Comprehensive Survey on Multi Attribute Decision Making Methods for Wireless Ad Hoc Networks

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Abstract

Recently, to design dynamic networks without existing infrastructure, wireless ad hoc networks have been proposed to establish self-organizing networks. In this type of network, to resolve the primary research challenge of establishing a stable path between source and destination, several metrics or utility values have been proposed to meet the specific objectives, as well as improve packet delivery ratio when developing communication protocols or addressing technical issues. Notably, most existing studies use the Multi Attribute Decision Making (MADM) algorithm to balance weights between relevant metrics to realize the above objective. However, despite their significant efforts, a comprehensive survey paper analyzing them together has not been published. Thus, in this paper, we describe the recent research and development efforts to employ MADM in ad hoc networks. First, we provide an overview of MADM and explain the well-known algorithms. After categorizing the current work according to the algorithms, the existing schemes are further divided by the type of networks. Based on this classification, we then detail the procedures with their research objectives. Furthermore, we present other research challenges and apparent problems in this research area.

Keywords: Ad hoc networks, Multi Attribute Decision Making, Communication protocol

1 Introduction

As opposed to conventional wired and wireless networks, which depend on pre-existing infrastructure, ad hoc networks have been recently proposed in situations where infrastructure is unavailable, such as in cases of infrastructure being damaged due to a disaster. Another good use case for an ad hoc network is establishing a temporary military communications network without relying on existing infrastructure. However, there are significant research challenges in building self-organizing networks with a communication protocol to establish and maintain a path between a source and a destination. Additionally, several other research studies have been conducted to implement this type of network in real time by solving the deployment issue. Nonetheless, challenges persist in the use of ad hoc networks.

Ad hoc networks are classified into several different forms based on the node type such as Mobile Ad hoc Networks (MANET) [1], Vehicular Ad hoc Networks (VANET) [2], Wireless Sensor Networks (WSN) [3], Opportunistic Networks (ON) [4], Delay Tolerant Networks (DTN) [5], and Space Information Networks (SIN) [6]. While these are all based on ad hoc networks, they exhibit different properties and network environments. This implies that different metrics and utility values are employed in each network to develop communication protocols and solve technical issues. Moreover, this feature is the major difference from typical networks, where one or few discrete metrics are usually considered.

Significant research studies have focused on MADM in ad hoc networks to account for the unique characteristics of various metrics and network environments. MADM is a feasible solution in operations research to explicitly evaluate multiple conflicting criteria in decision making. Similarly, MADM is regarded as a feasible approach in ad hoc networks because a single metric approach would be insufficient to meet the various requirements, as there may be varied conflicting criteria such as mobility, energy, and stability of the link.

However, a comprehensive survey paper is yet to be published examining the use of MADM algorithm in ad hoc networks. To overcome this shortage, we present recent research and deployment efforts using MADM in ad hoc networks. Firstly, as there are many well-known MADM approaches, it is essential to recognize and distinguish their prominent features. Among the many MADM approaches, we select

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DOI: 10.3966/160792642019092005022

several based on the frequency of usage in existing research papers. They include Analytic Hierarchy Process (AHP) [7], Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [8], Grey Relational Analysis (GRA) [9], and Simple Additive Weighting (SAW) [10]. After categorizing the MADM approaches according to the algorithms, the existing schemes are further sub-categorized by the type of network. Within each sub-category, we define the collected and related research work according to the research area or objective, such as communication protocol, security, and deployment issue. Therefore, Figure 1 shows the classification of MADM approaches in ad hoc networks. Unlike other categories, only research work for both MANET and VANET are compiled in the SAW algorithm. Similarly, some research has been conducted on employing AHP in SIN.

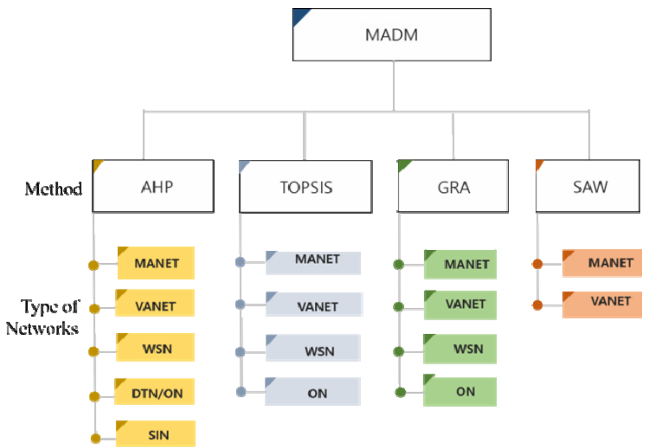

Figure 1. Classification of MADM algorithms in ad hoc networks

2 MADM Algorithm in Ad Hoc Networks

2.1 Overview of MADM

Occasionally, Multi-Criteria Decision Making (MCDM) and Multi Attribute Decision Making (MADM) are transposed. However, there are distinct differences between them. MCDM algorithm comprises of two types: Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM). The MCDM algorithm depends on several decision makers and criteria. While MODM problems arise in the design, modeling, and planning of many complex resource allocation systems, MADM includes goal Programming, fuzzy Programming, utility function method, global criterion method, and lexicographic method. Further, MADM refers to a process of making preferred decisions over the available alternatives, which are characterized by multiple (usually conflicting) attributes useful to improved decision making. These are multi-attribute utility theory, linear assignment method, AHP, TOPSIS, SAW, and GRA. This implies that MADM is a subset of MCDM solution.

2.2 MADM Algorithms

As mentioned, there are several existing methods to solve MADM problems. In this section, we briefly present their prominent features and the operation of the algorithms.

AHP. AHP depends on the hierarchical analytic computational model, which is based on the model of a human brain. AHP reduces the complexity of the decisions to a series of pairwise comparisons and then syntheses the results. It reviews a set of evaluation criteria and a set of alternative options, among which the best decision is to be made. Then AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. Higher weightage is assigned to the corresponding critical criterion. AHP can be implemented in eight consecutive steps. These eight steps can be further summarized into three stages: 1) Computing the vector of criteria weights, 2) Computing the matrix of option scores, and 3) Ranking the options.

TOPSIS. TOPSIS is used to rank and select several possible alternatives by measuring the Euclidean distances to the best and worst case. TOPSIS chooses alternatives that have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. Like AHP, a set of alternatives are compared by the weights assigned to each criterion, normalized score, and the geometric distance between each alternative and the ideal one.

GRA. GRA is one of the most widely used models of Grey system theory, with specific focus on the use of information. In this system, black is defined as no information while white is perfect information. However, these two cases rarely exist in the real world. Thus, in this model, grey is the situation between the two extreme cases. Based on this concept, GRA is usually introduced for relational analysis of the uncertainty of a system model and the incompleteness of information. GRA is used to identify the similarity or variance by computing the grey relational coefficient (GRC), which is within the range of 0 to 1. Subsequently, GRC is compared with the best case.

SAW. SAW utilizes a weighted linear combination or scoring method by introducing the weighted average using arithmetic mean. An evaluation score for each alternative is computed as the product of the given scaled value to the alternative of an attribute and the weights of relative importance. As SAW is accepted as a proportional linear transformation of the raw data, the relative order of magnitude of the standardized scores remains equal. The primary motive of the SAW method is to obtain a weighted sum of performance ratings for each alternative over all attributes.

2.3 Types of Ad Hoc Networks

According to the node type in the network, different types of ad hoc networks are developed. In this section, we explain five well-known ad hoc networks.

