

Sensing and Detection of Traffic Status through V2V Routing Hop Count and Route Energy

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Abstract—New approach to manage congestion using vehicular communication is presented in this work. The research work using MATLAB simulation, tracked communicating vehicles travelling on roads with constant registration of changes in routes, number of hops, and energy consumed as a function of travelled distances. The area of travel and simulation is divided into blocks or zones to enable sufficient allocation and distribution of Road Side Units (RSUs) that are used to relay communication signals and transmission of Basic Safety Messages (BSMs). The successfully concluded simulation is based on the assumption that as congestion occurs, the number of hops per route and associated energy consumption per transmitted packets will change patterns in terms of hops, routes and consumed energy as traffic passes from low to smooth (optimal) to high density (congestion) states, where at the start of congestion, vehicles start to slow down and become closer to each other in a two dimensional space. The output is used as input to traffic status pattern characterization algorithm (management system) that uses the data to indicate the start of traffic accumulation, thus pre-emptive measures can be taken to avoid congestion and reduction in mobility. The presented analysis proved that it is possible to predict congestion as a function of both hops sequences and consumed energy, depending on the hops pattern which is shown to be symmetric in the case of optimum traffic that flows smoothly. The analysis also showed that when congestion starts to occur, asymmetric hops pattern occurs with hops sequences elements switch and swap places within the identified pattern. Further analysis and polynomial curve fitting proved that congestion control and smooth traffic management using the proposed approach is achievable.

Keywords—V2V; consumed energy; congestion; hops; VANET; routing

I. INTRODUCTION

Mobile data is a critical issue in today's dynamic, fast moving environment. Data transmission requires a network of devices or nodes and links to enable information delivery. One of the most important areas of mobile data application is traffic management and interaction between infrastructure and travelling vehicles. Intelligent transportation system (ITS) enables a more optimized performance of transportation systems through the integration of advanced communication and sensor technologies [1], [2], [3].

A main component of intelligent transportation system is Vehicular Ad Hoc Network (VANET). VANETs are based on similar principles to mobile ad hoc networks (MANETs), where instantaneous formation of a wireless network is carried out in order to enable vehicular data exchange and delivery

within a smart vehicular-infrastructure domain. VANETs are enabled through the use of on-board-units (OBUs) installed in the vehicles and road-side-units (RSUs) installed along side roads [4], [5], [6], [7], [8].

Intelligent transportation systems for vehicular ad-hoc networks motivated a wide range of protective applications, such as vehicle collision warning, lane changing, driver assistance, automatic parking, among others. All of the mentioned applications aim to provide, safety, mobility, efficiency, and comfortable transportation, with main objective of reducing accidents and congestion on the roads that result in many cases from unsafe driving, weather conditions, traffic incidents, or simply from traffic mismanagement. Not to forget drivers conditions, attitudes and experiences [9], [10], [11].

The Road traffic faces congested situations that can lead to chaos. Use of connected vehicles that share information and work cooperatively, would result in safer and greener transportation system. Communication systems used to connect vehicles under cooperative driving principles with intelligent controlling algorithms, plays a critical role in traffic monitoring and management. Such technologies assist in the way that infrastructure is designed and built for a smarter environment. The developed wireless communications standards are now in a state where it can be effectively utilized to enable vehicular communication through Vehicular Ad-Hoc Networking [12], [13].

The main proposed wireless communication technology for vehicular connectivity is the Dedicated Short Range Communication (DSRC), which is mapped through the IEEE 802.11p. Such technology enables both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication [14], [15], [16], [17]. VANET communication is achieved using dedicated communications devices as part of the On-Board Units (OBUs) in the vehicles, enabling ad hoc networking among vehicles and between vehicles and infrastructure. This will give the ability to monitor vehicles movements and traffic patterns in order to manage safer, less congested and more reliable traffic motion. Effective VANET communications comprises the use of fast and reliable transmission of Basic safety Messages (BSM) to other vehicles on the road. The BSM should be communicated to sufficient number of vehicles in the shortest possible time with considerations to both consumed energy and bandwidth parameters [18], [19], [20], [21].

Wireless ad hoc networks require routing and management protocols, aims at reducing energy consumption together with

self-configuration. They apply real time messaging between vehicles (nodes) using radio wave transmission over specific distance (range). VANETS consist of vehicular mobile nodes, established without a centralized infrastructure, thus, each node will perform the functions of transmitter, receiver, and data router [22], [23], [24], [25], [26], [27], [28].

