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Using Derived Mobility Model Metrics to Evaluate the Impact of Transmission Range in Vehicular Networks

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Abstract: Mobile Ad -Hoc Networks (MANETs) is a spontaneous network that facilitates communication among nodes without a centralized-control device unlike the infrastructure network category. One of the major challenges with MANETs and Vehicular Ad -Hoc Networks (VANETS) in mobile communication is the problem of connectivity between Mobile Nodes (MNs). This dilemma occurs as a result of high mobility of nodes moving farther from each other in MANETs or VANETS or moving away from the base station as in a cellular network or in a Mobile Infrastructure Ad Hoc Networks (MI-VANETs) as a result of propagation effects. Mobility of nodes is one of the major impacts of routing in every mobile and wireless network because of high dynamic nature of mobile environments. Several factors that influence the evaluation of the networks depend mainly on the implementation of the mobility model and the mobility model in turn depends on several factors of the environment. This paper evaluates the impact of communication and transmission range on network connectivity due to high mobility of nodes in a mobile and wireless environment. The results obtained through derived mobility metrics and Rate Adaption (RA) show that communication range has impact on connectivity in a highly mobile environment such as in vehicular communications. MN in this context is same as vehicles in this article.

Keywords: Transmssion range, Mobility modeling, Mobile & wireless networks, MANTS, VANETs,ITS,Vehicle-to-roadside, MNs, Vehicular communications

1. INTRODUCTION

Mobile communication is the bedrock of the 21st century technological innovations. It has deployed several services and applications making mobile devices to have greater influence in many lives that multitudinous people cannot do without them. The most popular among mobile devices is the mobile phone, which is mainly for communicating around the globe. MANET is a highly dynamic wireless communication technology deployed among the most recent advancement in mobile communications [2].

MANETs and VANETS, have the characterized features of all mobile and wireless networks. MANET is an infrastructure- less network with the ability to self-configure networks [2]. This means that there is no need for an Access Point (AP) or router to deliver message to the next MN, rather the MNs have freedom of movement in the environment and obtain assistance from other intermediate nodes. With the prospects in mobile communications, there are tremendous growth and extensive research interest in VANETS, which is a special application of MANETs [1, 3]. The research on MANETS has been popular since late 1990s [4], since then, mobile communications have experienced a progression trend of about 26.5percent with about 33 Million subscribers of mobile phones in Japan since September, 1997 [5].

Mobility has great influence in the behavior of MNs, which may be exhibited negatively or positively. It predicts the pattern to be produced by the MNs, since different mobility schemes influence the pattern obtained by the MNs. As MNs change location to exchange information through communicating, they tend to deviate from the Road Side Unit (RSU), and base station or AP depending on the network settings. Mobility is an inherited trait in vehicles, because in the real world, vehicles cannot permanently remain static, hence must exhibit mobility at some point in time. In this paper, derived mobility metrics is used to implement the impact of mobility in mobile networks with an Adapted Context-

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Aware Rate Selection (ACARS) mobility model. ACARS is one of the RAs used in this simulation to implement mobility model [6].

Derived mobility metrics is a mathematical technique applied for modeling mobility model. In this paper, the metric is modeled and used for simulation in MATLAB. Details of the mathematical models are discussed in later sections.

The rest of the paper is organized as follows: Section II reviews on several mobility metrics, while Section III deals with network connectivity and the factors that influence signal reception. Mathematical model and analysis is considered in Section IV, while Section V analyze the results obtained from simulation and the paper is concluded in Section VI.

2. REVIEW ON MOBILITY METRICS

A. *Background*

The aim of Mobility model in mobile communication is to analyse the movement of nodes, which have substantial impact on the performance of the network [7]. Several mathematical models and simulations have been proposed in literatures on improved methods to apropos mobility in mobile wireless networks [8-17].

MNs have the freedom to move from one direction to the other while communicating with each other. These movements depend on the randomness and pattern exhibited my MNs during communicating [18-22]. However, mobility models can be classified into three categories based on their degree of randomness [23]. They are the traced-based with built on traces, the constrained topology-based, which is based on only partial randomness, and static-based, which is based on total randomness. To analyze the behavior of MNs, mobility metrics play a major role to determine the ideal mobility model to adopt in mobile communication networks. Direct and derived are the two known types of mobility metrics. They are explained in the next section.

