



# M-ODD: A Standard Protocol for Reporting MANET Related Models, Simulations, and Findings

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**Abstract.** There has been a steady increase in the number of research publications in the Mobile ad hoc Network (MANET) domain over the last two decades. However, several studies have indicated that the credibility of MANET simulation publications may be in question because numerous publications lack vital information (e.g., simulation tools, variables, parameters used) and statistical rigor. This has led to issues of repeatability and reproducibility of previous work and calls into question the validity of the simulation results which are difficult or impossible to verify. To address this, we propose a modified Overview, Design Concepts, and Details (ODD) protocol, based on the work of Grimm et al., as a standard documentation protocol for MANET simulation studies. The MANET ODD (M-ODD) protocol will promote credibility within the domain of study by increasing repeatability, reproducibility, and statistical rigor.

**Keywords:** MANET · Mobile ad hoc · Ad hoc networks · Standardization · Simulation · Scientific communication · Documentation protocol

## 1 Introduction

Mobile ad hoc Networks (MANETs) provide a means of communication between mobile users without the need for fixed infrastructure (e.g., wireless internet access points). Interest in MANETs has grown over the years as its applications have become more widespread and evident. Such applications are providing communication in disaster relief, providing wireless connectivity in suburban environments, as well as providing communication in military situations [1, 2]. However, multiple surveys of MANET simulation papers have found the credibility of MANET research to be severely compromised. It has been observed that there is a “lack of reliability of MANET simulation-based studies” by Kurkowski et al. [3] and that less than 15% of MobiHoc papers published between 2000 and 2005 are repeatable [3]. An analysis of MANET simulation papers published from the

Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM) between 2010 and 2017 held comparable results. It indicated that only 26% of papers were completely repeatable, and that there were design flaws, unrealistic assumptions, lack of reproducibility, and statistically invalid results in a large majority of published papers [4]. The reason most studies were found to lack reproducibility was that they were missing key information, such as the simulator used, type of simulation used, value of initial variables, number of simulations run, and Pseudo Random Number Generator (PRNG) information [3, 4]. The lack of reproducibility reduces author credibility and hinders further academic progress within the field since the stable and reliable groundwork that new researchers depend on to conduct their experiments and develop new methods is unverifiable, unreliable, or lacking in rigor. Instead, researchers must focus their efforts on correcting, verifying, or reinvestigating domain knowledge before further advancements can be made. Ultimately this reduces the credibility and trustworthiness of domain results.

These challenges are not unique to MANET simulation-based research. In fact, simulation-based research involving agent-based and individual-based models once shared similar issues: the research was difficult to replicate, difficult to understand, and was often described verbally rather than with equations, tables, figures, etc. [5]. These issues prompted Grimm et al. (2006) to create a standard documentation protocol for describing these models called the Overview, Design Concepts, and Details (ODD) protocol. The original ODD protocol included three main sections: Overview, Design Concepts, and Details. The Overview and Details sections were each further divided into three subsections. The Overview included subsections of 1) Purpose, 2) State Variables and Scales, and 3) Process Overview and Scheduling. Subsections of Initialization, Input, and Sub-models made up the details section. The protocol was updated in 2010 and again in 2020 [6, 7] to include a wider set of design concepts (e.g., adaptation, learning, prediction, sensing) [6], and to include example documents (e.g., TRACE documents, Nested ODD) to improve clarity, replication, and structural realism [7].

In this paper, we propose a modified version of Grimm et al.'s ODD documentation protocol, to provide a standard documentation protocol for future MANET simulation studies. Specifically, we propose the addition of two subsections to the details section that are necessary for reproducibility: System Requirements, and Software Overview. These two subsections will allow researchers to reproduce documented simulations accurately by ensuring they have the correct tools (e.g., simulation tools, computer setups, etc.) to do so. As such, the proposed MANET ODD (M-ODD), will provide a protocol for researchers to improve the reproducibility, consistency, and statistical soundness of their studies. Ultimately, M-ODD will improve the credibility of MANET simulation research.