II. RELATED WORK

Congestion control is a serious issue when dealing with traffic management. Ideally, vehicles would send BSM to other vehicles within a certain range in order to perform certain tasks required by the employed safety application. However, VANETS encounter several challenges due to various obstacles such as transmission delay, available bandwidth, multi-path fading, among others, which affect the performance of a formed network and associated applications [29], [30], [31].

The use of connected and automated vehicles will impose more pressure on reliability, latency, bandwidth conditions, and threshold levels in terms of vehicular communication. Such requirements will be even more stringent when autonomous vehicles are used, especially when entering or leaving roads under different weather and road conditions, during accidents, when changing lanes, among other conditions and under different scenarios [32], [33], [34].

When designing or modifying the management strategies of transportation network, it is essential to evaluate current performance and multiple scenarios, in order to optimize its operations and account for changing capacity in terms of vehicles and also in relation to wireless communication requirements, such as bandwidth, energy, time, and latency. This can be achieved through simulations using various routing algorithms in order to apply optimization to exchanged control message (BSMs) with minimal time delay, and number of hops among others [35], [36].

In this paper, an approach is proposed which uses transmitted bit energy, elapsed signal routing time, and number of hops, to enable better traffic management and congestion control in response to traffic density, which is a function of the increase in the number of vehicles per travelled area over time intervals. The aim here is to use such parameters as input variables to predict and alleviate road congestion, through route change, traffic lights timing change to better manage the existing traffic conditions in relation to infrastructure.

The rest of this paper is divided as follows: Methodology, Results, Analysis and Discussion, Conclusions, References.

III. METHODOLOGY

The main idea of this work is based on the hypothesis that when traffic is very low and traffic density is below a certain threshold with high vehicle mobility (speed, maneuver, lane changing), V2V communication will need to use longer routes with fewer connections between travelling vehicles. This means that the number of hops will increase in response to the reduction in available connections and available routes due to fewer available vehicles (nodes) with abundance of space between the travelling vehicles. However, as the traffic

density grows and number of travelled vehicles increase per travelled distance, it is expected that the number of connections and available communication routes will increase, which result in a decrease in the number of hops per route, as there will be more available connections due to the presence of more vehicles or nodes and less unoccupied spaces on the road. However, when the traffic is optimal and flowing smoothly and efficiently with maximum utilization of the road, then the number of hops and travelled routes should display a unique balanced characteristic that can be used to detect congestion. These assumptions are to be used in this work as indicators to predict congestion and enable better traffic flow and management. This is based on using the following parameters to characterize traffic condition on the roads:

- 1) Number of Vehicles (Nodes): N
- 2) Hops Count: H
- 3) Message Travelled Distance (Route): MTD
- 4) Connections Sequence: CS
- 5) Energy Consumed per Route: ECR

Fig. 1 presents the proposed management system. The system uses the mentioned parameters as inputs to decide if there is a congestion, and act upon such characterization. The simulation traces BSM wireless communication between two specific vehicles (nodes) and analyze the effect of congestion on their connectivity.

Using MATLAB code, the proposed system correlates the number of travelling vehicles (N) to:

- 1) Hops Count (H).
- 2) Message Travelled Distance (MTD).
- 3) Energy Consumed per Route (ECR).
- 4) Connections Sequences (CS).

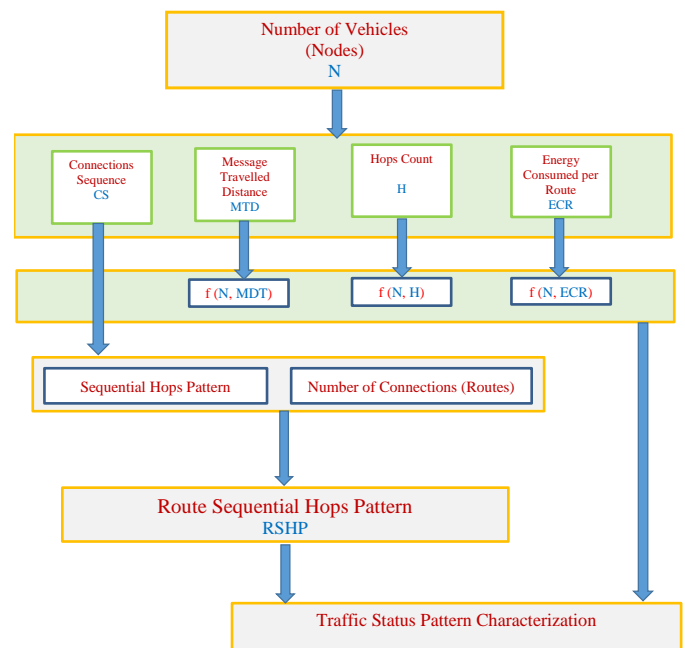


Fig. 1. Proposed Management System.