B. *Mobility Metrics*

One of the major factors that affect the performance of ad hoc wireless networks is node mobility [24, 25]. This is not strange because of the natural traits of MNs, since they are meant to be mobile and not to remain static like an office type network, which communicates without moving, but there is random movement in wireless mobile networks whose performance grossly rely on the type of mobility model in place.

This section considers mobility metrics developed to model the performance of vehicular networks so as to analysis the impact of communication range on connectivity of MNs.

i. *Direct Mobility Model*

In direct mobility model, the MNs move in such a way to minimum or maximum speed in which speed is directly measured. Measurement of other parameters such as relative speed can be made. The Random Waypoint mobility model is a good example of a mobility model that exhibit direct mobility metrics. The goal of this model is to measure different mobility models. Nevertheless, it is not all the models that possess the capacity to capture different characteristics of the models [26]. This type of model also perform same task as that of the trace type mobility model since trace mobility also does direct measurement of parameters. In essence, it is likened to traces in mobility models.

ii. *Derived Mobility Model*

This type of mobility metric is established primarily by using mathematical models to establish generic network performance. Derive mobility metrics are also derived from graphs and other probabilistic models [26]. The major difference between this model and the former is that the parameter measured in this metric model is derived from mathematical models, while the former is a direct measurement of these parameters. In both metrics, parameters such as speed and velocity that has impact on MNs can be measured by implementing any of these metrics. Derived mobility metrics also perform similar role as that of the synthetic mobility model, because it involves mathematical models, which is the preferred type of mobility model [26].

This paper implements a derived mobility metric with RA to validate the impact of communication range on network connectivity.

3. NETWORK CONNECTIVITY IN MOBILE NETWORKS

Single-hop Cellular Networks

The basis of all wireless communication networks is the single-hop cellular networks. In this network model, all communicating MNs depend absolutely on the wired backbone and fixed base stations as shown in Fig.1, which is in contrast to that of MANETs that does not involve any of the above-mentioned characteristics. There is unpredictable network change due to the dynamic nature of mobile environments with infrastructure [4, 25, 27, 41]. In mobile networks, connectivity is a factor that depends on communication range and the number of MNs sharing the network resources. This means that it depends on the number of nodes per unit and their radio transmission range [29].

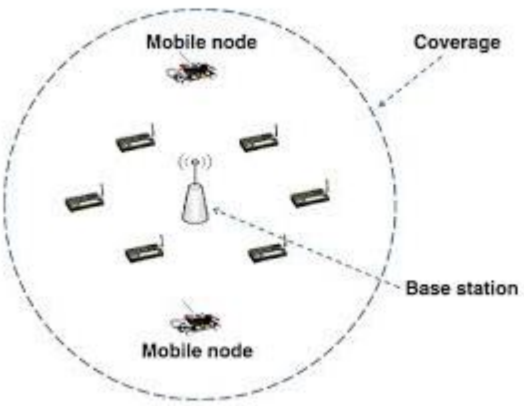

Figure 1. Communicating mobile nodes with fixed base station.

A. *MANETs*

MANET is a spontaneous network that is self-configured, self-organized, and self-maintaining with limited services such as processing power, on-board memory, and battery [30, 31]. The role of MANET is to establish an efficient routing protocol to enhance the performance of the network [30, 32]. This type of network is useful when dealing with wireless devices in which some of the devices are part of the network ONLY for duration of a communication session as shown in Fig.2 [31].

Figure 2.Typical architecture of a MANET.

Some of the challenges in MANETS at the Network Layer, Physical Layer (PHY), and Transport Layer are:

- Efficient routing
- Power control
- Quality of Service (QoS)

Despite some of these challenges susceptible to MANETs, one of the important advantages is that it grants MNs access to information and services.

MANETs offer numerous applications in mobile and wireless communications. It has much usefulness in safety and better network delivery. Some of the applications of MANETs are:

- disaster-rescue operations
- emergency search
- Classrooms
- military activities
- time-critical applications
- tactical communication
- Rescue operation
- QoS (good reception for mobile phone communication)
- Reliable safety messaging in vehicular networks etc. [4, 33-36].

