A Stochastic Mobility Metric to Enhance QoS/QoE in Mobile Ad hoc Networks

Hind Ziani, Nourddine Enneya, Mohammed Kaicer

***Abstract:** Nowadays, wireless networks have become a far-reaching part in contemporary life. They allow people to be connected to the Internet anytime and anywhere. And yet, the continual enhancement and/or updating of the Quality of Service (QoS)/Quality of Experience (QoE) on such platforms, notably for sensitive transmission, remains a particularly challenging matter within the networking research community. Indeed, the free mobility of Mobile Nodes (MNs) (i.e. their real-time physical location change, and intra-network movement), renders network topology often subject to unpredictable fluctuations. In this vein, the paper herein aims to lay down the framework for a stochastic mobility measure, to be considered in the future, for the enhancement and management of QoS/QoE in MANETs. Thus, the main endeavor of this project shall focus on the behavior of the dynamic aspect of MANETs. In fact, it proposes a mobility metric which shall be well-suited to accounting for the complex scenario of Network Mobility. Experimental results demonstrate that there is no stability of relationship between MNs: each node may change its neighborhood and, by extension, the overall communication range it belongs to, through the detection of new link breakages and/or link additions. Otherwise stated: mobile nodes are naturally subject to a non-negligible pattern of Poisson distribution. With mobility being the defining characteristic of MANETs, the proposed metric shall be of considerable added value, insofar as its integration into routing protocols is sure to improve both objective and subjective quality returns.*

***Keywords:** Ad hoc Networks, MANET Routing Protocols, QoE, QoS, Stochastic Modeling.*

I. INTRODUCTION

A Mobile Ad-hoc Network (MANET) [12] is a set of mobile entities that freely move within an independent network which requires no infrastructure, where in each MN communicates through a direct link to its neighboring node(s). With all their particularities such as fault tolerance, self-organizing capabilities, non-existent infrastructure and ease of deployment, applications dedicated to MANETs cover a very broad spectrum.

The idea of building portable networks with no infrastructure allegedly originates from the DARPA's (Defence Advanced Research Projects Agency) packet radio network days [15]. Due to the dynamic aspect of MANETs which gives rise to an unstable flow of link status between MNs, continuous changes may occur. Conversely, the network has to transmit and deliver services to the end-users with acceptable levels of quality, especially when there is multimedia traffic entailing real-time constraints. For those reasons, efficient routing protocols ought to be capable of supporting sufficient reliability & fidelity thresholds with minimal impact on the QoS (objective quality) ultimately delivering results with decent QoE (subjective quality) returns [6], [21], [13]. Indeed, QoE measurement functions can be obtained from QoS objective metrics by taking into account the human factors impacting the quality perception of the service, including user expectations, effectiveness and performance [24], [16], [4].

MANET routing protocols are categorized into three types: Proactive, Reactive and Hybrid protocols [25], [19]. Proactive routing protocols broadcast periodic monitoring messages for the creation, maintenance, and updating of routes in parallel with data transmission. In contrast, on Reactive protocols, routing tables are not created on a permanent basis: whenever a MN attempts communication with another, it initiates a route discovery mechanism, where by an on-demand route is created, and persists within the network only for as long as it remains valid -or until it "times out" (i.e. becomes superfluous &/or obsolete). Hybrid routing protocols, for their part, are eclectic combinations of both the Reactive and the Proactive modes. The chosen mode depends on the predefined conditions of the network.

If one is to afford satisfactory QoS/QoE levels in MANETs, the working principle is universal & self-evident: to capitalize on the double-edged element of node mobility by optimizing routing parameters while keeping all eventual entropy within manageable margins. Micro-management-wise, MANET routing protocols must fully factor in their inherent mobility for route selection, bolstered with new metrics which feature real-time mobility measure for optimal route plotting on the MN level.