MANET. Mobile Ad hoc Networks acquire nodes such as laptops and smartphones carried by people. It forms a temporary network without the aid of any centralized administration or standard support services. Topology control is dynamic as nodes join and leave. Additionally, self-configuration or reconfiguration are accomplished without a centralized control. In this network, nodes must route packets for other nodes to keep the network fully connected. Moreover, owing to the frequent route changes because of node mobility, routing problems must be addressed to retain a stable path without regard to the network dynamics.

VANET. While MANET acquires nodes based on human mobility, VANET utilizes automobiles. Though VANET is a specific form of MANET, it has two different types of communication: Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V). In addition, Road Side Units (RSU) work as base stations for vehicles. As cars exit the signal range and drop out of the network, other cars can join, connecting vehicles to one another so that a VANET enabled Internet is created. Thus VANET is expected to assist communication between police and fire vehicles for safety purposes. The architecture of a VANET is illustrated in Figure 2, where additional communication between RSUs is feasible by leveraging GPS.

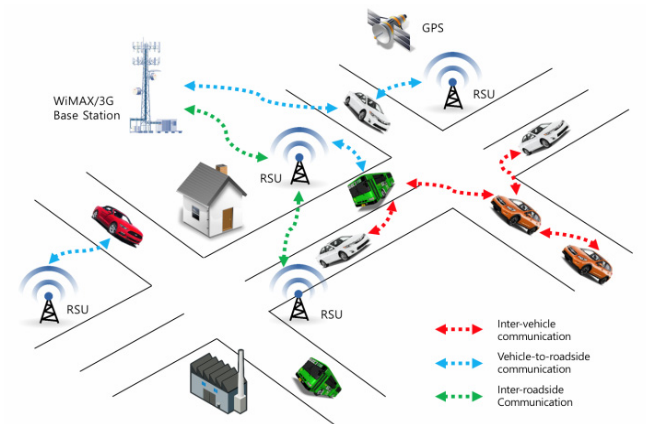

Figure 2. Example of VANET Environment

WSN. In contrast to MANET and VANET which adopt dynamic networks, static wireless sensor networks (WSN) are a distinct type of ad hoc networks. WSN consists of distributed sensor nodes to monitor eternal environments and a sink node to gather information from the sensor nodes. This collected information is managed by an analysis software. Enhanced sensor nodes, that are capable of computing and communication, compose ad hoc networks to perform a desired mission.

ON/DTN/SIN. Opportunistic Networks (ON) and Delay Tolerant Networks (DTN) are based on a new paradigm of store-and carry, rather than traditional store-and-forward. Store-and carry chooses the node closest to the target node to forward the data. Both ON and DTN capitalize on the broadcast characteristics of wireless medium. The basic function of ON/DTN is its ability to monitor the transmitted packet and to coordinate among relaying nodes. In ON and DTN, a candidate set is a potential group of nodes that is selected as the next-hop forwarders. Any candidate of a node that receives the transmitted packet may forward it. The decision of choosing the next forwarder is made by coordination between candidates that have successfully received the transmitted packet. In ON, data delivery between partitioned networks is attained by using a dynamic relay node to forward the packet.

As a special case, space information networks (SIN) have been recently proposed to acquire continuous information through satellites and high-altitude platform stations. SIN extends detection and transmission capabilities, rather than the current single Earth observation satellite.

3 AHP in Ad Hoc Networks

3.1 AHP-MANET

AHP is used to evaluate the trust model for security, improve the current protocol by choosing a better route, and select a routing protocol according to the objective and environment. Furthermore, because header selection in MANET is not achieved by a single factor, the cluster header selection problem in MADM becomes pertinent.

3.1.1 Communication Protocol

Communication protocol to use AHP focuses on improving routing performance and providing Quality of Service (QoS) over MANET. Therefore, most research work is related to route selection for QoS. In addition, most methods are combined with other algorithms, such as fuzzy logic, and then evaluated by comparing performance.

The first routing protocol [11] is obtained by improving the Ad Hoc On-Demand Distance Vector (AODV) protocol through AHP and Evolutionary algorithms (EA). In this protocol, an optimized path is obtained by applying EA and AHP, respectively. Subsequently, an optimized route is encrypted using cryptographic techniques. AHP considers three selection criteria: energy of the nodes, latency, and bandwidth of the channel. Simulation results are presented to prove that the proposed scheme based on AHP demonstrates better performance than the original AODV. To select the most reliable path, the authors in [12] propose an evaluation model with AHP, fuzzy set, and TOPSIS sequentially. Through the adoption of the three different algorithms, the rank of the route is determined by prioritizing weight, describing vagueness, and setting ranking of the routes. Another routing protocol based on a hybrid model called Fuzzy TOPSIS Rough Set Analytical Hierarchical Process (FTR-AHP) was proposed in [13]. To identify the reliable and optimal path against constraints in MANET, multi-hop, battery power, signal strength, mobility, and trustworthiness are chosen as selection criteria in the AHP model. Among them, signal strength contributes to ranking the routes based on reliability. The evaluation model is layered in the order of identification criteria, filtering of routes, calculating criteria weight, and fuzzy TOPSIS. The simulation results demonstrate that the performance of the proposed technique surpasses that of the existing approaches.

As the path selection is more accurate in QoS than in non QoS routing, AHP is used to select a path in QoS routing. First, on-demand source routing protocol with six QoS attributes, throughput, delay, jitter, reliability, load, and battery power are incorporated with AHP in [14]. The proposed scheme to identify the best route is composed of three blocks; flow classifier, Routing Information Base (RIB) and AHP engine. Specifically, AHP computes the weight of QoS parameters, where the engine acquires the QoS value for different routes from RIB. Second, Quality Aware routing algorithm with the Ad hoc On-demand Multipath Distance Vector routing protocol (QA-AOMDV) [15] is proposed to select a route through SAW and AHP. The main contribution of QA is to identify a path with adequate resources to meet QoS, by considering application classes in the routing process. The path is selected by employing SAW and AHP as decision making and weighting method, respectively. For the AHP process, delay, jitter, packet loss rate, and data rate are defined as pair wise comparison matrices. The simulation results demonstrate that the performance of QA-AOMDV surpasses the original AOMDV.

Instead of the choosing the best route, another approach is to select the applicable routing protocol to meet specific requirements by employing AHP. Best Effort QoS support (BEQoS) [16] routing consists of two algorithms, SAW-AHP and Fuzzy Preference Programming (FPP) depending on the different scenarios. SAW-AHP is applicable for uncertainty of the factors while the latter is applicable for uncertainty of the problems. To be more precise, the objective of BEQoS is to find the best routing protocol from among several alternatives in a MANET, based on the preference of various QoS metrics that are treated as criteria. To identify the applicable protocol, five criteria are considered, namely packet delivery ratio, delay, jitter, throughput, and energy cost are chosen. This scheme is executed by framework of the adaptive scheme, which is composed of protocol section trigger, decision, and execution procedures. Moreover, to implement the well-known proactive Optimized Link State Routing (OLSR) in MANET, it is essential to select the OLSR software that was implemented by a different institute and programming language. As there are more than seven available working OLSR versions, the authors propose an evaluation method of each software by AHP [17]. The criterion for selection are stability of software, maintainability by the developer, usage, security, cross-platform, and other features. As a result, OLSRd (by OLSR.org) is the most functional implementation for use in MANET. Besides routing protocol, various TCP versions over MANET were analyzed by AHP in [18]. The authors utilize the energy consumption of TCP SACK, Tahoe, Reno and New Reno against mobility, channel error, and node exhaustibility over MANET. The simulation results prove that SACK is the most energy efficient version. In parallel with the simulation study, AHP is performed to find the most energy efficient version. The objective, criteria, and alternative are illustrated in Figure 3. Based on the comparison of the results, the authors present that SACK is recommended as the most energy efficient option. Furthermore, Table 1 summarizes the advantages and disadvantages of the mentioned protocols for comparison.

