid Location Service (GLS), and Location Prediction Based Routing (LPBR).

Quality of Service (QoS)

Every application provides distinct services. Due to the mobility of MANETs, routing protocols have difficulty meeting the demands of various applications. Factors affecting the quality of these services include delay, jitter, reliability, throughput, network availability, resource conditions, and traffic such as memory, battery power, bandwidth, and so on. Instead of the traditional short-distance hop count metric, the requirements of the desired QoS factors are used to select the route [6]. Some examples are Ticket-Based QoS Routing (TBR), Core Extraction Distributed Ad Hoc Routing (CEDAR), Advanced-Optimized Link State Routing (A-OLSR), QoS Admission Control Routing Protocol (QACRP), and Ad hoc QoS on Demand Routing (AQOR).

Multipath

Multiple routes from the origin node to the end node are made by multipath routing schemes [1]. They address issues such as discovering multiple paths and maintaining them [7]. Indeed, network congestion is a prevalent occurrence, yet its impact can be significantly mitigated through the strategic availability of multiple pathways. Typical examples include Caching and Multipath Routing Protocol (CHAMP), Split Multipath Routing (SMR), Light-weight Mobile Routing (LMR), and Routing On-demand Acyclic Multipath (ROAM).

Security

Because they are wireless, MANETs are extremely susceptible to security attacks [8]. Both inside and outside of a system are potential origins of attacks [9]. Proper security measures must be considered before implementing a MANET. The goal here is to use several strategies based on cryptography and reputation-based solutions. When it comes to passive and active attacks, security-based routing protocols must be effective and difficult to break. Activities such as conversations are monitored [1]. Typical examples of routing protocols that are founded on security include Security Aware Routing Protocol (SAR), Secure Ad hoc On-Demand Distance Vector Routing (SAODV), Authenticated Routing for Ad hoc Network (ARAN), Ariadne, and Secure Efficient Ad hoc Distance Vector (SEAD).

Transmission

Routing protocols in MANETs can be categorised into two main types: multicast and anycast. Multicast routing enables the simultaneous transmission of information to a group of destinations in MANETs. This approach optimises network usage, ensures efficient data delivery, and prevents redundancy when links to destinations are undivided. On the other hand, anycast routing directs data packets to the nearest node providing the required service, ensuring effective and targeted communication. Mobility and Quality-of-Service Aware Anycast Routing (MQAR) is an example of this approach in MANETs. During multicast routing in MANETs, both multicast and unicast methods are used for data transmission. Tree-based and mesh-based protocols are the two main categories that multicast routing protocols fall under [7].

Any transmitter and receiver pair can only be reached via one path in tree-based multicast routing algorithms. Tree-based protocols exhibit great multicast efficiency. However, they may not be resilient against frequent topological alterations, and the PDR becomes low when mobility stays high. A well-known example of a tree-based protocol is the Multicast Ad Hoc On-Demand Distance Vector Routing Protocol (MAODV).

On the other hand, mesh-based protocols offer numerous paths to maintain connectivity for group members. These protocols are reliable despite frequent node movements. Nevertheless, redundant links are responsible for minimal multicast efficiency. On-demand Multicast Routing Protocol, sometimes known as ODMRP, is an example of a mesh-based protocol.

Power-aware

Various OSI reference model layers can be used to address the energy efficiency issue in MANETs. Currently, most researchers are focusing on optimising the energy consumption of nodes from various perspectives. The suggestions range from controlling wireless nodes' sleep states to modifying their transmission power. These ideas span from MAC layer proposals to combined MAC and routing function proposals. Furthermore, there are efforts to define an energy-efficient routing protocol that can route data while conserving batteries. Given the battery-powered nature of nodes in MANETs, optimising power consumption becomes paramount to extending their operational lifespan [10].