In this paper, we present a stochastic mobility measure apt to account for intra-MANET fluctuations (viz. within each MN and with relation to its neighbors, wherein every instance of one or more nodes joining or leaving a MN's neighborhood subdivision entails a new manifold sequence of route calculating & neighborhood readjustment).

The paper is organized as follows: Section 2 gives a short overview of QoS/QoE constraints within the MANET environment. In section 3, works relevant to the subject-matter are mentioned and briefly discussed. Section 4 presents our proposed stochastic mobility measure.

Revised Manuscript Received on January 06, 2020.

***Hind Ziani**, Department of Informatics, Systems and Optimization Laboratory, Faculty of Sciences, University of Ibn Tofail, BP 133, Kenitra, Morocco Email: hind.ziani@uit.ac.ma

Nourddine Enneya,. Department of Informatics, Systems and Optimization Laboratory, Faculty of Sciences, University of Ibn To fail, BP 133, Kenitra, Morocco Email: enneya@uit.ac.ma

Mohammed Kaicer, Department of Informatics, Systems and Optimization Laboratory, Faculty of Sciences, University of Ibn To fail, BP 133, Kenitra, Morocco Email: *kaicer.m@gmail.com*

Section 5 covers our simulations and analyses thereof. Lastly, section 6 concludes the paper and gives the gist of our future work in the field.

II. QOS/QOE IN MANETS: ISSUES AND DIFFICULTIES

The analysis and enhancement of QoS/QoE in MANETs is a high-stakes field which continues to attract many a researcher. With MANETs featuring several properties which render successful quality provisioning a more difficult task. These properties, which are inherently tied to MANETs' defining structure, may be summed as follows:

Unpredictable linkage: Inter-MN Wireless links are naturally unpredictable, and Packet collisions are inevitable in MANETs. Moreover, signal propagation is often prone to undesirable events such as signal fading, interference, and multi-path cancellation: All these properties further add to the extant difficulty of monitoring or anticipating QoE/QoS in general.

Node mobility: As the *de facto* defining characteristic of MANETs, The non-static aspect of MNs raises several issues as far as network management is concerned: High routing, packet collisions, Transmission Errors, Limited bandwidth, Limited security,… all of which make it an imperative for any & all routing protocols to thoroughly account for this plethora of difficulties in order to guarantee a decent QoS within the MANET environment.

Limited battery life: Each MN requires a dedicated amount of battery power in order to run network protocols for specific tasks in MANET. From a holistic perspective, this means that if one node happens to be cut off the power supply, the resulting shutdown would affect not only itself, but also the entirety of its neighborhood and, indeed, the network as a whole.

Route maintenance: The real-time flux of unpredictable changes throughout the network topology makes network state maintenance a delicate matter. In particular, routing protocols should be scripted to adequately respond to eventual contingencies; be it for quickly reestablishing broken paths, or creating new ones, all without loss of data packets.

III. RELATED WORKS

Recently, many advanced researches on MANET routing protocols have developed towards overcoming any potential faults deemed to be quality-degrading. Such routing protocols were developed forthe express purpose of enhancing network metrics (QoS metrics) and/or customer experience metrics (QoE metrics) [18], [20]. It should be noted, however, that QoE remains the key component with regard to ensuring a competitive edge. The QoE metric is based on the users' impressions, reactions and feelings [2], and there are many extant QoE metrics and PSQA (Pseudo Subjective Quality Assessment) which can help "emulate" the user's reaction, in terms of quality assessment, towards the delivered services [2] , [24].