B. *VANETs*

VANETs are a sub-class of MANETs with great promising trend for future Intelligent Transport System (ITS). In an ad-hoc network, wireless MNs interact to form a temporary network independent of any control device such as router or AP [37-40]. There is no fixed infrastructure in this type of network, rather MNs communicate with each other directly and rely on each other for network functionality as shown in Fig.3. One of the peculiar characteristics of VANETs is the mobility pattern exhibited by MNs due to the mobility model. These characteristics are quite different from that of the MANETs. The mobility patterns generated in VANETs actually have greater influence on the participating MNs, which predicts the performance measure of the MNs on the network [41]. Due to the performance criteria expected in VANETS, it has some applications such as mobile application, routing information, safety messaging, and traffic control [42]. VANET is a new approach in wireless communications with some of these advantages over the traditional single-hop cellular networks: lower latency due to direct communication, and broader network coverage.

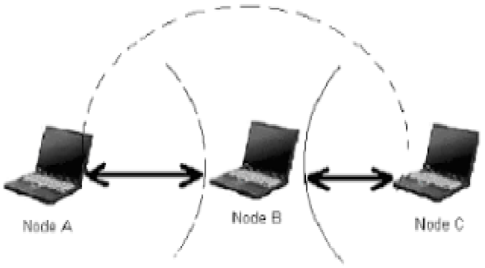

Figure 3. Typical architecture of a VANET.

The aim of extending data networks is to handle mobility to provide continuous network connectivity [43]. This makes routing protocol an important aspect of mobile communications to be considered. Due to the frequent mobility act prone to MNs, they change location constantly resulting to problem of connectivity. Various factors are responsible for creating difficulty in connectivity. These include node moving away from the base station, propagation effect, and out of transmission zone etc.

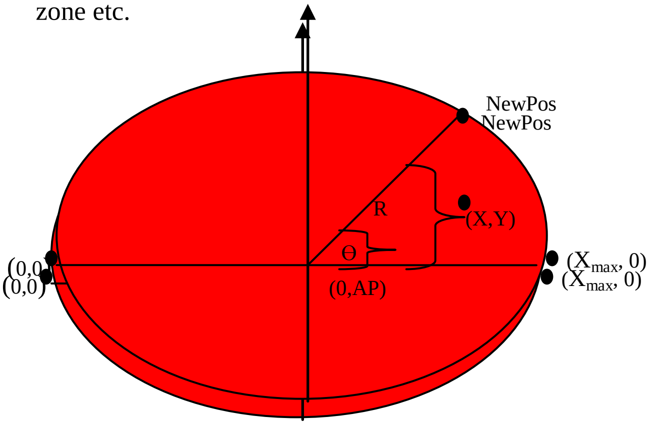

Figure 4. Movement of MNs with position change.

4. MATHEMATICAL MODELLING

This section expatiates on the mathematical model used in implementing the mobility metric for the simulation. Mobility in wireless networks determines the signal strength as nodes move randomly from one location to the other. As they communicate with each other on the network, the Received Signal Strength (RSS) varies depending on the mobility model, which is peculiar to all MNs [11].

A. Distance and position of MNs

We developed an algorithm with mathematical model using (1-11). These equations are to generate node positions; get the speed of the nodes, and communication range of MNs. Fig.4 shows how MNs change position generating angular inclination.

B. Constant Speed (ConstSpeed) Mobility Model

In the ConstSpeed mobility model, MNs can move along a lane with constant speed to a randomly chosen target, and when the target is reached, it will randomly select a new one. With this model, MNs select their speeds uniformly over this range as shown in (1-6). Initial positions of MNs are generated randomly.

C. Transmission and Communication Range Algorithm

Mathematical analysis in (12-16) is use to determine MNs that are in communication range and those out of range in the simulation. The communication range is the limit set for MNs to determine their access to the AP during communication. The simulation setup drops MNs that are out of range. This means that as the MNs change position, some of them move out of the range and are not consider to per take in the network resources.

D. Log-normal Shadowing

Communication channel is a time varying power gain, which consists of path loss, log-normal shadowing, and multipath fading. The receiver experiences a desired signal gain with respect to the transmit power $\mathbf{P_t}$ used by the transmitter. Algorithm 1 shows the RSS, while Table I shows the shadowing deviation used in the simulation. In addition, Fig.5. and (20) are used to determine RSS in Algorithm 1.