The majority of non-power-aware routing schemes prioritise network efficacy above power. Several routing protocols have been suggested to improve power efficiency, but none of them is ideal in every situation. Employing power-aware routing protocols reduces the amount of battery power used by each node. There are five crucial power-aware systems of measurement employed to assess the excellence of a path: minimising the energy consumed per packet, maximising time to network partition, minimising variance in node power levels, minimising cost per packet, and minimising maximum node cost [11]. Typical examples of power-aware routing protocols include the Power-Aware Routing Optimization Protocol (PARO), Ant Colony Optimization_AODV (ACO_AODV), Conditional Max-Min Battery Capacity Routing (CMMBCR), Power-Aware Multi-Access Protocol with Signalling Ad-Hoc Networks (PAMAS), Dynamic Source Routing Power-Aware (DSRPA), Lifetime-Aware Multipath Optimized Routing (LAMOR), Predictive Energy-Efficient and Reliable Multicast Routing (PEERMR), EnergyAware OLSR (OLSR_EA), Efficient Power-Aware Routing (EPAR), and Energy-Level-Based Routing Protocol (ELBRP) [1].

CLASSIFYING POWER-AWARE PROTOCOLS IN ROUTING

These protocols are classified into eight groups as shown in Figure 4, namely: Transmission Power Control-Based Approach, Location-Based Approach, Load Balancing-Based Approach, Multicast-Based Approach, Link

State-Based Approach, Source-Initiated-Based Approach, Power Management-Based Approach, and Metaheuristic-Based Approach.

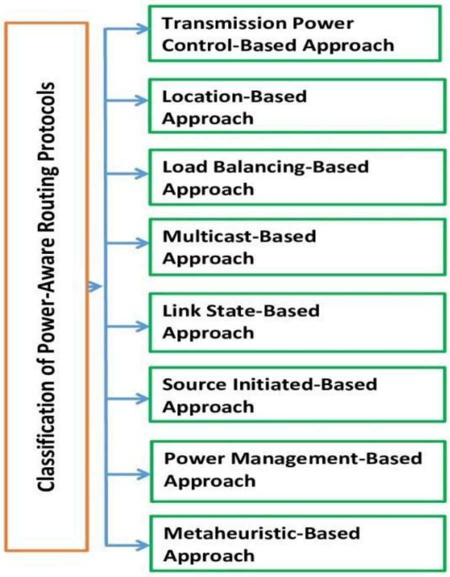

Figure 4. Power-aware Routing Classification

Transmission Power Control-based Approach

Power transmission can be controlled by regulating the structure of a MANET. Transmission strength determines the range across which the sent signal is completely acquired, and this is crucial for assessing network performance based on throughput, delay, and power consumption. These protocols find the most practical pathway that lowers overall transmission power between the origin and the target. The proposed transmission power matches the link's weighted link cost, which is analogous to a graph-related optimization task. The weighted graph's smallest cost path is identical to the shortest power path from origin to target. On a networked graph in which a node is given by a vertex and a link between two nodes is given by an edge, the routing algorithm looks for a realistic way to the end node [10]. Typical examples of Transmission Power Control-Based Approaches include Online Max-Min Routing Protocol (OMM), Face-Aware Routing (FAR) protocol, Efficient Power-Aware Routing (EPAR), and Power-Aware Routing Optimization Protocol (PARO).

Location-based Approach

The energy minimisation mechanism employed is based on the location of the nodes. For instance, to increase the speed of pathfinding, the Zone-Based Routing with Parallel Collision Guided Broadcasting Protocol (ZCG) uses a parallel-distributed technique for broadcasting. In this approach, the clustering algorithm employed is one-hop-based in which the network is partitioned into zones known as static reliable leader-assisted zones. LAPAR, that is, the Location-Based Approach protocol, is yet another example of Location-Aided Power-Aware Routing (LAPAR).