We begin with a summary discussion of the common pitfalls in MANET simulation studies that have been identified in previous reviews, particularly those that hinder replicability and verifiability in Sect. 2. Following this, we present the subsections of the proposed M-ODD protocol in Sect. 3. In Sect. 4 we evaluate

a series of MANET papers against the proposed M-ODD protocol (co-authored by one of the authors of this work) and provide specific examples that could improve the work. This is not to suggest that the findings are invalid, but that improvements in documentation could be helpful to ensure reproducibility of the work. Discussion and conclusions are provided in Sect. 5.

## 2 Common Pitfalls in MANET Research

In this section, we summarize some of the findings of two review papers of the MANET research domain. This is necessary to contextualize the proposed M-ODD framework.

### 2.1 Simulation Identification

Identifying the simulator used in a MANET simulation study is a key factor in determining a study's validity and reproducibility. It is vital that researchers identify and list the simulator used in their paper. Of 114 simulation papers surveyed in [3], roughly 30% failed to identify the simulator used and 27% used a custom simulation tool. Similarly, fewer than 40% of the simulation studies reviewed in [4] reported the simulation tool and version used. Neglecting to specify the simulation tool and version, or failure to provide access to the custom simulation tool compromises the repeatability and reproducibility of the simulation.

### 2.2 Input Parameters

Clearly identifying the input parameters used in a MANET simulation study is a crucial factor in determining a study's reproducibility. It was found that 10% of MANET simulation study papers surveyed in [4] did not report any parameters used in the simulation, and only 32% provided partial information. Of the papers surveyed in [3], 43% did not state the number of nodes used or the transmission range, 55% did not state the simulation duration, 64% did not state the number of simulation runs, and 47% did not state the size of the simulation area. The lack of incomplete parameters given (along with the lack of identifying simulation tools) rendered 53% of papers reviewed in [4] non-reproducible. It is important to list the input parameters, as the default parameters are not always appropriate for the purpose of the study. This may cause a researcher attempting to reproduce the simulation to choose incorrect parameters or assume that the default parameters are correct, making it impossible to reproduce (and verify) simulation results. See Fig. 1 for example.

parameter	symbol	value(s)
Number of nodes	$n$	127, 2110, 37777, 108360
Node speed	$v$	(0,10) m/s
Node pause time	$p_t$	(0,20) s
simulation length	$T$	4h
world area		5km x 5km
routing protocol		DSDV
messages sizes		512 bytes
number of iterations per setup		30
Radio model		802.11b, 2.4GHz
propagation delay model		constant speed delay
propagation loss model		log distance loss
loss exponent		3
loss reference loss		41.7dB
antenna Rx gain		0 dB
antenna Tx gain		0 dB

**Fig. 1.** An example list of parameters from a proposed simulation study in [8].

### 2.3 Mobility and Propagation Models

The mobility models used in a MANET simulation study are important for the verification of the study. This is because different mobility models result in different movement characteristics of nodes [9,10]. It allows other researchers to verify the validity of the study and the information presented. For example, using a freeway mobility model to represent node mobility of students walking on campus would be an inappropriate choice. In [4], Only 5% of studies provided complete information on the mobility and propagation models used, while 47% did not mention the mobility model used and 69% did not report the radio propagation model used. Additionally, in [3], 42% did not mention the type of mobility tool used, while approximately 57% did not state the type of mobility model used. For the correct conclusions to be drawn in MANET research, it is imperative that a peer reviewer be able to verify the validity of a MANET study, and to do so a researcher needs to provide complete information regarding the mobility model and propagation model used. It is also equally important that the appropriate mobility model is chosen, as using the incorrect mobility model renders the simulation and its findings irrelevant.