In terms of research avenues pertaining to QoS enhancement, many extensions of standard MANET routing protocols, such as AODV [23], DSR[14], TORA [22], ZRP [10], OLSR [5] etc ..., have been developed to ensure lossless transmission of sensitive flows, suggesting specific levels of QoS (delay, bandwidth, jitter, ...) [24],[11], [27],[3]. In addition to this protocol, many others are devised to further enhance QoS management: for example, a Multi-Path QoS Routing protocol derived from the ticket-based probing technique is proposed in [29]. Furthermore, Core-Extraction Distributed Ad hoc Routing (CEDAR) [28] is also a QoS-centered routing algorithm, albeit devised for monitoring limited subdivisions of MANET: based around the framework of a sub-network made of only some MNs, where the chosen Node sin question are incorporated from either the core network or its neighborhood, following an algorithm based on bandwidth estimation. The CEDAR protocol then selects routes with suitable bandwidth potential, then spreads its control information and stable link bandwidth variation from the core network environment. In [24], the QoE-aware sub-optimal routing protocol (QSOpt) is geared toward improving the response time for finding convenient solutions that will lead to an ingenious MANET management protocol, aiming to increase the MOS (Mean Opinion Score), notwithstanding network constraints, by monitoring real-time variation within the latter, and attempting to positively manage their impact on quality. On the other hand, a combination of QoE and MPOLSR [17],, named QoE-aware MPOLSR (QMPOLSR) represents a heuristic approach which describes and calculates the mathematical relation between the objective metrics loss rate (LR), mean loss burst size (MLBS) and the subjective indicator (MOS) in real-time [26]. Thus, the maximum value of MOS derived from the two-hop protocol in real time is integrated as a parameter within the algorithm, in order to select the most optimal routing course.

IV. PROPOSED MOBILITY METRIC

In the MANET environment, there are four possible system states between each MN & its neighbors:

1. The node is moving and its neighbors are not moving.
2. The node is moving and its neighbors are moving.
3. The node is not moving and its neighbors are not moving.
4. The node is not moving and its neighbors are moving.

As such, there is a strict correlation between the mobility of a node within MANET,and the state (& changes thereto) of its interlinkage to its neighborhood. Such change occurs at once as old nodes leave the communication range and/or new nodes join in, respectively. Consequently, these real-time, continuous shifts of node interlinkage (per-node re-allocation of link-status & neighborhood) have an immediate bearing on the MANET's performance.

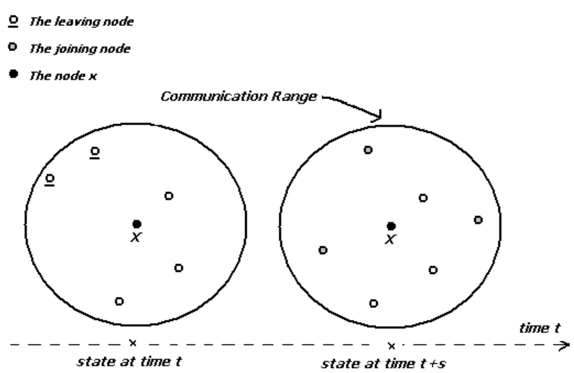

Figure 1. Example of neighboring change of node i during a period of time $\Delta t = s > 0$

According to this analysis, the mobility measure of a Node in MANETs can be defined as the variation of its link-status change in function of time, where variation is the result of the number of changes occurring at node-level with relation to its neighborhood. Based on this closed relationship between the variation (link-status change with relation to neighbors) and the inputs-output MN matrices referring to their communication range, we can observe the mobility of a given node, in a wireless network, as the variation of its neighboring configuration through time.

$$\mathrm{M(s) = N(t + s) + N(t)} \qquad (1)$$

Indeed, let: I(t) be the number of the arrival nodes within range of node x during the time interval [0;t]. O(t) is thus the number of nodes leaving the range of node x at time t.
So, the number of nodes neighboring the node x at time t noted N(t) is given as follows:

$$\mathrm{N(t) = I(t) - O(t)} \qquad (2)$$

In view of the above, it would be logical that the value I(t) has the stochastic properties listed below [8]:

- Independent increments: the numbers of input entities emerging in separated intervals of time are independent.
- Static increments: the numbers of input entities emerging at a fixed time interval depends only on the size of this interval.
- The probability of one input entity emerging in a time interval of length δt is λt + o(δt) for δt → 0.
- The probability of two or more entities emerging in a time interval of length δt is o(δt) for δt → 0.