Load Balancing-based Approach

This approach underscores the significance of proactive involvement, aiming primarily to equitably distribute energy usage across network nodes, thus extending the network's longevity. It achieves this by steering clear of high-energy-consuming nodes while selecting routes. Only intermediate nodes that are rich in energy are allowed to transmit data packets. Such protocols also avoid overloading certain nodes, which increases the networks' longevity. Typical examples of Load Balancing-Based Approaches include Conditional Max-Min Battery Capacity Routing (CMMBCR), Energy-Efficient and Load-Balanced Geographic Routing (ELGR), and Local Energy-Aware Routing (LEAR).

Multicast-based Approach

As data is sent simultaneously to several recipients, multicast routing aims to minimise the cost of transmission. Nevertheless, the main objective of multicast routing is to ensure energy efficiency, reduced delay, and stability of paths. Thus, multicast routing protocols can be created with a focus on energy efficiency in the routing process. PEERMR, that is, Predictive Energy Efficient and Reliable Multicast Routing is a common illustration.

Link State-based Approach

Protocols classified under this group have their energy minimisation mechanisms based on the links established among the nodes. For example, in Energy-Aware OLSR (OLSR_EA), a reviewed path estimation algorithm is used for the election of paths. The energy utilised per link is predicted and computed using a technique known as auto-regressive integrated moving average series of time. Other examples of the Link State-Based Approach include Lifetime-Aware Multipath Optimized Routing (LAMOR), and OLSR Monitoring (OLSRM).

Source-initiated-based Approach

Protocols under this group have their energy consumption mechanisms initiated by the source node. In DE-AODV, which is the Dynamic Energy Ad-hoc On-Demand Distance Vector Routing Protocol scheme, the transmit, active, and sleep modes of the nodes are considered by the energy scheme. The protocol chooses the best and quickest route between origins and targets by evaluating the energy efficiency and trustworthiness of the nodes. Other well-known examples of the Source-Initiated-Based Approach include the Energy-Level-Based Routing Protocol (ELBRP), and Proactive Source Routing (PSR).

Power Management-based Approach

This strategy is used if saving energy for battery-operated devices is the ultimate goal. The numerous performance needs introduced by the various programs in use, such as throughput, and so on must be taken into account by power management strategies. Historically, comprehensive research has delved into disc management, memory, and CPU. This concept revolves around transitioning nodes into low-power states during periods of device inactivity, encompassing various operational modes such as transmitting, receiving, idle, and sleep modes [10]. A typical example of a Power Management protocol is the Power and Delay aware Temporally Ordered Routing Algorithm (PDTORA).

Metaheuristic-based Approach

Most metaheuristic-based approach power-aware routing algorithms are nature-inspired. Typical examples include the Ant Colony Optimization_AODV (ACO_AODV), Predictive Energy Efficient Bee Routing algorithm (PEEBR), Energy-aware Biologically Inspired Routing (EBIR), Genetic Algorithm-based Secure and Energy-aware Routing (GASER), and BeeAdHoc.

BROADCASTING IN MANETS

Broadcasting is defined as a fundamental operation which allows a station (node) to communicate a message to all other stations (nodes) within a network or a communication strategy used by MANET multicast or unicast routing protocols to send control messages [1]. The routing protocols mainly use broadcasting methods in the route discovery process when advertising an error message to erase invalid routes from the routing table or as an efficient mechanism for reliable multicast in fast-moving MANETs [3].

Applications of Broadcasting in MANETs

Spreading Information to All Intended Nodes

Broadcasting is vital for widespread information dissemination, especially in emergencies, aiming for efficient delivery to numerous network nodes. The focus is on minimizing broadcast messages while ensuring swift transmission to reduce latency. In the IEEE 802.11p standard, safety-related messages hold the highest priority in broadcasting packets within the MAC layer.

Finding Available Paths

Broadcasting in routing protocols identifies recipients for unicast or multicast, not reaching every node. It seeks a route to a specific node, using broadcast packets directed at the recipient. AODV, DSR, and DSDV often use flooding, but it's inefficient and leads to broadcast storms.