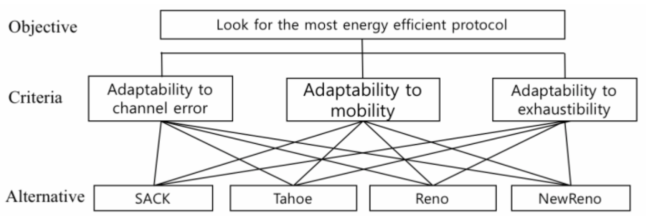

Figure 3. AHP hierarchy structure for energy efficient protocol

Table 1. Protocol comparison of advantages and disadvantages for AHP-MANET

Method	AHP Parameters	Goal	Advantage	Disadvantage
[11]	Energy of the nodes, latency, bandwidth of the channel	Optimal route	Security through encryption	No consideration for mobility
[12]	Number of hops, minimum signal strength	High reliability	Extensible architecture for security	No consideration for mobility
[13]	Number of hops, battery power, signal strength, mobility, trustworthy	High reliability	Extensible architecture for security	No concrete calculation of metric for each parameter

Table 1. Protocol comparison of advantages and disadvantages for AHP-MANET (continue)

Method	AHP Parameters	Goal	Advantage	Disadvantage
[14]	Throughput, delay, jitter, reliability, load, battery power	QoS routing	Supporting multiple paths	No consideration for channel status
[15]	Delay, jitter, packet loss rate, data rate	QoS routing	Supporting multiple paths	No consideration to channel status
[16]	Packet delivery ratio, delay, jitter, throughput, energy cost	QoS routing	Selecting route and protocol	No clear definition to switch mode
[17]	Stability of software, maintainability by developer, usage, security, cross-platform	Selecting the best OLSR implementation	Providing the version selection method	No further newly released OLSR implementation.
[18]	Mobility, channel error, node exhaustibility	Analysis of energy consumption of TCP	High energy efficiency	Rare applications over TCP in MANET

3.1.2 Clustering

The second research area is clustering in MANET. First, an enhancement to the existing Cluster based Routing Protocol (CBRP) called Trust Energy Availability based Cluster Based Routing Protocol (TEA-CBRP) is proposed in [19]. The cluster head is selected according to the key decision parameters Trust Value (TV), Remaining Energy Level (REL), and Time of Availability (ToA) to enhance cluster stabilization. Additionally, a Secondary Cluster Head (SCH) is elected to take the role of the Primary Cluster Head (PCH) whenever the latter exits the cluster. Furthermore, TV, REL, and TOA are used as criterion to select a cooperative CH in AHP. In parallel with the simulation result, cluster head election in case of a merge and split is described. Another study to use AHP for selecting cluster head is presented in [20]. As criteria, the authors select battery power, residence time, and distance summative. Through simulation results, they demonstrate that the proposed scheme achieves more stable cluster rather than the existing one, in the aspects of management overhead and load balance. To manage node failure, Load Balancing Factor (LBF) is introduced to increase throughput and reduce delay in clustering. AHP-Entropy-TOPSIS based Clustering Protocol (AETCP) [21] is proposed to integrate AHP, Entropy, and TOPSIS. By allowing only mobile nodes that satisfy the energy threshold join in cluster head election, energy, and load balance are achieved by the AETCP. The criteria used in head selection in AHP for AETCP are mobility, residual energy, node degree, and distance to neighbors.

3.1.3 Security-Trust Model

For the security issue, AHP is used to evaluate the trust management model. First, the trust model is studied in [22] to determine the trust value consisting of security trust and quality trust in MANET. To achieve this objective, AHP is used to consider the classification of service and evaluate the multiple decision factors. The criteria for AHP in a trust management model include transmitting, energy, delay, and delay jitter trust. Thus, the proposed scheme can adapt to the transformation of services and obtain a relatively reliable trust value irrespective of the service change. Another trust evaluation model based on AHP and fuzzy logic rule is proposed in [23]. In this model, the authors propose a novel trusted routing algorithm to obtain a reliable path by excluding untrustworthy nodes. An extended dynamic source routing called fuzzy trusted dynamic source routing (FTDSR) can identify the malicious node and resist against attack. The criteria for AHP are direct trust, recommendation trust, incentive function, and active degree. Additionally, trust derivation, attacks on trusted routing protocols, and black list are suggested as open issues that merit further discussion. Finally, Xia et al. [24] presented another model called AFStruct, which is based on AHP and the fuzzy logic rules prediction method. Simulation results are provided to evaluate the proposed scheme in the aspects of interaction quality, trust dynamic adaptability, malicious node identification, and attack enhancements of systemOS security.

3.2 AHP-VANET

Similar to AHP in MANET, research in VANET for AHP focuses on communication protocol, security and deployment issue. Specifically, the deployment issue is related to the placement of the RSU.

3.2.1 Communication Protocol

Regarding the communication protocol, the channel allocation problem in the link layer is addressed in [25]. In this work, RSU coordinated multi-channel MAC with a centralized multi-criteria service channel allocation and a scheduling scheme are presented to handle low spectrum efficiency in a dense environment. AHP is introduced to solve the transmission opportunity allocation problem under multiple criteria and maintain a high throughput. The objective of AHP is to identify the stream to be allocated based on the following criteria: throughput, priority, backlog, and remaining time. The detailed procedure consists of preprocessing, first allocation using AHP, and adjusting the resource.

Moreover, Katsaros et al. [26] present the performance of routing protocols in distributed vehicular networks and propose a cross-layer, weighted, position-based routing. To propose a routing protocol by combining multiple decision criteria, AHP is utilized to make forwarding decisions. Figure 4 shows the AHP hierarchy for cross-layer, weighted, position-based routing in their work. As shown in Figure 4, the objective of their approach is to calculate the weight of all individual nodes from the neighbors list and to subsequently select the neighbor with the minimum weight. The first level of hierarchy includes the high-level decision criteria: mobility, link quality, and node utilization. The second level further expands these criteria into more detailed sub-criteria. Another routing protocol in the matter of stability in VANET during the routing process is proposed in [27]. An agent-based routing protocol employs AHP to handle the problem of stability by ensuring high throughput and packet delivery ratio with short delay. In the proposed scheme, the AHP hierarchy structure for QoS selection comprises mobility, processing power, bandwidth, memory availability, delay, battery power, and interest level. The mobile agent based AHP protocol consists of three phases: Initialization, route formation, and route maintenance. Experimental results demonstrate a superior network stability over existing schemes in a VANET environment.