Algorithm 1: Received Signal Strength Algorithm

```
Take transmitted signal strength $P_t$
Calculate the distance between sender and receiver d}
Calculate the cross distance $d_c$
IF $d>d_c$ then
    Calculate Friis path loss l
ELSE
    Calculate received signal strength $P_r= P_t-l$
```

Definition I (movement of the Mobile Nodes (MNs))

$$d= \sqrt{(x_2 - x_1)^2+(y_2 - y_1)^2 + \cdots + (x_n - y_n)^2} \quad (1)$$

Where **d** is distance in meters, **x** and **y** are node positions in the **x** and **y** coordinates, **t** is time, and θ is angle.

ΰ= đ * v (2)

Where ΰ is last speed, **đ** is the direction, and **v** is speed.

ţ = ŧ - ŋ (3)

Where **ţ** is elapsed time, **ŧ** is simulation time, and **ŋ** is last update.

ρ = ΰ * ţ (4)

Where ρ is last position, **ΰ** is the last speed, and **ţ** is the elapsed time .

Definition II (Speed of MN)

Assuming a set of nodes $\mathrm{n} = \{u_1, . . . , u_n\}$ is moving along a road model with length, i.e., R = [0, 1]. Considering N MNs moving on [0, 1). At some random times $0 \leq t_1 < t_2 < \cdots$ a new speed and a new direction (also called orientation) are selected. The selection of the speed and direction at time t_k ($k \geq 1$) initializes the j^{th} movement of the mobile. Let $\tau j = t_k+1 - t_k$, $j \geq 0$, During the interval $[t_j , t_{j+1}]$ the MNs travels at constant speed sj ∈ S, where S is any topological subset of (0,∞). Typically, S = (σ1, σ2) with 0 < σ1 < σ2 or S = {σ1,...,σk} with σi > 0 for i = 1,...,j. Let $\theta_k \in \{-1, +1\}$ be

the new direction selected at time t_j , $j \geq 1$, with $\theta_k = +1$ (resp. $\theta j = -1$) . Let θ_0 be the orientation of the MNs at time t = 0., and $\theta(t)$ is the direction of the MNs at time $t \geq 0$. We assume that $\theta(t)$ is right-continuous, so that $\theta(t_j) = \theta j$ for $j \geq 0$. The selection of the new direction at time t_k , $k \geq 1$, is done as follows. Let $\gamma 1, \gamma 2, \ldots$ be $\{-1, +1\}$.
Each MN is assigned to a determined mean speed, V̏, and mean direction Đ of its movement. For each determined time period, a MN calculates the speed and direction of its movement by referring on speed and direction during the previous time period, throughout with a certain degree of randomness joined in the calculation. Then MN is moved with assumed calculated speed and assumed calculated direction during the time period. For a specified time period t, the speed and direction of a node is calculated as follows [4]:

$$v_n = \alpha_{sn-1} + (1 - \alpha)\text{V̏} + v_{xn-1} \tag{5}$$

$$d_n = \alpha_{dn-1} + (1 - \alpha)\text{Đ} + d_{xn-1} \tag{6}$$

Where:

v_n and d_n are the new speed and direction of MN at time interval n ;

α, where $0 \leq \alpha \leq 1$, is the tuning parameter used to vary the index of randomness;

$\alpha = 1$: mobile nodes move linearly;

v and d are constants, represent mean value of speed and direction at n;

$v_{xn-1}$and $d_{xn-1}$are random variables from a Gaussian distribution.

To determine the degree of randomness, which is a combination of speed and direction that predicts the direction of movement for a certain period; we define the parameter α ($0 \leq \alpha \leq 1$). The value of α is increased from 0 to 1, the degree of randomness decreases. And when it is close to 0, the degree of randomness becomes high that may result in consistent sharper turns. On the other hand, when α is nearest to 1, speed and direction of the previous periods are temporally dependent, which means that MN move in close to what it previously had [4].