Connection Sequences are further used to establish connectivity pattern that is implicitly related to Hops Count (H), Message Travelled Distance (MTD), and the Energy Consumed per Route (ECR) through monitoring of repetitive number of hops for each single connection and over the whole travelled route, which is projected onto two parameters:

- 1) Sequential Hops Patterns
- 2) Number of Connections (Routes)

Both Sequential Hops Patterns and Number of Connection (Routes) are then used per number of vehicles in a scenario that is simulated in urban area to produce the Route Sequential Hops Pattern (RSHP) for the state of traffic, enabling traffic density and congestion level characterization through correlation with MTD, H, and ECR all as a function of number of travelling vehicles. This will eliminate errors in traffic characterization and management, when the driver is driving slowly by choice and not as a result of congestion.

The proposed approach eliminates the need to consider travelling time as roads speed differ in different areas and is a function of road design and purpose. Thus making the presented model and simulation applicable to any road type and structure.

As vehicular communication covers both V2V and V2I, with V2V is also accomplished as a result of V2I communication to communicate certain data obtained from Road side Units (RSUs), then it is necessary to establish communication zones over the physical roads to enable determination of transmission ranges within each zone or area of vehicular travel, so that coverage is guaranteed and signal strength is within acceptable limits.

The travelled area or area size is divided into zones of 40 m by 40 m. The proposed and simulated block division allows for addition and operating of RSUs as a function of the total travel distance by vehicles.

The transmission range in one dimension (Longitudinally or laterally) is specified according to equation (1):

$$Transmission\ Range\ (TR) = \beta * ZS \quad (1)$$

Where $\beta \leq 1$ and ZS : Zone Size

The condition of β to be less than one is essential to guarantee non-interference of communicating vehicles groups within each zone and to enable more accurate traffic management especially in the cases of work zones and accidents zones. However, as vehicles are moving there will be no interruption of communications as they move from one zone to the next, very similar to cellular communication that uses cells and handover regions from one coverage to the other. The ratio can be one only if the area is considered as one zone covered by one RSU.

From equation (1), Transmission Range (TR) can be related to Message Travelled Distance (MTD) through equation (2).

$$Transmission\ Range\ (TR) \geq MTD \quad (2)$$

Thus the dynamic MTD for a direct V2V communication between any two vehicles can be approximated as in equation (3).

$$MTD \leq (\beta * ZS) \quad (3)$$

From equation (3), the consumed energy is approximated by equation (4).

$$ECR_{consumed} \leq (ECR * \beta * ZS) \quad (4)$$

Each Hop will consume energy within the specified zone according to equation (5).

$$ECR_{consumed(Hop)} \leq \left(\frac{ECR * \beta * ZS}{H} \right) \quad (5)$$

In this work the used ratio is 0.75 as more than one zone is considered in the simulation as shown in Fig. 2. The transmission range is dynamic and a function of vehicles movements and time. Hence, it is of great advantage to subdivide the travelled area into Zones in case of temporary vehicular groups, where it becomes much easier to manage their communications as they move and leave one group to enter another temporary group that belongs to a different zone.

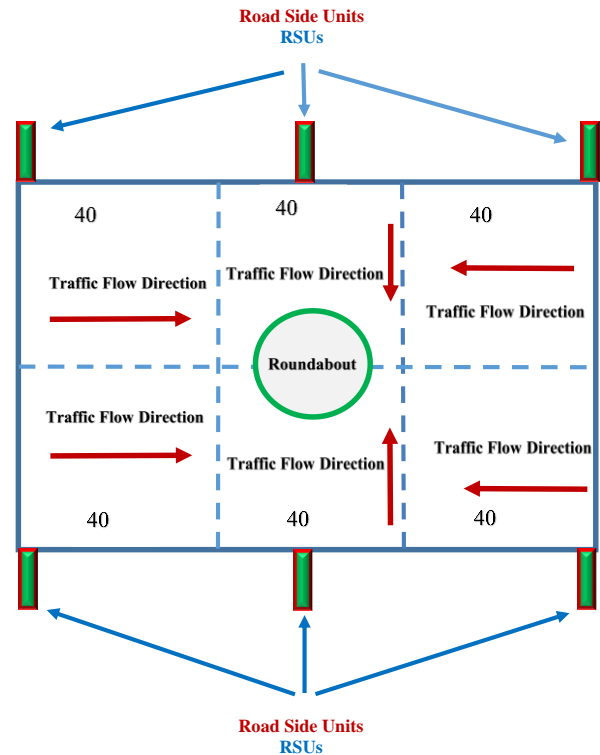


Fig. 2. Simulated Area with Divided Blocks (Zones).