Offering Positioning Assistance

Nodes disseminate position information throughout the network to construct a network map, which serves as a foundation for routing protocols to find routes to specific recipient nodes. One example of a protocol utilising this localization service is Location-Aided Routing (LAR).

Maintaining Path

Nodes regularly share Hello packets to update routing tables for neighbouring nodes, crucial in AODV and DSR routing protocols. If a sender node doesn't receive Hello packets from a particular neighbour for a defined number of periods, it assumes the neighbour is out of range and removes it as a current neighbour. In the Destination Sequence Distance Vector (DSDV) routing protocol, nodes exchange routing table details to uphold routes to all network nodes.

Sharing of Nearby Data

Nodes exchange neighbouring information, including speed, density, etc., especially within a one or two-hop distance in protocols like Optimized Link State Routing (OLSR). This helps select MultiPoint Relays (MPRs) for efficient routing.

The Broadcast Storm Problem

The traditional simplistic technique used in broadcasting messages in MANET is flooding. In flooding, each message is rebroadcast exactly once and each node rebroadcasts a message as soon as it receives it for the first time [12]. Even though flooding ensures that there is a high success rate in reaching all nodes in the network, it often generates redundancy which is characterised by high contention (neighbouring nodes disagree with the host and among themselves to rebroadcast an already broadcasted packet) and collision rates (as a result of lack of collision detection and acknowledgement). These challenges can become very increasing in dense networks, which may lead to a sharp degradation of overall network performance and is often referred to as the broadcast storm problem.

Let us assume a MANET which is made up of a set of mobile devices or nodes that are cooperative. Each mobile node uses a transceiver that has Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) adopting the IEEE 802.11 protocol to use the air medium for communication. The following drawbacks are characteristic of this MANET.

Unplanned Transmission

Nodes, lacking advanced knowledge of local information for global network topology, can initiate broadcasts at any time in this scenario of highly mobile and unsynchronized nodes.

Inconsistent Transmission

In the communication process using the CSMA/CA technique, recipient nodes don't provide feedback to senders regarding packet reception due to potential network isolation, and to prevent endless retransmissions, broadcast packets include a tuple of source ID and sequence number for duplicate packet detection in MANET.

Broadcasting Approaches in Manets

Deterministic, probabilistic and hybrid-based broadcast schemes are the three main categorisations of broadcast techniques that are mostly deployed to mitigate the problems caused by simple flooding. Under the assumption of an ideal MAC layer, deterministic schemes mainly build a network backbone that guarantees reachability of approximately 1. However, a huge overhead is mostly encountered as a result of the time and complex nature of building and maintaining the communication backbone. Deterministic broadcasting schemes face challenges. Continuously updating the node subset as the network backbone is costly and complex due to varying network dynamics and algorithmic data needs. Moreover, in power-constrained MANETs, selected nodes can quickly deplete their batteries, risking network partitioning. Additionally, these schemes are susceptible to malicious or malfunctioning nodes, especially if they are chosen for data forwarding. Typical examples of deterministic schemes include pruning, multipoint relaying, node-forwarding, neighbour elimination and clustering [6].

On the other hand, probabilistic broadcast schemes try to solve the problems of the simple flooding method by assigning a predetermined probability, p, of re-broadcasting for each node that belongs to the set of nodes in the overall network. The predetermined probability could be a constant value or be determined dynamically by each participating node in the network. In broadcasting, involving all nodes balances power consumption, yet some not rebroadcasting helps manage network congestion. However, this increases the risk of message omission for some nodes. Precise probability configuration is crucial for probabilistic broadcasting, considering potential adverse effects from altering the probability value due to interconnected variables. Typical examples of probabilistic schemes include probability-based, counter-based, distance-based, location-based, color-based, dynamic probabilistic counter-based and adjusted counter-based broadcast schemes.