Where o(h) is some unstated lemma that tends to a low value, non-inconsiderable compared to h itself as h → 0.
Then, we can suppose that MNs arrive at a MN x according to a homogenous Poisson process [1], [9] with intensity λ> 0. That is, for any t > 0:

$$\mathrm{P(I(t) = k)} = e^{-}\lambda t\frac{(\lambda t)^k}{k!}, \qquad \mathrm{k = 0, 1, 2 \ldots} \qquad (3)$$

In order to derive an expression for the probability distribution of the process O(t), it would be of convenience to use the fact that its conditional probability on the process I(t) can be chosen as Binomial.
Fix an integer k > 0, and by conditioning on I(t), we may find:

$$\mathrm{P(O(t) = k)} = \sum_{j\geq 0} P(O(t) = k|I(t) = j)P(I(t) = j) \qquad (4)$$

Under the assumption that the distribution of O(t) conditionally by I(t) = j is a Binomial distribution, with parameters j and p -where p is the percentage of abandonment of the neighborhood of node x ,we arrive at the following:

$$\mathrm{P(O(t) = k)} = \sum_{j\geq k} C_j^k p^k (1-p)^{j-k} e^{-\lambda t\frac{(\lambda t)^j}{j!}}$$

$$= e^{-\lambda pt\frac{(\lambda pt)^k}{k!}}$$

Then:

$$\mathrm{P(O(t) = k)} = e^{-\lambda pt\frac{(\lambda pt)^k}{k!}} \qquad (5)$$

Now if k = 0, we obtain:

$$\mathrm{P(O(t) = k)} = \sum_{j\geq 0} P(O(t) = 0|I(t) = j)P(I(t) = j)$$

$$= e^{-\lambda t} + \sum_{j\geq 1} C_j^0 (1-p)^j e^{-\lambda t\frac{(\lambda t)^j}{j!}}$$

$$= e^{-\lambda tp}$$

And so:

$$\mathrm{P(O(t) = 0)} = e^{-\lambda pt} \qquad (6)$$

Finally, we conclude that O(t) is a homogenous Poisson process with an intensity of λp.
In order to determine the distribution of the number of nodes neighboring node x at time t & according to equation (2), we may use the same arguments as above, where, for any integer k > 0:

$$\mathrm{P(N(t) = k)} = \sum_{j\geq k} P(O(t) = j-k|I(t) = j)P(I(t) = j)$$

$$= \sum_{j\geq k} C_j^{j-k} p^{j-k} (1-p)^j e^{-\lambda t\frac{(\lambda t)^j}{j!}}$$

$$= e^{-(1-p)\lambda t\frac{((1-p)\lambda t)^k}{k!}}$$

Then:

$$\mathrm{P(N(t) = k)} = e^{-(1-p)\lambda t\frac{((1-p)\lambda t)^k}{k!}} \qquad (7)$$

If k=0, we have:

$$\mathrm{P(N(t) = 0)} = \sum_{j\geq 0} P(O(t) = j|I(t) = j)P(I(t) = j)$$

$$= e^{-\lambda t} + \sum_{j\geq 1} C_j^j p^j e^{-\lambda t\frac{(\lambda t)^j}{j!}}$$

$$= e^{-(1-p)\lambda t}$$

And so:

$$\mathrm{P(N(t) = 0)} = e^{-\lambda(1-p)t} \qquad (8)$$

Then, N(t) is a Homogenous Poisson process of intensity $\lambda(1-p)$. This result corroborates that the number of neighboring nodes to the node x in the time interval [0,t] is Poisson distributed by a mean of$\lambda(1-p)t$. Generally stated ,the number of neighboring nodes in a various interval of time has a Poisson distribution with a mean of$\lambda(1-ps$.This is from the memoryless property of the homogenous Poisson process. We may then define the node mobility between t and t + s as follows:

$$\mathrm{M(s) = N(t + s) - N(t)} \qquad (9)$$

These mobility measures are quantified at regular time intervals; no unit is mentioned and they do not depend on any simulation parameters/infrastructure or mobility characteristics whatsoever.