### 2.4 Statistical Validity

Statistical analysis is necessary to ensure the validity of findings of any simulation-based paper. MANET simulation studies are not exempt from this. Regardless, of the papers reviewed in [4], 84% did not report the seed value,

61% did not report the number of simulations run, and 66% did not report confidence intervals. Further, 64% of papers in [3] failed to indicate how many simulations were conducted. This is problematic as observations from a single simulation run should never be used for conclusive or generalizable results; single simulation runs fail to account for the stochastic nature of a simulation [3]. It is also important to identify sources of bias (removing or mitigating bias where possible) for a study to be statistically sound and generalizable. However, over 90% of studies in [3] may have suffered from initialization bias - the influence of initialization settings on study results. The presence of this bias may result in “contamination” of the conclusions determined by the study. To avoid this bias, researchers often delay gathering data from a simulation for a given period, called the “warm up” period [11]. Overall, less than 6% of the simulation studies reviewed in [3] and [4] were statistically sound. Statistical validity is essential to the credibility of a simulation paper. Thus, it is important to provide all required statistical information, as “lack of statistical information puts the validity of the paper in doubt” [4].

## 2.5 File Accessibility and Sharing

The lack of file accessibility and sharing impedes MANET research. It hinders the ability of researchers to reproduce a given simulation, which in turn makes the validity of a simulation extremely difficult to determine. Of the hundreds of MANET simulation papers available, it is impossible to expect a reader to be able to perfectly reproduce a simulation study with only a (partial) list of variables, functions, processes, equations, and the simulator details. Not being able to access simulation code and data sets creates a barrier for researchers trying to reimplement an algorithm. It leaves researchers and peer reviewers with no way to verify that the simulation was properly coded or configured, that the data used in the simulation was feasible, or that a replicated simulation is accurate. Despite this, not a single paper reviewed by [3] provided statements about code or dataset availability. This makes it so that new researchers cannot reproduce any studies [3], hindering further research and advances in the space. Thus, MANET simulation code, configuration files, and data sets should be publicly available, or described in sufficient detail to facilitate reproducibility.

## 3 M-ODD Protocol

The purpose of the M-ODD protocol is to provide a structure and guideline for future MANET simulation studies that ensures all information required to verify the validity of the study is present. The M-ODD protocol can be broken into three main sections with nine subsections (compared to the original seven subsections). We retain the three main sections of Overview, Details, and Design Concepts [5]. The Overview section remains unchanged with three subsections: Purpose, State Variables and Scales, and Process Overview and Scheduling. The purpose of the Overview section is to provide the reader with a skeleton of the

program implemented for simulations [5]. We follow the outline of the design concepts section, which discusses related general concepts, the design of the model, model objectives, and collection of observations [7]. We also propose two additional subsections (System Requirements and Software Overview) to the Details section to ensure that researchers know which materials are required to reproduce the simulation study. As such, the Details section is now composed of Initialization, Input, System Requirements, Software Overview, and Sub-models subsections. The details section aims to provide the reader with enough information to “re-implement the model and run the baseline simulations” [5].

### 3.1 The O of M-ODD: Overview

**Purpose.** The Purpose subsection is used to justify the model chosen, and to list the goals of the model [5]. Due to the nature of MANET studies, it is important that all models and algorithms be listed in the Purpose subsection, along with a short and concise justification of the chosen model or algorithm, and what the researcher hopes to achieve with the use of the model or algorithm. For example: if one uses a random waypoint mobility model with a quality-of-service algorithm, there should be a brief description of the model and algorithm, appropriate references, and justification and expectations of both items. This is typically provided in the introduction of the paper [5].

**State Variables and Scales.** The State Variables and Scales subsection is used to list all the state variables needed for the simulation study. State variables or low-level variables are variables that cannot be derived from other variables. Such variables should include the number of nodes, transmission range, movement speed, pseudo random number generator seed, and more. The unit of measurement should be provided for variables that require them. State variables should be presented in a table along with a brief description of the variable (see table 3 in [5] for an example). Scales can be presented in a separate table with the scale name. Network topology can also be described. A list of all messages and functions should be provided (for examples, see [12,13]). Due to the considerable number of variables needed to conduct a MANET simulation, it may be challenging to list all variables in a table in a conference or journal paper. We suggest that variables most integral to the study be published in a table in the body of the paper, with a complete list of simulation variables provided in supplementary materials or publicly available.