Hybrid-based broadcasting schemes combine the superlative features of two or more broadcasting schemes to introduce a higher optimum broadcasting scheme to solve the broadcast storm challenges. Typical examples include the new adaptive broadcasting schemes, mobility-aware velocity-based broadcasting schemes, and hybrid broadcasting schemes.

MOBILITY MODELS

Since the nodes in MANETs rapidly change their locations, there must be a way of modelling their movement patterns. To properly simulate MANETs, every feature of the network protocol being used must be carefully considered. Therefore, it is crucial to use the right mobility model in any research on mobile networks. The mobility model provides real scenarios concerning speed, acceleration, direction, location, and movement patterns [1], [13]. The integrity of the model in use becomes apparent when a real-life situation is selected and the simulation settings and parameters are designed to replicate the network.

In simulating MANET protocols, mobility models can be categorised into two types: real-world traces and synthetic models [14]. Real-world tracing involves observing movement patterns within real-life environments, often with a large participant base over an extended duration. However, privacy concerns and a focus on certain locations might limit data availability and relevance. Additionally, real-world traces tend to emphasise users at access points, leading to a skewed representation of communication ranges, and much of the data pertains to stationary nodes rather than mobile ones, resulting in a partial reflection of usage rather than mobility patterns. Hence, while these traces offer real-world context, they may miss genuine communication dynamics.

It is difficult to trace MANETs before they are modelled. Synthetic mobility models aim to simulate node behaviour when traces are unavailable [15]. Although synthetic models may not achieve trace-level accuracy, they offer cost-effective and timely estimates of node movements. These models are broadly categorised into two types: individual or entity mobility and dependent or group mobility [14], [15]. Thus, synthetic mobility models serve as valuable alternatives to tracing, providing insights into node behaviours and movement dynamics.

In entity mobility models, each node moves independently, charting its course without being influenced by others. Entity mobility models are classified into random, geographic, and temporal dependency models. The Random WayPoint is most widely used in the field of MANET research [16]. Other well-known examples of entity mobility models include the Random Walk, Random Direction, Pathway Mobility, Obstacle Mobility, and Manhattan Mobility models.

In group mobility models, every node is put into a distinct group, and the area covered by every group is defined as an absolute radius. Nodes within a specific group's coverage area are designated as group members, confining their movements to this defined region. In contrast, the entire group possesses the flexibility to traverse across the network's available areas, allowing for collective mobility beyond individual group boundaries. The classification of group mobility models is determined by different approaches to understanding how mobile nodes can move collectively as a group [17].

Group mobility models encompass Point-Based Group Mobility (PBGM) and Region-Based Group Mobility (RBGM) models, with PBGM involving group members mirroring the movements of a guiding point, whether physical or conceptual. Reference Velocity Group Mobility (RVGM), Group Force Mobility Model (GFMM), Multi-Group Coordination Mobility (MGCM), and Reference Point Group Mobility (RPGM) are examples of PBGM. In RBGM, each member of a group may follow a route through a real-time or predefined, dynamically established series of regions or areas. Some well-known examples include Virtual Track Group Mobility (VTGM), Reference Region Group Mobility (RRGM) and the Community-Based Mobility Model (CMM) [17], [18]. Figure 5 illustrates the classification of mobility models in MANETs.