V. SIMULATION AND DISCUSSION

In this section we shall discuss the results obtained from running many simulation scenarios where our MANET setup included some randomly-moving MNs.

A. Simulation Environment

To validate our proposed mobility metric, we have considered the following configuration for our MANET:

Table 1. Network simulation parameters.

Simulation Settings

Number of Nodes	30 nodes
Topology area	1000m X 1000m
Transmission range	100m
Time interval	0.10 sec
Simulation time	100 s

An adequacy test was carried out based on real observations of O(t) and I(t), with some values of uncountable sets, affirming that both O(t) and I(t) follow with a weak risk of Poisson distribution.
In response, we opted for two standard approaches for adequacy testing: graphical analysis and hypothesis test, by studding:

- H_0: O(t) follows a Poisson distribution
- H_0' : I(t) follows a Poisson distribution

For this paper, the adequacy simulation was run by a graphical analysis of QQ-plot and PP-plot comparing the quartiles and observed distributions, with those theoretical of a proposed Poisson distribution of O(t) and I(t).

Outgoing O(t) - Incoming I(t)

In order to validate the proposed model illustrating the number variability of outgoing-incoming MNs, we performed a numerical simulation. The model generates the observations of O(t) (respectively I(t)) as a random variable following a Poisson distribution P(λpt) (respectively P(λt)), while complying with its true distribution of probability (respectively to I(t)).
Based on the table input, the simulation may be broken down into four Figures (Figure 2, Figure 3, Figure 4 and Figure 5), where each curve is visibly superimposable on the diagonal line y = x.

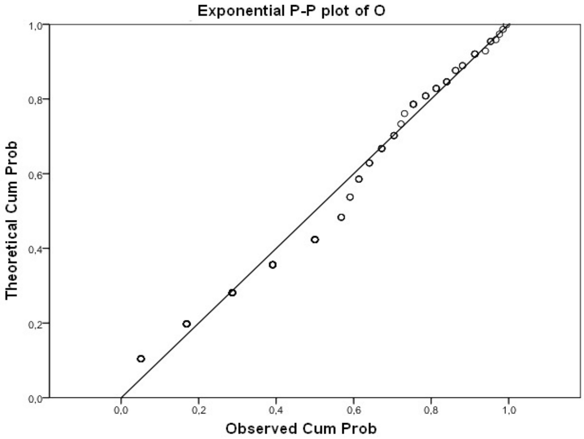

Figure 2. PP-plot of O(t), the line y = x adjusts the point cloud in terms of a distribution function.

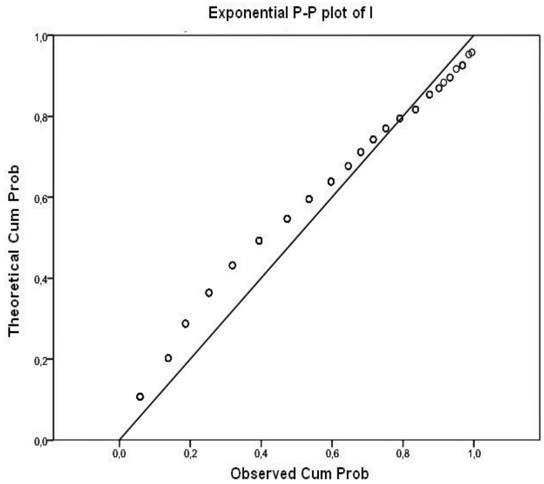

Figure 3. PP-plot of I(t), the line y = x adjusts the point cloud according to a distribution function.