**Process Overview and Scheduling.** The Process Overview and Scheduling Subsection should provide the user with a “skeleton” of the functions and algorithms used in the simulation. Each process (including the order in which they are executed) and the effects of the process (including the order in which variables are updated) should be described for the reader [5]. If there are many processes used for the model, a table with all the processes listed should be provided [5]. See section V of [13], or [14,15] for several good examples of this. In

particular, [13] describes the algorithms included in each function and the order in which the processes occur. To improve readability and understanding, the use of flow charts, sequence diagrams, class diagrams, and other UML diagrams are highly encouraged.

### 3.2 The First D of M-ODD: Design Concepts

Description of general design concepts begins with the inclusion of the basic principles and objectives of a simulation. General concepts, theories, hypotheses, and modelling approaches related to the simulation design are included here, as well as a description of how they relate to the simulation's execution [7]. The scope of the system and applications of the simulation should be discussed, as well as its objectives, how the objectives will be measured, and potential thresholds to determine if a simulation has achieved its objectives [7]. The simulation design should also be clearly stated.

In the case of MANET simulation studies, it is particularly important to address the following two questions as part of the simulation design: 1) how are things grouped, and 2) how are data collected from the simulation for testing, understanding, and analysis? [5]. In the former case, this question should be used to provide details about how a cluster is grouped, how a network partition is grouped, and so on (see [16] for a detailed discussion describing how a node is grouped into a network partition). In the latter case, details regarding the method of collecting data across all simulation runs are required. For example, if the first 400 seconds of data were ignored in a 2000-second-long simulation, justification and reasoning should be provided. If simulations were completed under different scenarios (e.g., using a different number of nodes, transmission range, grid size, etc.) then each scenario should be described, including purpose and justification for inclusion in the study. Researchers may also want to include a description of the traffic model here. Which nodes are sources and sinks? How many of each, how often are they generating packets? Of what size? Is the payload constant, or variable? Is it using TCP, UDP, QUIC, or something else? What is the network stack model? Is it using a TCP/IP stack? Is it using 802.11 WLAN? Something custom? Has any of it been modified? If so, are those algorithms provided?

Here we also discuss the results and analysis of the study, specifically addressing whether the observed outcomes matched expected outcomes. For clarity, observations should be provided in accessible tables or figures (including the unit of measurement when needed). Figures should be labelled and drawn to support accessibility and understanding. Any other additional visual materials used to support the analysis of simulation results can be included in the observation subsection.

### 3.3 The Second D of ODD: Details

**Initialization.** The Initialization subsection is similar to the State Variables and Scales subsection from the Overview section. However, rather than listing a

brief description of each state variable, we now provide a table with a list of all the state variables and their values. If the values change per simulation, then it is recommended to include multiple tables or a multi-column table with the values for each simulation run. The initialization table and the state variables table can be viewed as one table shown in [5]. Just as mentioned in the State Variables subsection, the units of measurement must be included with the values of the variables that require them. As a MANET simulation typically has hundreds of variables, it is unreasonable to expect all variables to be listed in the paper given space constraints. A reference to a publicly available table with all variables and their values should be provided in the paper or in supplemental materials. The initialization table must include: the transmission range, the transmission range type (e.g., asymmetrical), number of nodes, PRNG seed, number of simulations run (for each simulation type), data generation variables, how nodes are placed, the length of time the simulation is run. If there are additional factors that may alter the communication range of a node (e.g., constructive, or destructive interference), they should be listed as additional notes relating to the initialization table.

**Input.** The Input subsection follows a similar format to the Initialization subsection. Specifically, a table describing all simulation input variables and their values across each simulation is required. If the number of input variables is large (relative to publication guidelines), a reference to a publicly available input file should be available. It is incredibly important that all input variables are provided and correctly recorded, as the simulation output is a direct reflection of the dynamically input variables [5].

**System Requirements.** The System Requirements subsection provides the tools that a researcher will need to replicate output from a MANET simulation. For transparency, a list of system requirements should be provided. The list should consist of CPU specifications, the operating system and version, the kernel version, the storage space needed to run the simulation and host all the files and programs needed for the simulation, along with any additional requirements needed to run the simulation (for example, see Fig. 2).