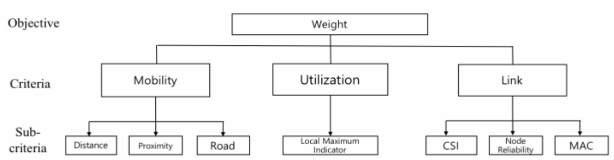

Figure 4. AHP hierarchy structure for VANET

In addition to unicast routing, multi-hop broadcasting to transmit time-sensitive safety warning information to potentially affected vehicles was discussed in [28]. To prevent a broadcast storm, the technical issue for an optimal forwarder to minimize the number of rebroadcasting nodes and guarantee fast and efficient safety warning information dissemination is discussed. The optimal forwarder selection is based on AHP with the following criteria: longitudinal distance, communication range, lateral distance, and traffic density. Additionally, an alternative is set to candidate forwarder vehicles within the communication range of the previous forwarder vehicle. In the aspect of application, the issue of seamless handover to meet stringent time constraints related to safety applications is discussed in [29]. Because handover is closely related to network selection, MADM in conjunction with AHP has been proposed. For example, AHP criteria includes availability, latency, packet loss, and monetary cost, where availability is represented by the Received Signal Strength (RSS). However, as the MADM algorithm has high time complexity, its suitability must be empirically validated and feasibly studied on embedded boxes in vehicles. The main contribution of this work is to evaluate the experimental results to verify whether MADM algorithms are feasible in real life scenarios. Consequently, due to the calculation delay, no suitable algorithm for time-sensitive applications is available. Rather, it is proven that the ID3-AHP decision tree generates a decision up to four times faster than any other techniques. Furthermore, Table 2 summarizes the advantages and disadvantages of the mentioned protocols for comparison.

Table 2. Comparison of advantages and disadvantages for clustering algorithms using AHP-VANET

Method	AHP Parameters	Goal	Advantage	Disadvantage
[25]	Throughput, priority, backlog and remaining time	High throughput	RSU coordinated multi-channel MAC	No consideration for mobility
[26]	Mobility, link quality, node utilization	Selecting the next hop	Position based routing	No consideration for delay
[27]	Mobility, processing power, bandwidth, memory availability, delay, battery power, interest level	High throughput, high packet delivery ratio	High stability with respect to mobility	Too many parameters and high complexity
[28]	Longitudinal distance, communication range, lateral distance, traffic density	Fast and efficient safety warning information dissemination	Supporting real-time communications	No consideration for channel status
[29]	Availability, latency, packet loss, monetary cost	Seamless handover	Realistic experimental model	Measuring availability depending on varying RSS

3.2.2 Security

A novel VANET trust system called multi-level Fuzzy Comprehensive Evaluation (FCE) model with AHP is presented in [30]. This scheme evaluates the trustworthiness and accuracy of information propagating in VANET. FCE provides a scientific assessment based on the fuzzy statistical method, while considering all the influential factors. However, though

FCE method consists of many parameter settings, it requires that the subjective parameters are set in a more reasonable fashion. AHP is used for this objective with four criteria, group, speed, hop count, and direction. The simulation results demonstrate that the proposed scheme can efficiently prevent dissemination messages from malicious vehicles. In addition, Saraswat et al. [31] present a method to compute trust though AHP in VANET. The proposed AHP based scheme has the following three steps: (1) reputation-based trust computation, (2) direct ranking trust computation, and (3) indirect ranking. Reputation value is acquired from trust value, which is dependent upon the previous records of vehicle, while direct ranking value is acquired from the trust value which is based on the messages received from other vehicles. The last indirect ranking is to evaluate the number of authentication certificate exchanges at a certain time for vehicles within the communication range. Another reputation-based trust management system is proposed by a similarity-based bootstrapping method using AHP in [32]. The proposed scheme is based on user behaviors as well as historic features. AHP considers the following criteria: Experience in Driving, Experience in Application (EiA), and Unreliable Behavior (UB). The simulation results prove that the proposed scheme is more stable against high density of malicious nodes than a scheme without it.

3.2.3 Deployment Issue

The placement of the RSU can affect the performance of VANETs significantly and is one of the predominant deployment issues. Because a high density of RSUs causes extra overhead, optimal placement of RSUs has evolved into a major research challenge. To identify the optimal placement of RSU, Patra et al. [33] makes use of AHP to reduce the overall cost. For the system model, one-dimensional road with multiple land and intersection regions are simulated. The vehicle population distribution has been sampled from Pareto distribution for various densities to match historical data while vehicle speeds follow a truncated exponential distribution. AHP has the following criteria: average vehicle density, vehicle speed, and event generation rate. The simulation results exhibit that the proposed scheme outperforms the existing scheme with varying vehicle densities.

3.3 AHP-WSN

3.3.1 Communication Protocol

Due to severe constraints on energy consumption, power aware routing becomes a major research challenge in WSN. To address this issue, an Analytical hierarchy process based Energy aware Geographical Multipath Routing (AE-GMR) scheme for WSNs is proposed in [34]. In this protocol, the most suitable next hop is determined by AHP, which possesses the following criteria: distance to the destination location, remaining battery capacity, and queue size of candidate sensor nodes in the local communication range. The routing protocol consists of three steps: (1) collect information and formulate as AHP, (2) determine the rank, and (3) obtain the weight and identify the next best hop with the largest weight. Extended lifetime, reduced packet loss as well as reduced link failure rate are observed through the analysis of the simulation results.

3.3.2 Deployment Issue

To resolve deployment issues, a stochastic deployment problem is addressed by Otero et al. [35]. The methodology uses simulation, statistical analysis, and AHP correspondingly to determine the best deployment strategies. AHP criteria consists of radio range, connectivity, sensor range, coverage, and power. By employing AHP in the decision process, it is possible to expand the proposed model to compare deployment strategies. On the other hand, due to inheritance from ad hoc networks, WSNs operate in self-organizing networks. Thus, the task of selecting self-organizing algorithm in WSN according to networks environment is pivotal. Bezruk et al. [36] use AHP to rank the suitable self-organizing algorithms among the nine relevant algorithms: (1) optics based algorithm, (2) persistent algorithm, (3) payment scheme algorithm, (4) rapid algorithm, (5) bio-Inspired mechanisms based algorithm, (6) SIDA algorithm, (7) UWB technology based algorithm, (8) expanding ring algorithm, and (9) BOOTUP algorithm. Analysis of the results demonstrate that the payment scheme algorithm receives the highest weight by payment scheme using transmission power as a mediator.

3.4 AHP-DTN/ON

Communication protocol. AHP is used to develop a communication protocol for DTN and ON. First, multicast and QoS routing strategies are analyzed through AHP. Zhang and Zhou [37] propose a Rough Ret Approach for Multicast Routing strategies (RSAPEMR) for DTNs. A multi-layer evaluation index system (EIS) based on AHP is proposed to classify the current strategies into groups. EIS of DTN multicast routing strategies comprising of four layers which are objective layer (OL), standard layer (SL), metric layer (ML), and reserve metric layer (RML). Moreover, SL contains three primary evaluation indexes, functionality, practicability, and applicability, whereas the ML consists of fourteen secondary evaluation indexes.

Another QoS routing protocol for DTN is proposed in [38]. The protocol, which is dependent on connectivity, is developed by AHP. This implies that different criteria for AHP hierarchy is applied. First, QoS demand with delay and bandwidth, as well as link stability with energy and hops, are used for connected networks. On the other hand, for the interrupted networks where buffer and connection time are critical for the store and carry scheme, QoS demand consists of delay, bandwidth, and communication time. Moreover, instead of link stability, node performance with energy and buffer are considered for criteria. By means of AHP with the mentioned criteria, the proposed scheme with QoS aware routing can maximize the delivery ratio while minimizing delay.