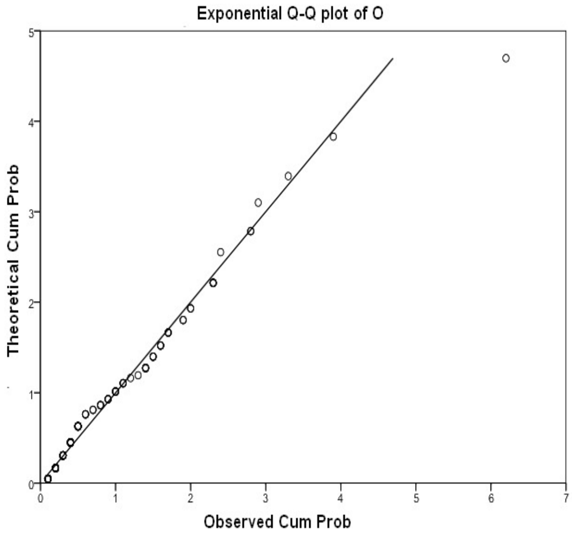

Figure 4. QQ-plot of O(t), the line y = x adjusts the point cloud according to a probability density function.

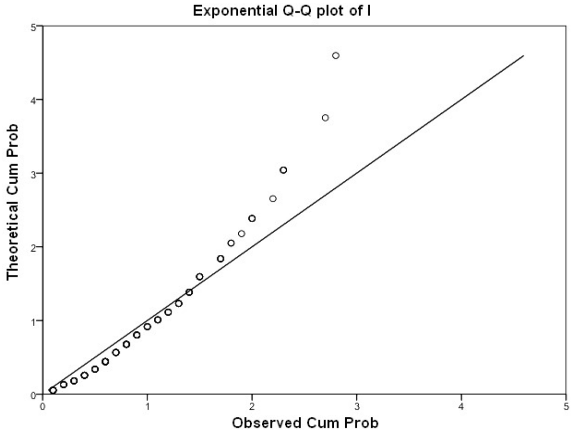

Figure 5. QQ-plot of I(t), the line y = x adjusts the point cloud according to a probability density function.

Mobility M(t)

Based on equations 2 & 9, since the number of observations in the studied dataset is equal to 1000, then M (t) ~ N (λ(1 − p), λ(1 − p)).
Thus, we may illustrate the mobility distribution defined as M(t):

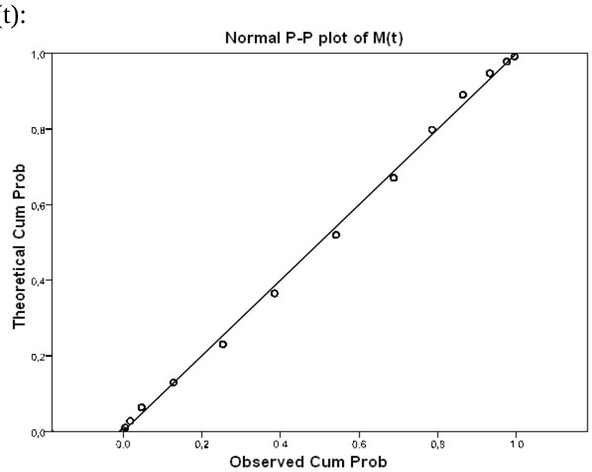

Figure 6. PP-plot of M(t), the line y = x adjusts the point cloud points according to a probability density function.