**Software Overview.** The Software Overview subsection is an essential subsection of the M-ODD protocol, as there is no way to reproduce a simulation if the tools used to program and run the simulation are unknown to a researcher. To facilitate reproducibility, the simulation software and version should be documented, along with any additional simulation software modules used. Animator software and version, code language and version, data types, variable settings, and encryption standards also need to be documented in the paper. In addition, if a finite state machine is used, the name of the machine, along with the appropriate state diagram and transition table should be included. All configuration and scenario files and code should be made publicly available and referenced

Item	Version
CPU	Ryzen7 2700x
GPU	ROG Strix 2080ti-OC
Operating system	Fedora 31
Kernel version	5.8.18-100
NS3 version	3.32
Netanim	3.108
Python	3.7.9

**Fig. 2.** Example system requirements list [8].

in the paper. If a custom simulation tool was used, the simulation tool should also be made publicly available for download and referenced in the paper (or described in sufficient detail to support replication). See [17] for example. It is also recommended to reference a Docker image or an executable that is runnable on most machines. For example, the simulation study described in Fig. 2 indicates it was implemented using a Fedora 33 operating system, with kernel version 5.12.8-200, using simulation tool NS3 version 3.32.

**Sub-models.** The Sub-models subsection provides the reader with an in depth understanding of the processes listed in the “Process Overview and Scales” sections in [5]. There are two approaches that can be taken to the Sub-models subsection, which depends entirely on the space limitation of the paper. The reader should be provided with enough detail to thoroughly understand and re-implement the model to complete the simulation themselves. The first option, if limited in space, is to supply a mathematical “skeleton” of the model [5]. The skeleton version should consist of a list of the equations, parameters and rules used in the model. Each equation and rule should have a brief explanation, while parameters should have a slightly more in-depth explanation. If the list of equations is too long, a complete list should be referenced and publicly available to the reader.

Our second option is to provide a full model description. The full model description is a more detailed version of the skeleton version. This means that the choice of equations and parameters should be fully explained and justified. All assumptions made must also be explained and justified. When completing a full model description, you want to answer questions such as: “What specific assumptions are underlying the equations and rules? How were parameter values chosen? How were sub-models tested and calibrated?” [5]. We can see a brief list of the parameters used in the model in Fig. 1. To improve upon this table, we could include a brief explanation of the parameter. It would also be helpful to provide a list of equations used for the calculations of any parameters or values. In addition, when providing a full model description, we will be following the

“Inclusion of rationale” guide provided by Grimm et al. (Section 4.3, [6]). This includes providing clarity and credibility to the readers by answering “why was this model chosen?” [6].

## 4 Application of the M-ODD Protocol

In this section, we begin with a review and ranking of a series of research publications by Ernst and Brown [17–23]. Each paper is reviewed and ranked based on the presence (+1 point) or absence (no points) of information required by the M-ODD protocol. Each paper can achieve a total of 35 points: 6 points from the Overview section; 2 points from the Design Concepts section; and 27 points from the Details section. Points are achieved by including information such as initialization of variables, system requirements, design concepts, and any other information suggested in the M-ODD outline. Following this, we describe the work of [17] through the lens of the M-ODD protocol and in comparison to [18–23]. We chose to apply the M-ODD protocol to [17] as it was neither the highest nor lowest ranked paper, but still performed well in comparison to [18–23].

### 4.1 Ranking

Each paper [17–23] was reviewed and scored using a simple presence/absence scoring system (see Table 1). The total score is a weighted average of the scores achieved in the Overview, Design Concepts, and Details sections of the M-ODD protocol. A score of 0% indicates that the article did not satisfy any of the M-ODD requirements, and we assert would be difficult to reproduce. A score of 100% indicates that an article satisfied all the M-ODD requirements, and by extension should be reproducible.