3.5 AHP-SIN

Communication protocol. Because clustering in SIN is quite different from common self-organizing networks, different cluster head and cluster maintenance algorithms are demanded. To make decisions for cluster head, a decision model based on AHP is proposed by Ye et al. [39]. To rank nodes for cluster head, power level, relative velocity, node, and surplus energy are considered as criteria. Additionally, mobile agent technology to rotate cluster head is accomplished in this work. With the help of the mobile agent, it is possible to migrate cluster information effectively.

4 TOPSIS in Ad Hoc Networks

Comparable to the AHP algorithm, most ad hoc networks consider TOPSIS to solve MADM problems. Moreover, because AHP reveals the rank reverse problem and high computing complexity with many alternatives, TOPSIS is a more suitable solution for the above-mentioned situation.

4.1 TOPSIS-MANET

Antenna. First, Bandyopadhyay et al. [40] address the use of directional antenna in MANET to improve system performance. However, as it is not affected and guaranteed by a single factor, the authors identify several criteria and investigate their interrelationships. Thus, to employ MADM in this research area, both AHP and TOPSIS are utilized to identify relative weights of the different criteria and identify the ideal case. To model the directional antenna, the beam-angle is varied from 30° to 360°. Both AHP and TOPSIS consider longevity, medium utilization, cost of antenna, and cost of overhead to rank the alternatives.

Handover. Handover and network selection process over MANET need to be processed as rapidly as possible. To defeat computation complexity of the heavy network selection algorithm, Dynamic-TOPSIS (D-TOPSIS) is defined by Bisio et al. [41]. The attributes for the D-TOPSIS are, Received Signal Strength Indicator (RSSI), Available Capacity (AC), Monetary Cost (MC), and Power Consumption (PC). The numerical results reveal the execution time reduction through D-TOPSIS with respect to the standard algorithm and current technique for handover.

4.2 TOPSIS-VANET

Handover. Comparable to MANET, handover issue is also an important research challenge in VANET. Thus, a new handover decision strategy is introduced with vertical handover criterion through TOSPIS in [42]. To build a decision matrix, bandwidth, delay, jitter, error, and cost with four traffic patterns are employed. The handover is performed in the order of rating attribute, ranking networks, and handover execution. Additionally, TOPSIS based analysis is compared with other algorithms.

Real-time delivery. Further research required in VANET is to assess the Quality of Experience (QoE) levels and supporting on-road real-time video delivery. Multi-flow-driven VIdeo DElivery (MVIDE) [43] integrated with routing protocol is proposed to select the best routes for live video sequences in VANETs. Each route is characterized by multiple paths such as vehicle mobility and application requirements and is then ranked by TOPSIS. The five attributes in TOPSIS include 1-hop distance, direction, speed, delay, and the buffer level of its neighbors. For real-time video delivery, forward decision and multi-flow handling process are defined in MVIDE as shown in Figure 5. Finally, MVIDE is integrated with Greedy Perimeter Stateless Routing protocol with Movement Awareness (GPSR-MA) protocol to deal with multi-flow and improve the received video quality.

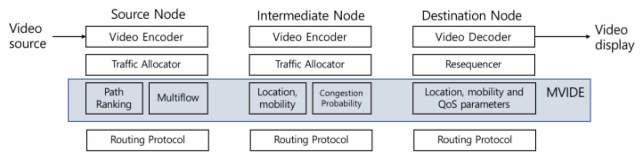

Figure 5. MVIDE architecture at each node

Communication protocol. The last protocol in VANET is a bio-inspired unicast routing protocol based on attractor selecting (URAS) [44]. TOPSIS is employed to reduce the number of redundant candidates for next-hop selection while enhancing the performance of attractor selection mechanism. Their major technical contribution is the process to identify a better path adaptively, based on the performance of the current path, as a way of self-evolution until the best routing path is identified and established. The four attributes included in TOPSIS are, the projection of the relative speed between nodes, the projection of the relative speed of the node and the destination node, the distance between node and destination, and congestion degree of data buffer of node. These parameters assist in displaying the mobility pattern and congestion level.

4.3 TOPSIS-WSN

Clustering. Energy efficiency problem in collaborative wireless sensor networks (CWSN) is addressed by Li et al. [45]. TOPSIS is used to build a metrics system by including cost and benefit parameters to perform the numerical analysis of energy efficiency of the clustering protocol. Popular clustering protocols called LEACH, LEACH-C, SEP, and HEED are compared in this work. Cost parameters include the area of the rectangular field, density of sensor nodes, number of all nodes, sum of all the nodes' initial energy, and distance between the center of the area. Benefit parameter includes the time when first invalid node appears or time at which the first dead node appears, time when all nodes run out of energy, the ratio of the two mentioned parameters, total bits of effective data received by the base station, standard deviation of the round at which the first dead node appears and computed values. Each protocol is evaluated under different cost conditions and compared with each other. The numerical results contribute to the selection of collaborative protocols. Similarly, Hamzeloeia and Dermany [46] address clustering architecture for energy efficiency through clustering in WSN. To select a cluster head and manage the entire networks, it is essential to select the cluster head through MADM. Accordingly, the four chosen parameters for TOPSIS are, the residual energy, the number of neighbors, the distance below the base station, and the transmission range for each node. The proposed method contributes to cluster head selection with a higher accuracy and an extended network lifetime.

4.4 TOPSIS-DTN/ON

Communication protocol. ON with smartphone in peer-to-peer manner was studied by Liyanage et al. in [47]. The major objective of this work was to propose an energy-aware forwarding protocol for large data messages and implement it over the Wi-Fi. TOPSIS with parameters, hop count, and the tightness values for each path to the destination are utilized to rank the weight and find the best route. Moreover, the proposed routing scheme is implemented by contact history table and the connection time between nodes.

5 GRA in Ad Hoc Networks

In contrast to AHP and TOPSIS, sparse research work has been conducted into the use of GRA. GRA is adapted for MANET, VANET, WSN, and DTN/ON for communication protocol or network selection problem.

5.1 GRA-MANET

Communication protocol. First, Chu et al. [48] proposed a weighted ad-hoc routing protocol to achieve low cost and high efficiency. The weight value is computed through GRA with the factors hop count, end-to-end delays, and node's residual energy. Thus, the proposed routing protocol can handle changed network topology, energy consumption, and end-to-end delay for QoS.

Handover. Handover problem is also solved and analyzed through GRA in [49] by using FRA to decide the optimal next handover node under cross layer architecture. The evaluation factors considered in their work were Received Signal Strength Indicator (RSSI), payload, and the queue length in the buffer indicating a node's congestion level. The network layer handover scheme is triggered according to the relative movement tendency. In other words, a node measures the distance to the corresponding node periodically and computes the relative velocity. Subsequently, the network layer handover is activated and performed for the most suitable node computed by GRA.

5.2 GRA-VANET

Communication protocol. Network selection problem for vehicle equipped with multiple network interfaces is presented in [50]. The proposed scheme intends to serve a best Concurrent Multipath Transfer (CMT) service in VANET. To achieve this, Grey Relational Analysis based Concurrent Multipath Transfer (GRA-CMT) is extended for Stream Control Transport Protocol (SCTP). While GRA-CMT aims at efficient data scheduling algorithms, GRA-based CMT Retransmission algorithm does efficient retransmission. To calculate GRC, network parameters and quality of path are determined by parameters such as delay, packet loss rate, and bandwidth. Delay and packet loss are required to be smaller. On the other hand, larger bandwidth is regarded as optimal.