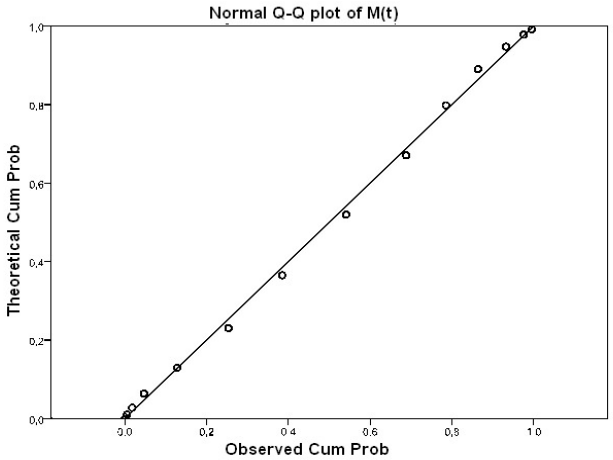

Figure 7. QQ-plot of M(t), the line y = x adjusts the point cloud according to a probability density function.

B. Simulation results

The results & analyzes of the simulations are summarized in the following table:

Table 2. Empirical verification of the hypotheses with results chart

	Chi-squared test χ^2_{obs} Vs. χ^2_{theo} (QQ Plot)	Conformity to the distribution probability (PP Plot)	Hypothesis Validity ⁄ Conformity Rating
Outgoing Nodes – O(t)	Decent conformity with a minor deviance factor	Above average	Average
Incoming Nodes – I(t)	Average conformity with a moderate deviance factor	Average	Average
Node Mobility – M(t)	Quasi-flawless	High	Good

Comments

The empirical results are satisfyingly close to the theoretical results we calculated for the incoming and outgoing Nodes, with certain matching differences. Nevertheless, the hypothesis is highly verified for the mobility of a MANET node that does not change its communication range status.

VI. Conclusion

QoS & QoE in MANETs remain ultimately dependent on the Routing Protocols' performance, as well as their potential for adapting to the dynamism of said networks' elementary Mobile Nodes. In this context, enhancing the QoS/QoE in such networks, requires that their dedicated routing protocols strike the perfect balance between two factors which generally tend to be at odds with each other: fool-proof route-plotting on one hand, & optimal response time on the other. These two principles, further complimented by the ever-entropic Node Mobility of MANETs in general, are the crux of the matter as far as QoS/QoE are concerned; the mastery of which remains the guiding horizon for all research on the subject matter. In this vein, our future work shall endeavor to implement and integrate our proposed mobility metric, as a QoS/QoE parameter, into several kinds of MANET routing protocols, while studying its impact on their end-user performance in particular. The MANET routing protocols to be considered for our future work shall include: AODV (reactive type) , OLSR (proactive type), and ZRP (hybrid type).

REFERENCES

1. B. Zhang, J. M. Fadili, and J.-L. Starck, "Wavelets, Ridgelets, and Curvelets for Poisson Noise Removal," *IEEE*, vol. 17, no. 7, pp. 1093 - 1108, July 2008
2. I. T. U. (ITU), "General Characteristics of International Telephone Connections and International Telephone Circuits," 1998.
3. I. Ahmad, U. Ashraf, and A. Ghafoor, "A comparative QoS survey of mobile ad hoc network routing protocols," *Journal of the Chinese Institute of Engineers*, vol. 39, no. 5, 2016.