The lowest scoring paper [18] achieved a score of 16%. This score was due to the lack of inclusion of purpose, state variables, initialization variables, software overview, system requirements, input, and grouping information (to name a few). The paper provided insufficient information to allow a researcher to easily reproduce or verify it. The same can be said for [20] which scored only slightly higher at 19%. On the opposite end of the spectrum, [23] scored 61%. This paper satisfied all the requirements of the Overview section, Design Concepts section, and half the requirements of the Details section. The unsatisfied requirements of the Details section come from initialization values not being specified (i.e., transmission range, pseudo random number generator seed, etc.), as well as lack of information regarding system requirements.

The remaining papers have scores that range between 30% and 40%. The variation is due to the amount of detail provided in the papers that sufficiently describe the initialization variables, system requirements, and software overview. None of the surveyed papers provided information describing the system requirements, the pseudo random number generator seed, or the transmission range. Very few of them described the simulation tool(s) used, the number of nodes, the number of simulations run, or the length of the simulation.

**Table 1.** M-ODD protocol performance scores of [17–23]

Article	Article total score	Overview score	Design concepts score	Details score
[17]	40%	75%	100%	28%
[18]	16%	25%	50%	11%
[19]	37%	75%	100%	24%
[20]	19%	8%	50%	15%
[21]	27%	33%	100%	20%
[22]	30%	42%	100%	24%
[23]	61%	100%	100%	50%
Average	33%	51%	86%	25%

## 4.2 Application of the M-ODD Protocol

In this section, we further explore Ernst and Brown’s research in [17]. Their study aimed to improve the performance of multi-hop wireless networks as peripheral nodes would often suffer from poor performance due to starvation. They analyzed the performance of multi-hop wireless networks using the mixed-bias technique, TS mixed-bias technique, as well as the evolutionary mixed-bias technique. Here we provide a detailed discussion of the scores this paper achieved in reference to the requirements of the M-ODD protocol.

**Overview.** As indicated in Table 1, [17] achieved a score of 75% for the Overview section of the M-ODD protocol. This score was achieved because the paper clearly described its purpose and because it described the necessary details required of the Process Overview and Scheduling subsection. However, it failed to describe the state variables and scales that are needed to improve the reproducibility of the work.

**Purpose.** The paper describes that the purpose of the use of mixed-bias scheduling is to “improve the performance of peripheral nodes in multi-hop networks,” and “give more resources to nodes closer to gateways to improve their ability to handle their own traffic and peripheral traffic” [17]. This information is clearly included in the introduction and excerpt of the paper. Further, the paper describes how mixed-bias scheduling was chosen as “mixed-bias has a lower likelihood of starvation compared to max-min, and proportional fairness may not contain a strong enough bias to support nodes which are multiple hops away from the gateway” [17]. Overall, [17] fulfilled the Purpose requirements, as it justified the scheduling algorithm chosen, as well as its main goal in the introduction.

**State Variables and Scales.** In the case of state variables, not much information is provided. While the paper indicates that the number of routers used

in the simulation is 100, the number of clients is not known. Further, the pseudo random number generator seed is not provided, neither is the transmission range of the nodes. In terms of the State Variables and Scales subsections, [17] performs extremely poorly.

**Process Overview and Scheduling** All information needed in the Process Overview and Scheduling subsection can be found in section 3 of [17]. In section 3, a handful of algorithms are provided to the reader, as well as a detailed explanation of the purpose and function of each algorithm. This provides the reader with a clear understanding of the “flow” of the program, along with its purpose.

**Design Concepts.** Ernst and Brown’s research in [17] received a Design Concepts score of 100%. For grouping, the paper describes that nodes on the network were grouped into one of three types: gateway, router, client. We also note that all observational figures and graphs were labelled properly, and that the data was color coded depending on the algorithm used for readability. All graphs were followed by a paragraph discussing the results of the simulations. All the requirements for the Design Concepts section were clearly satisfied by the information provided in [17].

**Details.** Ernst and Brown’s research in [17] received a sub-par score for the Details section of the ODD protocol (28%). The score was the result of failing to satisfy most of the subsections of the M-ODD protocol.