Definition III (transmission range)

Let Z_r be the route or flow of traffic in the network. There are several nodes in the network to form the sequence. And let R be a set of possible routes and r be the set of nodes.

$$Z = (Z_r, r \in R) \tag{7}$$

$$Pos_{old} = Pos_{new} + v \times t \tag{8}$$

Where Pos_{old} is Old position, Pos_{new} is new position, v is velocity and t is time

$$P_n = mod(P_n, x_{max}) \tag{9}$$

Where x_{max} is maximum range, mod = modulus function implemented in the MATLAB program, and $P_n =$ is the result positions of the nodes.

This ensures that nodes are in Communication range

$$d = abs(Pos_{new} - Pos_{AP}) \tag{10}$$

Where d is the distance, abs is absolute value, Pos_{AP} is position of the AP

This gives the distance between the new position and AP.

$$d = |Pos_{new} - Pos_{AP} \ldots + Pos_{n-new} - Pos_{n-AP}| \tag{11}$$

$$Node_{inrange} = d < t_r \tag{12}$$

Where $Node_{inrange}$ is node in communication range, t_r is communication range

This ensures that determines nodes in range and out of range.

$$\mathrm{I}_{(\mathrm{vi})} \triangleq \; = \begin{cases} 1 \; if \; v(i) is \; in \; CommRange \\ \quad 0 \; \; otherwise \end{cases} \tag{13}$$

$$N_{total\ in\ CommRange} = \sum_{i=1}^{N_{total}} I(_{vi}) \tag{14}$$

Hence:

$$N_{total\ not\ in\ CommRange} = N_{total} - \sum_{i=1}^{N_{total}} I_{(vi)} \tag{15}$$

If **C** is a class of MNs in communication range, then from Eq.14 that $v_1 \ldots v_n$ will be elements of C. i.e $(v_1, v_2, \ldots v_n) \epsilon C$. Equations(13-15) are used as counter to determine the MNs in communication range and those outside the communication range.

$$t_r \geq \sqrt{\frac{1 - ln\left(1 - p^{\frac{1}{n}}\right)}{\rho^{\pi}}} \tag{16}$$

Where t_r is communication range, ρ the node density, p is probability, n is the number of node. Equation (16) is used to determine MNs in communication range. The node density depends on the number of nodes and the area of coverage. This also results to the probability level of determining if node is in range or out of range, and when node density is neglected, (14) and (15) is to determine MNs in communication range and those out of range.

Definition IV (Free Space Path Loss)

Free space path loss model is a power off that relates to distance. Due to high mobility of nodes as speed changes, the distance between the transmitter and receiver changes. This makes empirical free space path loss necessary in order to model the effect of distance on packet delivery probability. This space loss accounts for the loss due to spreading of Radio Frequency (RF) energy as transmission of signals propagates through free space. From the equation of path loss, it is observed that the power density reduces by $\frac{1}{R^2}$ as distance is increased.

$$P_{rx} = P_{tx}\left(\frac{\lambda}{4\pi R}\right)^2 \quad (17)$$

Where $\frac{P_{tx}}{4\pi R^2}$ is the power density in free space, the power of electromagnetic radiation varies inversely with the square of the distance, making distance an ideal indicator of signal level, as well as loss rate. Due to imperfect propagation environment, in practice it is not exactly the inverse square. Distance between sender and receiver gives a high correlation between signal level and error rate as this affects the number of transmitted packets to be received [44].

One of the important parameters to evaluate propagation effect in the simulation is RSS. In order to analysis it, we first need the power gain, and transmit power. It can be derived from (15) and (16), and Fig.5.

$$g_{(t)} = g_{p(t)} + g_{s(t)} + g_{m(t)} \quad (18)$$

$$P_{rx} = P_{tx} - g_t \quad (19)$$

$$RSS = P_{rx} - P_{noise} \quad (20)$$

Where $g_{(t)}$ is power gain, $g_{p(t)}$ is path loss, $g_{s(t)} + g_{m(t)}$ is shadowing and $g_{m(t)}$ is multipath fading and RSS is the received signal strength.