Security-Trust model. In VANET, as the trust between nodes is continuously changed due to network dynamics, a reputation-system plays a significant role in detecting malicious and selfish nodes in VANET. However, as it is not an easy task to obtain trust experience between nodes, a simple approach cannot adequately meet the trust evaluation requirements. To resolve this problem, Hong et al. [51] propose a new reputation method based on GRA in VANET by presenting trust relationship between nodes.

Multimedia service. In VANET, due to its high dynamic topology, packet loss, and delay are frequently observed, resulting in researchers preferring low video quality. To meet this interest, robust Scalable Video Coding (SVC) based streaming over VANET is proposed through path diversity and network coding by Razzaq and Mehaoua in [52]. The proposed scheme calculates the quality of all candidate paths based on GRA and then assigns paths to different layers according to their importance. Each path is evaluated by GRA with delay, jitter, loss rate, and throughput.

5.3 GRA-WSN

Communication protocol. Because energy-efficient routing protocols do not offer a complete framework for service differentiation, a new routing approach requires various cost metrics that can parametrize the requirement. In this work, Azim et al. [53] propose an application-aware routing protocol (AARP) that takes into consideration the battery power, data transaction reliability, and end-to-end delay for service differentiation. To achieve this, AGP and GRA are incorporated for node selection. The simulation results prove that the proposed routing protocol can offer service configurability across a wide range of applications.

Deployment issue. Mobile Agent (MA) in WSN performs the task of data processing and data aggregation to eliminate the redundant network overhead. A significant technical issue for MA is planning an itinerary for MA traversal, as addressed in [54]. To determine the itinerary of MA traversal, GRA selects the next node in the itinerary considering the factors, residual energy, migration cost, and information gain. In addition, GRA contributes to identifying the importance level through weight values of each node.

5.4 GRA-DTN/ON

Security-trust model. Xu and Shou [55] propose a Grey Relational Analysis Trust Model (GRATM) that is based on GRA and cooperative computation for a trust model in ON. GRATM presents a method to calculate the trust value with recommendation from other nodes. Trust information is sent to others by exchanging regular packages and to determine forwarding, the evaluated node is compared to the threshold. GRA considers the following as factors: contact intimacy, delivery reliability, and location intimacy.

6 SAW in Ad Hoc Networks

Among the four algorithms, SAW has the least amount of research to account for the MADM problem. Moreover, most of the research work is involved in MANET. There are no SAW studies yet for WSN and DTN/ON.

6.1 SAW-MANET

Deployment issue-protocol selection. For the QoS in MANET, routing protocol plays an important role. Due to large number of attributes of QoS metrics, it is imperative to balance the competing QoS metrics through SAW-AHP. The proposed SAW-AHP model in [56] primarily involves two steps, performance evaluation and adaptive process. The former is to select an optimal protocol and the latter is to switch dynamic protocol. AHP considers packet delivery ratio, delay, jitter, throughput, and energy cost. On the other hand, dynamic protocol considers reactive DSR and proactive DSDV.

Deployment issue-gateway selection. To address security, secure gateway selection problem is a far-reaching research challenge to prevent information leak and data falsification. However, higher cost to manage multiple gateways prevents an optimum solution in selecting an appropriate gateway with feasible metrics, specifically, remaining energy and gateway load to connect MANET and infrastructure. To achieve this, Patra and Mallick [57] propose SAW method to calculate weights of gateway nodes and then select the highest weighted node as the gateway. In addition, Dynamic MANET On demand (DYMO) routing protocol is proposed and implemented to take the requirement of application into account. The application is divided into special data and normal data. A further similar work based on DYMO is proposed in [58]. This approach also considers the mobility metrics, namely inter and intra MANET traffic load and residual energy, to evaluate weights of each gateway node. In contrast, Setiawan et al. [59] follow the same steps for gateway selection but apply different metrics to SAW. The remaining energy metric is considered positive criteria while negative criteria includes number of hops and mobility metric. The last method to employ SAW for gateway selection is mentioned in [60]. The authors utilize three QoS metrics, traffic load of gateway, path quality from MANET node to the gateway, and hop count to the gateway. Simulation results reveal that the proposed scheme improves packet delivery ratio and reduces end to end delay.

6.2 SAW-VANET

Deployment issue-gateway selection. Gateway selection problem is an essential research challenge in VANET as well. However, due to a higher dynamic topology, channel fading affects network efficiency and stability of link. To select an efficient gateway in [61], correctly decoded probability, network delay, and relative velocity are used for metrics in SAW. Gateway selection algorithm consists of initialization and a mobile gateway selection phase. For the simulation, actual VANET scenario, channel fading and shadow factors are considered in modeling.

7 Open Issues

Varying parameters. Due to a dynamic network topology, the values of several parameters in ad hoc networks vary according to the nodes' mobility. Despite the considerable research work conducted to establish a stable path, some criteria and metrics freely change. However, as MADM schemes cannot reflect these changes promptly, in most cases the established path is not the optimal one. It is essential to determine when the parameter is changed and how the parameter is computed to reflect these changes appropriately.

Integration into protocol. Even though MADM can generate the optimal solution, it should be integrated with the communications protocol. Without integration, it is simply an ideal case and solution. To integrate it with the protocol, it is required to define information that will be exchanged and the type of actions to be taken according to the message exchanged. Additionally, as frequent triggering on the protocol is a further overhead in the protocol, it is necessary to decide how the protocol initializes and operates. Besides, most MADM algorithms assume that all pertinent information is known to each node prior to computation, and hence its integration with the communication protocol is another issue.

Integration into network simulator. Akin to the rationale for varying parameters, MADM algorithms should be evaluated and compared with other algorithms. In ad hoc networks, simulation is the popular and frequently used performance evaluation tool. However, the current network simulator is not a suitable environment to implement MADM algorithm due to its event driven operation. Moreover, there is no available open source for MADM to be integrated in the network simulator yet. Hence, it is recommended to implement an available MADM to a well-known network simulator, such as NS-2 and NS-3.

Combination with other algorithms. Because each MADM algorithm has unique characteristics, there are both advantages and disadvantages. This implies that it is possible to combine more than two schemes. For example, SAW-AHP and AHP-GRA are used to elaborate the MADM solution as we mentioned earlier. However, because other combinations are available as well, it is recommended to combine them to efficiently solve the complex problem.

8 Conclusion

To illustrate decision making, MADM algorithms in ad hoc networks have been detailed in this paper. We explain the four well-known MADM algorithms, AHP, TOPSIS, GRA, and SAW. Furthermore, each scheme is further categorized based on the type of ad hoc network: MANET, VANET, WSN, or DTN/ON. In each categorization, the existing research work is grouped based on the research objectives such as communication protocol and deployment issue. Notwithstanding the significant research work studied and conducted in this area, some challenges persist that need to be addressed to enable the effective utilization of these solutions. Furthermore, our effort to discover the related work on fuzzy logic based scheme is not included in this paper and remains a topic to be analyzed in a future study.

Acknowledgements

This work has been supported by the Small-scale Mobile Adhoc Network with Bio-networking Technology Project of Agency for Defense Development (UD170097ED).

References

[1] N. Gupta, R. Gupta, Routing Protocols in Mobile Adhoc Networks: An Overview, *International Conference on Emerging Trends in Robotics and Communication Technologies*, Chennai, India, 2010, pp. 173-177.

[2] S. Singh. S. Agrawal, VANET Routing Protocols: Issues and Challenges, *International Conference on Recent Advances in Engineering and Computational Sciences*, Chandigarh, India, 2014, pp. 1-5.