*Initialization.* The initialization subsection performs well compared to other papers surveyed in this study, as the transmission type, number of nodes, and placement of nodes are discussed. However, the transmission range, pseudo random number generator seed, number of simulations run, length of time a simulation is run, as well as any data generation variables were not listed. Initialization variables can be found in Table 2. Additional information such as the number of nodes, the number of points that generate the nodes, and maximum delay time were also not included. These are all variables that are referenced in [17], but whose values are not defined. In addition, there is no reference to, or mention of, a file or additional table which holds all the initialization variables. Due to the considerable number of variables and unprovided values, [17] does not satisfy the requirement of the Initialization subsection.

*Input.* There is no mention of whether any values were input into the simulation, and no table or additional file is referenced.

*System Requirements.* The System Requirements subsection remains unsatisfied. There is no information regarding the CPU used, OS version and kernel, or storage space required. However, the paper does provide some information describing the finite state machine used (in the form of a state table and transition table).

**Table 2.** Initialization values described in [17]

Parameter	Value
Size of network	100 (10 × 10 routers)
$\alpha$	0.5
$\beta_1$	2
$\beta_2$	5
Transmission type	IEEE 802.11
Inter-arrival rate	0.01
Node distribution	Uniformly distributed

*Software Overview.* There is some improvement in the Software Overview subsection, as we can note the simulation tool used is ns-3.13. However, information such as if any additional modules are required, the data types, variable settings, animator software version, and encryption standards are not mentioned. There is also no executable referenced. Some of the requirements of the Software Overview section are satisfied, but overall [17] performs poorly here.

*Sub-models.* Various mathematical formulas and calculations are provided, along with an explanation of the variables, and purpose of the formula. Any assumptions made are stated in the paper, along with a justification for the assumptions made. Most parameters are listed and explained, however, they are not provided in a table and the reader is forced to search through various sections of [17] to gather all the parameters. For that reason, we have created a list of parameters that can be viewed in Table 3 that would improve the readability and ease of reproducibility.

**Table 3.** Parameters of [17]

Parameter	Value
$\alpha$ Controls mix between strong and weak bias	$0 \leq \alpha \leq 1$
$\beta$ How strongly to bias against a characteristic?	N/A
$c$ characteristic one wishes to bias proportionally against	N/A
$Q_{max}$ Limit of the maximum number of states a machine is allowed to process in an evolutionary process.	N/A
TABUMOVE Number of iterations before a new move is attempted on the network.	N/A
TABURESET How long before a reset back to the current known best solution	N/A

## 5 Conclusions

Creating reproducible and credible work should be a top priority for researchers. Yet, there are and continue to be shortcomings in published MANET research that hinders reproducibility. As noted by previous reviews, a majority of Mobile-Hoc papers published between 2000 and 2005, and IEEE and ACM papers published between 2010 and 2017 are not reproducible. The aim of the M-ODD protocol is to provide researchers with a standard format for publicizing MANET simulation research papers. This will in turn ensure that a simulation paper is reproducible, statistically sound, and credible. Improving the reproducibility of MANET simulation papers will allow peer reviewers to be able to verify the validity of the results presented, and provide a stable stepping stone for future researchers to be able to expand upon existing research and conduct the simulations presented with greater ease.

Further, the M-ODD protocol should allow researchers to achieve the green, blue, or red Artifact Available badge (see [24]) for their simulations. The green artefact signifies that any artefacts are available in a permanent archival repository while a red artefact signifies that “a reviewer has verified that the artefact is documented, complete, consistent and exercisable” [24]. Lastly, the blue artefact means that an independent reviewer has successfully reproduced the study and obtained the results of the paper [24].

In the 4-year span between the publication of [5] and [6], Grimm et al.’s ODD protocol was included in over 50 publications. This is a result we hope to see in Mobile ad hoc Network Simulation publications with the presentation of the M-ODD protocol in this document. With the achievement of such a result, and a continuous increase of papers published using the protocol, the reproducibility of MANET simulation papers should improve over the years.

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