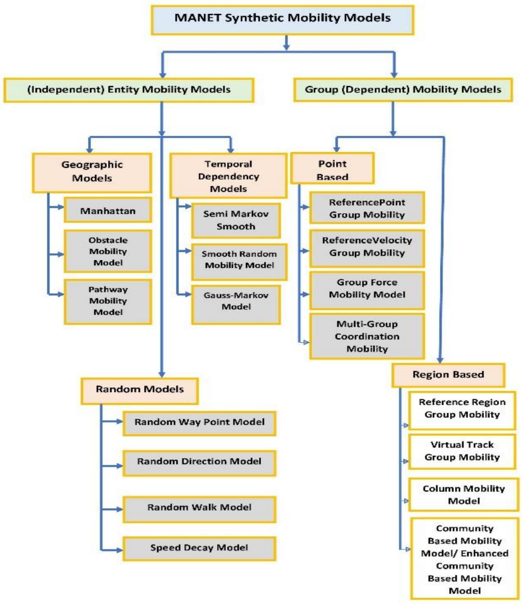

Figure 5. MANET Synthetic Mobility Models

HIGHLIGHTS ON NETWORK SIMULATOR 2 AND 3 SERIES

In recent times, simulation has become very useful in scientific research [19]. For research where experimentation or analytical methods are not realistic, simulation is used as an alternative [20]. Researchers have proposed so many open-source simulation tools for analysis including QualNet, GloMoSim, NS-2, NS-3, OMnet++, J-Sim, Optnet, NCTns 6.0, SSFNet, GNS3, OpenWNS, Mininet and so on. In this study, we attempt to give a brief description of NS-2 and NS-3.

NS-2 is object-oriented and the simulator code is made up of OTcl and C++. The two levels of the hierarchy of this simulator are the C++ hierarchy and the interpreted OTcl which has a one-to-one relationship. OTcl and C++ are linked to ensure efficiency. Researchers employ OTcl to define the protocols, network layout and applications that they are to simulate. C++ hierarchy provides an in-depth description, definition and activities of packets, protocols and processing time [15].

NS-3 was introduced in 2008 as the third iteration of the ns series, which includes ns-1 and ns-2 [21]. The creation of NS-3 is based on the creation of NS-2. It is a substitution for NS-2 and not an extension as such is not backward compatible with NS-2 [15]. Similar to NS-2, NS-3 is a discrete event, open-source simulator [22]. It employs both C++ and Python [23]. It has support for several network protocols including Wi-Fi, LTE, IEEE 808.15.4, SigFox and other networks. It's modular and has support for both graphical and command-line interfaces.

CONCLUSION

In conclusion, this paper categorises MANET routing protocols into eight groups, including transmission, power-aware, security, multi-path, QoS, geolocation, topology structure, and update mechanism. The power-aware routing protocols are further classified into eight groups based on their approach, such as transmission power control, location, load balancing, multicast, link state, source-initiated, power management, and metaheuristic methods. Broadcasting protocols are grouped into three categories: deterministic, probabilistic, and hybrid approaches. The paper also highlights the essential properties for designing routing protocols in MANETs, outlines the ideal characteristics of a hybrid protocol, and discusses broadcasting applications and the broadcast storm problem in MANETs. Moreover, the paper explores and classifies mobility models, and provides highlights on ns-2 and ns-3 simulation platforms.

ETHICAL DECLARATION

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REFERENCES

[1] A. M. Abdullah,(2021). “Mobile ad hoc networks: A survey of existing mobility models and routing protocols,” Ph.D. dissertation, Dept. Comp. Sci., University of Sulaimani, Kurdistan Region, Iraq, 2021.

[2] A. M. Soomro et al., “Comparative review of routing protocols in MANET for future research in disaster management,” *Journal of Communication*, vol. 17, no. 9, pp. 734-744, 2022.

[3] D. Ramphull, A. Mungur, S. Armoogum, and S. Pudaruth, “A review of mobile ad hoc NETwork (MANET) protocols and their applications,” in *2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*, May 2021, pp. 204-211.

[4] K. Divya and B. Srinivasan, “Routing protocols in MANET: A survey,” *International Journal of Research in Engineering and Science (IJRES)*, vol. 9, no. 7, pp. 51–57, 2021.

[5] A. C. Onuora, E. E. Essien, and P. Ana, “A comprehensive review of routing protocols for mobile ad hoc networks (MANETS),” *International Journal of Information System and Computer Science (IJISCS)*, vol. 6, pp. 1–13, 2022.

[6] A. D. S. Salman, “Quality of service aware routing protocol for a self-organized communication network,” Ph.D. dissertation, Fac. ElET, TU Ilmenau, Ilmenau, German, 2016.