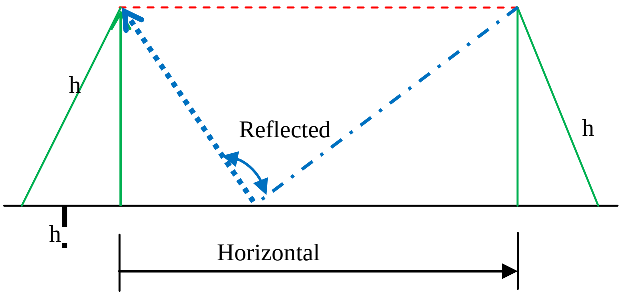

Figure 5. Two-ray ground model.

5. RESULTS AND EVALUATIONS

A. Discussion of Results

The simulation was implemented with three important parameters that are crucial to connectivity of signal in mobile and wireless environments shown in (17-20). Also, speed, distance, and the number of nodes on the network are also key variables that impact signal reception. The simulation was implemented with 100 MNs on the network to test the impact of congestion on the above-mentioned parameters. Simulation parameters are shown in Table I.

TABLE I. SIMULATION PARAMETERS CONT.

Parameters (Units	**Values**
Maximum Retransmission	4
Data rate (Mbps)	3, 4.5, 6,9,12,24,27
Log Normal deviation (dB)	8
cwMinData	31
Carrier frequency (GHz)	2.4
Simulation time (s)	172,800
Mobility model	ConstantSpeed
ϒ (Path Loss exponent, Urban area cellular radio)	2.56

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Carrier frequency (GHz)	2.4
Simulation time (s)	172,800
Mobility model	ConstantSpeed
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A. Evaluation of Results

From network theory, it is evident that congestion mitigates the performance of the network. Throughput is one of the basic metric of system measurement to test for QoS. From Fig.6, it is observed that AARF is not capable to withstand network congestion, especially sharing network resources with other RAs. It is observed from the graph that from the minimum to the maximum number of MNs utilizing network resources, AARF did not perform well under this propagation condition. The throughput achieved by ACARS and ModifiedCARS with 100 nodes is greater than that of AARF even at the least number of nodes. Although SampleRate and ONOE performed well under less congestion, but they are greatly affected as the number of MNs increases as they share in network resources.

The trend of the graph obeys the theory of network performance as the throughput decreases proportionately with the increase in the number of nodes agitating for network resources. It is true in the fact that when the number of MNs increase on the network, many tends to access the network at same time leading to collision of packets and many of them are dropped , thereby reducing the number of successfully received packets at the destination. This means that, out of the 1000 packets that were sent per simulation, when the MNs increase, predominately sent packets will not arrive at the receiver because of collision encountered by participating nodes.

The speed of the vehicles was modeled using (2-6) to constrain the vehicles within the speed limit. From the graph obtained in Fig.7, result shows that the vehicles clustered within the speed limit for the simulation. Within this limit, ACARS performed better than the other algorithms, while AARF has poor performance because of the network conditions that is not favorable to this RA caused by the propagation conditions. There is just negligible difference between ModifiedCARS, SampleRate, and ONOE in performance measure as they all clustered almost at same level.

From Fig. 8, result shows that ACARS is a robust algorithm that is able to sustain connectively more than the others even as the vehicles move further from the base station. It can be observed that the throughput obtained by ACARS at 300m is even more than what AARF obtained within less than 10m from the base station. This shows that, AARF would not be a good RA at this point for connectivity because the MNs will easily loose communication at earlier movement. It also implies that mobility is concern to this algorithm especially with this propagation condition implemented in this simulation.

On the other hand, AARF may work better than others in other propagation condition with different configurations. The simulation was carried out with path loss exponent of 2.56, which correspond to the value of free space. Moreover, the shadowing deviation was 8.0, which is an outdoor. SampleRate also performs as good as ACARS as seen from the graph, and would also be a better recommendation for network connectivity for this environmental conditions.

From the results obtained as shown in Fig.6-8, it can be analyzed that these results validate the goal of network connectivity in mobile communications. From the results, network signal degrade as the MNs move further from the base station. It also deteriorates when congestion increases on the network as seen in (1-16) showing distance relationships. Any of the MNs depending on feedback from the base station would degrade in signal reception because of congestion, and this occurs as earlier seen when the number of nodes increases.