[3] J. Kumari, Prachi, A Comprehensive Survey of Routing Protocols in Wireless Sensor Networks, *International Conference on Computing for Sustainable Global Development,* New Delhi, India, 2015, pp. 325-330.

[4] S. Bharamagoudar, S. Saboji, Routing in Opportunistic Networks: Taxonomy, Survey, *International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques*, Mysuru, India, 2017. pp. 300-305.

[5] R. Amirthavalli, R. Dhaya, N. Chandrasoodan, A Survey of Routing Algorithms in Delay Tolerant Networks, *International Conference on Applied and Theoretical Computing and Communication Technology*, Bangalore, India, 2016, pp. 469-473.

[6] K. Dai, C. Zhu, A New Architecture Design of Space Information Networks, *International Conference on Internet Computing for Science and Engineering*, Henan, China, 2012, pp. 217-220.

[7] T. Saaty, Decision Making with the Analytic Hierarchy Process, *International Journal of Services Sciences*, Vol. 1, No. 1, pp. 83-98, January, 2008.

[8] C. Hwang, K. Yoon, *Multiple Attribute Decision Making: Methods and Applications*, Springer, 1981.

[9] J. Deng, Control Problems of Grey Systems, *System & Control Letter*, Vol. 1, No. 5, pp. 288-294, March, 1982.

[10] K. Yoon, C. Hwang, *Multiple Attribute Decision Making: An Introduction*, Sage, 1995.

[11] R. Kumar, P. Verma, Y. Singh, An Efficient Routing Scheme for MANETs, *International Conference on Computational Intelligence and Computing Research*, Coimbatore, India, 2014, pp. 1-7.

[12] V. Saini, V. Kumar, AHP, Fuzzy Sets and TOPSIS Based Reliable Route Selection for MANET, *International Conference on Computing for Sustainable Global Development*, New Delhi, India, 2014, pp. 24-29.

[13] C. Josephine, V. Somasundaram, Implementation of FTRAHP Routing Scheme for Enhancing the Mobile Ad-hoc Networks, *International Journal of Scientific & Engineering Research*, Vol. 8, No. 2, pp. 31-34, February, 2017.

[14] A. Uddin, M. Monir, S. Iqbal, A QoS Aware Route Selection Mechanism Using Analytic Hierarchy Process for Mobile Ad Hoc Network, *International Conference on Computers and Information Technology*, Dhaka, Bangladesh, 2009, pp. 552-557.

[15] M. Thaalbi, N. Tabbane, T. Bejaoui, A. Meddahi, A Weighted QoS Aware Multipath Routing Process in Mobile Ad Hoc Networks, *International Conference on Computers and Communications*, Split, Croatia, 2013, pp. 336-341.

[16] H. Luo, *Best Effort QoS Support Routing in Mobile Ad Hoc Networks*, Ph.D. Thesis, The University of Edinburgh, 2012.

[17] A. Malik, T. Khan, A. Mahboob, Evaluation of OLSR Protocol Implementations Using Analytical Hierarchical Process (AHP), *International Journal of Advanced Computer Science and Applications*, Vol. 7, No. 11, pp. 338-344, November, 2016.

[18] L. Heng, G. Ai-Huang, Energy Efficiency Comparison of Sack, Tahoe, Reno and Newreno over Ad Hoc Network Based on Analytic Hierarchy Process, *International Conference on Wireless Communications, Networking and Mobile Computing*, Wuhan, China, 2006, pp. 1-4.

[19] U. Venkanna, R. Velusamy, TEA-CBRP: Distributed Cluster Head Election in MANET by Using AHP, *Peer-to-Peer Networking and Applications*, Vol. 9, No. 1, pp. 159-170, January, 2016.

[20] S. Francis, E. Rajsingh, G. George, Enhancing Stability of Network through Clustering in Mobile Ad Hoc Networks, *International Conference on Next Generation Mobile Application*s, Services and Technologies, Cardiff, UK, 2009, pp. 461-466.

[21] R. Deepa, S. Swamynathan, Load Balancer for Energy Efficient Clustering Protocol in MANETs, *International Conference on Advances in Computing, Communications and Informatics*, Chennai, India, 2012. pp. 269-274.

[22] L. Yu, C. Qian, Z. Liu, K. Wang, B. Dai, Ad-hoc Multi-dimensional Trust Evaluation Model Based on Classification of Service, *International Conference on Communications and Networking in China*, Beijing, China, 2010, pp. 1-5.

[23] H. Xia, Z. Jia, L. Ju, Y. Zhu, Trust Management Model for Mobile Ad Hoc Network Based on Analytic Hierarchy Process and Fuzzy Theory, *IET Wireless Sensor Systems*, Vol. 1, No. 4, pp. 248-266, December, 2011.

[24] H. Xia, Z. Jia, L. Ju, X. Li, Y. Zhu, A Subjective Trust Management Model with Multiple Decision Factors for MANET Based on AHP and Fuzzy Logic Rules, *International Conference on Green Computing and Communications*, Sichuan, China, 2011, pp. 124-130.

[25] J. Wang, Y. Ji, X. Wang, F. Liu, RSU-coordinated Multi-channel MAC with Multi-criteria Channel Allocation, *International Conference on Connected Vehicles and Expo*, Beijing, China, 2012, pp. 60-65.

[26] L. Katsaros, M. Dianati, Z. Sun, R. Tafazolli, An Evaluation of Routing in Vehicular Networks Using Analytic Hierarchy Process, *Wireless Communications and Mobile Computing*, Vol. 16, No. 8, pp. 895-911, June, 2016.

[27] Y. Rajkumar, Agent Based Dynamic Analytical Hierarchy Routing Protocol for Vehicular Ad Hoc Networks, *International Journal of Computer Science and Information Technologies*, Vol. 7, No. 5, pp. 2175-2182, September, 2016.

[28] D. Ou, Y. Yang, L. Xue, T. Shen, L. Zhang, The Analytic Hierarchy Process Based Optimal Forwarder Selection in Multi-hop Broadcasting Scheme for Vehicular Safety, *International Conference on Intelligent Vehicles*, Dearborn, US, 2014, pp. 999-1004.

[29] I. Chantaksinopas, P. Oothongsap, A. Prayote, Network Selection Delay Comparison of Network Selection Techniques for Safety Applications on VANET, *International Conference on Network Operations and Management Symposium*, Taipei, Taiwan, 2011, pp. 1-7.

[30] B. Cheng, G. Liao, C. Chen, H. Chen, A Multi-level Fuzzy Comprehensive Evaluation Approach for Message Verification in VANETs, *International Conference on Mobile, Ubiquitous, and Intelligent Computing*, Vancouver, Canada, 2012, pp. 176-181.

[31] D. Saraswat, B. Chaurasia, AHP Based Trust Model in VANETs, *International Conference on Computational Intelligence and Communication Networks*, Mathura, India, 2013, pp. 391-393.

[32] D. Alishev, R. Hussain, W. Nawaz, Social-aware Bootstrapping and Trust Establishing Mechanism for Vehicular Social Networks, *International Conference on Vehicular Technology*, Sydney, Australia, 2017, pp. 1-5.

[33] M. Patra, S. Mishra, C. Murthy, An Analytic Hierarchy Process Based Approach for Optimal Road Side Unit Placement in Vehicular Ad Hoc Networks, *International Conference on Vehicular Technology*, Seoul, Korea, 2014, pp. 1-5.