4. A. Magee and al, "Monitoring Parameters relation to QoS/QoE and KPIs," *The Combo Consortium,* June 2014.
5. T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)," October 2003.
6. C. Lozano-Garzon, C. Ariza-Porras, S. Rivera-Diaz, H. Riveros-Ardila, and Y. Donoso, "Mobile Network QoE-QoS Decision Making Tool for Performance Optimization in Critical Web Service," *IJCCC,* vol. 7, 2012.
7. C. Lozano-Garzon, C. Ariza-Porras, S. Rivera-Diaz, H. Riveros-Ardila, and Y. Donoso, "Mobile Network QoE-QoS Decision Making Tool for Performance Optimization in Critical Web Service," *IJCCC,* vol. 7, 2012.
8. B. E. Fristedt and L. F. Gray, *A Modern Approach to Probability Theory*. Springer, 1997.
9. G. Grimmett and D. Stirzaker, *Probability and Random Processes: Problems and Solutions.* Clarendon Press, Oxford, 1997.
10. Z. J. Haas, M. R. Pearlman, and P. Samar, "The Zone Routing Protocol (ZRP) for Ad Hoc Networks," *IETF Internet Draft,* July 2002.
11. L. Hanzo and R. Tafazolli, "A SURVEY OF QOS ROUTING SOLUTIONS FOR MOBILE AD HOC NETWORKS," *IEEE,* vol. 9, no. 2, pp. 50 - 70, 2007.
12. R. Hekmat, "Adhoc Networks: Fundamental Properties and Network Topolo- gies," *The Netherlands:Springer Dordrecht,* 2006.
13. R. J. S. Iborra, "Contribution to Quality of user Experience Provision over Wireless Networks ", universidad politcnica de cartagena, 2015.
14. D. Johnson, D. Maltz, and Y.-C. Hu, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks for IPv4,," *RFC 4728,* 2007.
15. . Jubin and J. D. Tornow, "The DARPA Packet Radio Network Protocols," *IEEE,* vol. 75, p. 21 − 32, Jan 1987, Art. no. 1.
16. M. Katsarakis, R. Teixeira, M. Papadopouli, and V. Christophides, "Towards a causal analysis of Video QoE from Network and Application QoS," *Proceedings of the workshop on QoE-based Analysis and Management of Data Communication Networks,* pp. 31-36, 2016.
17. W.-H. Liao, S.-L. Wang, J.-P. Sheu, and Y.-C. Tseng, "A Multi- path QoS Routing Protocol in a Wireless Mobile ad Hoc Network," presented at the International Conference on Networking ICN, 2011.
18. S. Malisuwan, D. Milindavanij, and W. K.-. phanuekrungsi, "Quality of Service (QoS) and Quality of Experience (QoE)of the 4G LTE Perspective," vol. 5, no. 3, June 2016.
19. R. Michoud, A. M. Orozco, and G. Llano, "Mobile ad-hoc routing protocols survey for the design of VANET applications," presented at the Colombian Intelligent Transportation Systems Symposium (CITSS), Bogota, Colombia, 2012.
20. N. B.-i. a. T. c. (NBTC), "Tutorial Document on QoS and QoE,,Internal Report,," December 2015.
21. P. Goudarzi and M. Hosseinpour, "QoE enhancement for video transmission over MANETs using distortion minimization," vol. 19, no. 3, pp. 696-706, June 012.
22. V. Park and S. Corson, "Temporally-Ordered Routing Algorithm (TORA)," *IETF Internet Draft,* Jume 2001.
23. C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc On-demand Distance Vector (AODV) Routing," July 2003.
24. T. A. Q. Pham, "Algorithms and optimization for QoE aware routing in wireless networks: from centralized to decentralized solutions," PHD Thesis, IRISA Rennes, 2017.
25. C. V. Raghavendran, G. N. Satish, P. S. Varma, and K. N. S. L. Kumar, "Challenges and Advances in QoS Routing Protocols for Mobile Ad Hoc Networks," *IJARCSSE,* vol. 3, no. 8, August 2013.
26. P. Rodriguez-Bocca, "Quality-centric design of Peer-to-Peer systems for live-video broadcasting," University of Rennes 1, 2008.
27. G. Santhi and A. Nachiappan, " SURVEY OF QOS ROUTING PROTOCOLS FOR MOBILE AD HOC NETWORKS," *IJCSIT,* vol. 2, no. 4, August 2010.
28. R. Sivakumar, P. Sinha, and V. Bharghavan, "CEDAR: A Core-Extraction Distributed Ad Hoc Routing Algorithm," *IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,* vol. 17, no. 8, AUGUST 1999.
29. J. Yi, A. Adnane, S. David, and B. Parrein, "Multipath optimized link state routing for mobile ad hoc networks," *Elsevier,* vol. 9, no. 1, pp. 28 - 47, January 2011.