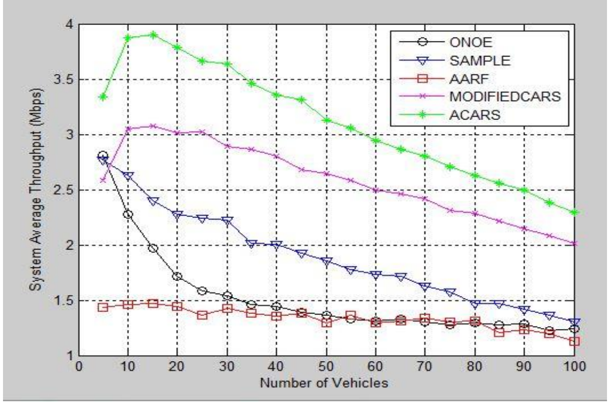

Figure 6. System Throughput vs. Number of Vehicles.

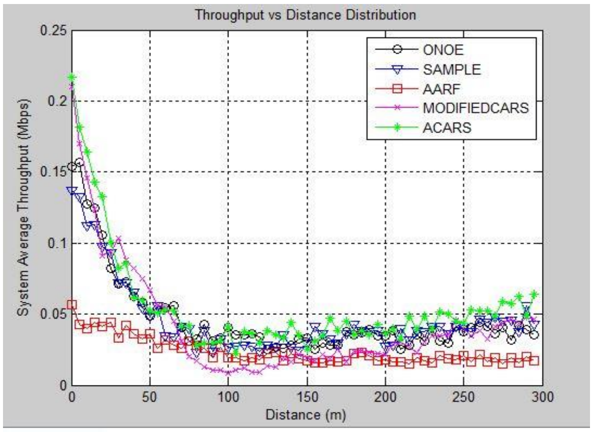

Figure 7. System Throughput vs. Speed of Vehicles.

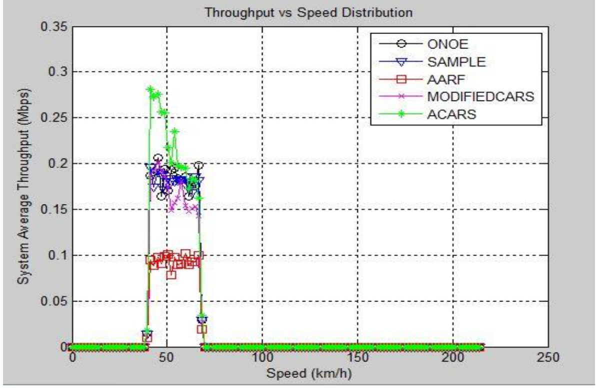

Figure 8. System Throughput vs. Distance of Vehicles.

6. CONCLUSION AND FUTURE WORK

A. Conclusion

The simulation results demonstrate the correlation between mathematical model and simulations. It is a combination of mathematical modeling, RA, and simulation. From the results obtained, different RAs have their peculiar characteristics and the environmental conditions that enhance their performances. The results from different RAs show that AARF cannot in any of the simulations perform as good as the others because of environmental factors. This means that in order to boost signal strength and sustain communication among vehicles, it is expedient to have the appropriate RA to be used. Safety is one of the core issues in vehicular communication; hence, if they lose communication, it could lead to accident and miss-direction with communicating vehicles.

The results will also help to estimate the minimum communication range needed to maintain signal strengths in mobile networks. The trade-off will be how to increase communication range and still maintain strong signal strength for QoS, and for application in rescue operation. Since mobility is a default characteristic of all MNs, the mobility model implemented here shows that not all RAs can combat with mobile environments as in this scenario.

B. Limitation and Future work

A typical infrastructure network was deployed in this article in which the vehicles communicate with each other via an AP. This network configuration results to delay in receiving messages because it will be faster to receive messages if they communicate directly with each other without an AP. In the future, the ad hoc network configuration will be considered, and will be nice to simulate for more vehicles to observe the trend of a densely populated network, say about 200 vehicles on the network.

Discrete Event Simulators (DES) such as Network Simulator (NS), OMNET++ will be an alternative choice to implement similar network configurations, as they are mainly designed for network purposes especially for mobile and wireless networks. Future work will also consider increasing the communication range between MNs and the base station, and on the other hand, implementing an ad hoc network (VANET) where MNs could communicate with each other without an intermediary node to deliver messages.

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