[7] A .R. Rajeswari, “A mobile ad hoc network routing protocols: A comparative study,” *Recent Trends in Communication Networks*, vol. 6, no. 1, pp. 1-24, 2020.

[8] B. Banerjee and S. Neogy, “An efficient swarm-based technique for securing MANET transmission,” in *24th International Conference on Distributed Computing and Networking*, Jan. 2023, pp. 300–304.

[9] U. I. B. Khan, R. F. Olanrewaju, F. Anwar, A. R. Najeeb, and M. Yaacob, “A survey on MANETs: Architecture, evolution, applications, security issues and solutions,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 12, no. 2, pp. 832–842, 2018.

[10] D. E. M. Ahmed and O. O. Khalifa, “A comprehensive classification of MANETs routing protocols,” *International Journal of Computer Applications Technology and Research*, vol. 6, no. 3, pp. 141–158, 2017.

[11] S. Mishra and B. K. Pattanayak, “Power-aware routing in mobile Ad hoc networks: A survey,” *ARPN Journal of Engineering and Applied Science*, vol. 8, no. 3, pp. 173–189, 2013.

[12] C. Ho, K. Obraczka, G. Tsudik, and K. Viswanath, “Flooding for reliable multicast in multi-hop ad hoc networks,” in *Proceedings of the 3rd International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications*, pp. 64-71, Aug. 1999.

[13] K. Wane, N. Chopade, and G. Rahate, “A comprehensive survey of routing techniques in MANETs,” in *2nd International Conference on IoT Based Control Networks and Intelligent Systems (ICICNIS 2021)*, Jul. 2021, pp. 1–9.

[14] H. Adarbah, “Bandwidth and energy-efficient route discovery for noisy mobile Ad-Hoc networks,” Ph.D. dissertation, Dept. Tech., De Montfort University, Leicester, UK, 2015.

[15] S. Shrivastava, “Survey of routing protocols, simulation, testing tools and mobility models in MANET,” *Journal of University of Shanghai for Science and Technology*, vol. 22, no. 9, pp. 70–77, 2020.

[16] A. Saad, H. Osman, and M. Mukaz Ebedon, “Review of Ad hoc networks scenarios and challenges in years 2015-2019,” *International Journal of Electrical and Computer Engineering Systems*, vol. ICICTM, no. special issue, pp. 39-50, 2021.

[17] Y. Regragui, “Mobility modelling and simulation in tactical networks and smart cities,” Ph.D. dissertation, Université Chouaïb Doukkali, Grand-Casablanca Region, Morocco, 2019.

[18] C. Y. Aung, B. C. Seet, M. Zhang, L. F. Xie, and P. H. J. Chong, “A review of group mobility models for mobile ad hoc networks,” *Wireless Personal Communications*, vol. 85, no. 3, pp. 1317–1331, 2015.

[19] S. K. Panigrahy and H. Emany, “A survey and tutorial on network optimization for intelligent transport system using the Internet of vehicles,” *Sensors*, vol. 23, no. 1, pp. 1–30, 2023.

[20] H. M. A. Fahmy, “Simulators and emulators for WSNs,” in *Concepts, Applications, Experimentation and Analysis of Wireless Sensor Networks*, Feb. 2023, pp. 547-663.

[21] A. Odelstav,“Evaluation of simulated 802.11p and LTE communication at road intersections and urban area of self driving cars,” M.S. thesis, Mid Sweden University, Östersund, Sweden, 2021.

[22] U. A. R. Khan, S. M. Bilal, and M. Othman, “A performance comparison of network simulators for wireless networks,” in *2012 IEEE International Conference on Control System, Computing and Engineering*, Jul. 2013, pp. 34-38.

[23] A. I. Griva et al., “LoRa-based IoT network assessment in rural and urban scenarios,” *Sensors*, vol. 23, no. 3, pp. 1–14, 2023.