[34] X. Wu, J. Cho, B. dAuriol, S. Lee, Energy-aware Routing for Wireless Sensor Networks by AHP, *International Conference on Software Technologies for Embedded and Ubiquitous Systems*, Santorini Island, Greece, 2007, pp. 446-455.

[35] C. Otero, I. Kostanic, L. Otero, S. Meredith, M. Whitt, Analysis of Wireless Sensor Networks Deployments Using Vertical Variance Trimming and the Analytic Hierarchy Process, *International Journal of Ad Hoc, Sensor & Ubiquitous Computing*, Vol. 2, No. 1, pp. 169-190, March, 2011.

[36] V. Bezruk, J. Skorik, V. Vlasova, Y. Koltun, A. Kostromitsky, Analytic Hierarchy Process for Choosing the Self-organization Algorithm for Wireless Sensor Network, *International Conference on Problems of Infocommunications Science and Technology*, Kharkiv, Ukraine, 2016, pp. 189-191.

[37] L. Zhang, X. Zhou, A Rough Set Performance Evaluation Approach for Multicast Routing Strategies in Delay and Disruption Tolerant Networks, *International Conference on Future Information Networks*, Beijing, China, 2009, pp. 280-284.

[38] Q. Jiang, C. Men, B. Zhang, S. Fu, A QoS Aware Routing for Intermittently Connected Mobile Networks, *International Conference on Internet Computing for Science and Engineering*, Harbin, China, 2015, pp. 202-207.

[39] N. Ye, R. Geng, X. Song, Q. Wang, Z. Ning, Hierarchic Topology Management by Decision Model and Smart Agents in Space Information Networks, *International Conference on High Performance Computing and Communications*, New York, US, pp. 1817-1825.

[40] S. Bandyopadhyay, M. Pal, D. Saha, T. Ueda, K. Hasuike, R. Pal, Improving System Performance of Ad Hoc Wireless Network with Directional Antenna, *International Conference on Communications*, Anchorage, US, 2003, pp. 1146-1150.

[41] I. Bisio, C. Braccini, S. Delucchi,. F. Lavagetto, M. Marchese, Dynamic Multi-attribute Network Selection Algorithm for Vertical Handover Procedures over Mobile Ad Hoc Networks, *International Conference on Communications*, Sydney, Australia, 2014, pp. 342-347.

[42] M. Kumaran, M. Jeyakumar, Performance Analysis of Vertical Handover Algorithm in Vehicular Ad-hoc Network Using IEEE 802.21, *International Journal of New Innovations in Engineering and Technology*, Vol. 6, No. 1, pp. 13-18, September, 2016.

[43] C. Quadros, E. Cerqueira, A. Santos, A. Santos, M. Gerla, A Multi-flow Driven Mechanism to Support Live Video Streaming on VANETs, *International Conference on Computer Networks and Distributed Systems*, Florianopolis, Brazil, 2014, pp. 468-476.

[44] D. Tian, K. Zheng, J. Zhou, X. Duan, Y. Wang, Z. Sheng, Q. Ni, A Microbial Inspired Routing Protocol for VANETs, *IEEE Internet-of-Things Journal*, Vol. 99, pp. 2293-2303, August, 2017.

[45] J. Li, J. Zhou, Y. Zhang, Comprehensive Evaluation of Energy Efficiency Based on TOPSIS for Protocols of Collaborative Wireless Sensor Networks, *International Journal of Distributed Sensor Networks*, Vol. 11, No. 4, pp. 1-13, April, 2015.

[46] F. Hamzeloei, M. Dermany, A TOPSIS Based Cluster Head Selection for Wireless Sensor Network, *Procedia Computer Science*, Vol. 98, pp. 8-15, October, 2016.

[47] M. Liyanage, C. Chang, S. Sriram, An Energy-aware Forwarding Protocol for Multimedia Opportunistic Networks, *International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services*, Hiroshima, Japan, 2016, pp. 274-275.

[48] H. Chu, Y. Hsu, Y. Lai, A Weighted Routing Protocol Using Grey Relational Analysis for Wireless Ad Hoc Networks, *International Conference on Autonomic and Trusted Computing*, Oslo, Norway, 2008, pp. 655-663.

[49] H. Tang, S. Yao, Y. Zhang, Study on the Cross-layer Handover Method Based on Grey Relational Analysis in Ad Hoc Network, *International Conference on Natural Computation*, Shanghai, China, 2011, pp. 2042-2045.

[50] Y. Cao, C. Xu, J. Guan, J. Zhao, W. Quan, M. Zhang, H. Zhang, Relational Analysis Based Concurrent Multipath Transfer over Heterogeneous Vehicular Networks, *International Journal of Computer Science Issues*, Vol. 9, No. 5, pp. 1-9, September, 2012.

[51] L. Hong, W. Chen, C. Fu, G. Zhang, Research on Node's Trust Computation Based on Grey Relational Analysis Theory in MANETs, *International Conference on Information Science and Engineering*, Nanjing, China, 2009, pp. 5389-5392.

[52] A. Razzaq, A. Mehaoua, Video Transport over VANETs: Multi-stream Coding with Multi-path and Network Coding, *International Conference on Local Computer Networks*, Denver, USA, 2010, pp. 32-39.

[53] M. Azim, M. Kibria, A. Jamalipour, Designing an Application-aware Routing Protocol for Wireless Sensor Networks, *International Conference on Global Telecommunications*, New Orleans, 2008, pp. 1-5.

[54] D. Lohani, S. Varma, Itinerary Planning Using Grey Relational Analysis for Mobile Agent Based Wireless Sensor Networks, *International Conference on Contemporary Computing*, Noida, India, 2013. pp. 29-34.

[55] S. Xu, A Trust Model Based on Grey Relational Analysis and Cooperative Computing in Opportunity Networks, *International Conference on Wireless Communication and Sensor Network*, Wuhan, China, 2016, pp. 142-147.

[56] H. Luo, D. Laurenson, A. Guo, J. Chen, P. Yang, H. Jiang, A QoS Balancing Model for Mobile Ad Hoc Networks, *WSEAS Transactions on Communications*, Vol. 13, pp. 372-377, January, 2014.

[57] S. Patra, J. Mallick, On Demand Load Balance Secure Routing Scheme for Mobile Adhoc Network, *International Journal of Engineering and Computer Science*, Vol. 4, No. 2, pp. 10529-10532, February, 2015

[58] R. Gargi, Y. Chaba, R. Patel, Multi-criteria Gateway Selection & Multipath Routing Protocol for Hybrid MANETs, *International Journal of Computer Applications*, Vol. 49, No. 7, pp. 33-40, July, 2012.

[59] F. Setiawan, S. Bouk, I. Sasase, An Optimum Multiple Metrics Gateway Selection Mechanism in MANET and Infrastructured Networks Integration, *International Conference on Wireless Communications and Networking*, Las Vegas, USA, 2008, pp. 2229-2234.

[60] Y. Yan, L. Ci, Z. Wang, W. He, QoS-based Gateway Selection in MANET with Internet Connectivity, *International Conference on Advanced Communication Technology*, PyeongChang, Korea, 2013, pp. 195-199.

[61] K. Chen, L. Chen, J. Mao, D. Zhao, A Multiple Metrics Gateway Selection Algorithm for Vehicular Ad Hoc Networks in Fading Channels, *International Conference on Computation Intelligence and Security*, Leshan, China, 2013, pp. 648-652.

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