IV. RESULTS

Tables I to III present the initial simulation results with traffic density or vehicles numbers (nodes): {40, 280, 440}.

TABLE I. ENERGY VARIATION AS A FUNCTION OF NUMBER OF CONNECTIONS FOR 40 VEHICLES

Connections Sequence	Hops Count	Message Travelled Distance (m)	Consumed Energy Per Route (J)
1	3	72.83	0.0015
2	3	53.91	0.0009
3	3	52.74	0.0008
4	3	52.29	0.0008
5	3	52.40	0.0008
6	3	52.82	0.0008
7	3	53.43	0.0009
8	3	54.17	0.0009
9	3	55.01	0.0009
10	3	55.95	0.0009
11	3	56.99	0.0010
12	3	58.11	0.0010
13	3	59.32	0.0010
14	3	60.63	0.0011
15	3	62.02	0.0011
16	3	63.50	0.0012
17	3	65.07	0.0012
18	3	66.73	0.0013
19	3	68.46	0.0013
20	3	70.28	0.0014
21	3	72.16	0.0015
22	3	74.12	0.0015
23	3	76.15	0.0016
24	3	78.23	0.0017
25	4	94.34	0.0024
26	4	95.11	0.0024
27	4	96.11	0.0025
28	4	97.31	0.0026
29	4	98.70	0.0026
30	4	90.95	0.0022
31	4	101.57	0.0028
32	4	103.15	0.0029
33	4	104.88	0.0029
34	4	93.74	0.0024

TABLE II. ENERGY VARIATION AS A FUNCTION OF NUMBER OF CONNECTIONS FOR 280 VEHICLES

Connections Sequence	Hops Count	Message Travelled Distance (m)	Consumed Energy Per Route (J)
1	4	110.40	0.0032
2	4	107.98	0.0031
3	4	105.59	0.0030
4	4	103.25	0.0029
5	4	100.97	0.0027
6	4	98.91	0.0026
7	4	97.03	0.0025
8	4	95.17	0.0024
9	4	93.34	0.0024
10	4	94.61	0.0024
11	4	99.45	0.0027
12	4	98.12	0.0026
13	3	87.73	0.0021
14	3	82.18	0.0019

15	3	80.76	0.0018
16	3	79.47	0.0017
17	3	78.31	0.0017
18	3	75.54	0.0016
19	3	80.36	0.0018
20	3	72.04	0.0015
21	3	70.38	0.0014
22	3	69.41	0.0014
23	3	68.06	0.0013
24	3	66.86	0.0013
25	3	65.87	0.0012
26	3	71.58	0.0014
27	3	71.94	0.0015
28	3	76.52	0.0016
29	3	76.47	0.0016
30	2	55.25	0.0009
31	2	53.84	0.0009
32	2	52.50	0.0008
33	2	51.25	0.0008
34	2	50.10	0.0008
35	2	49.07	0.0007
36	2	48.18	0.0007
37	2	47.44	0.0007
38	2	46.86	0.0007
39	2	46.47	0.0007
40	2	46.27	0.0007
41	2	46.27	0.0007
42	2	45.69	0.0007
43	2	45.48	0.0007
44	2	45.31	0.0007
45	2	45.16	0.0007
46	2	45.04	0.0006
47	2	44.94	0.0006
48	2	44.86	0.0006
49	2	44.80	0.0006
50	2	44.76	0.0006
51	2	44.73	0.0006
52	2	44.72	0.0006
53	2	49.27	0.0007
54	2	50.64	0.0008
55	2	52.09	0.0008
56	2	63.41	0.0012
57	2	63.42	0.0012
58	3	60.26	0.0011
59	3	67.24	0.0013
60	3	69.24	0.0014
61	3	81.21	0.0018
62	3	73.24	0.0015
63	4	76.40	0.0016
64	4	77.70	0.0017
65	4	96.36	0.0025
66	4	96.44	0.0025
67	4	96.61	0.0025
68	4	96.86	0.0025
69	4	97.19	0.0025
70	4	97.61	0.0026
71	4	98.13	0.0026

TABLE III. ENERGY VARIATION AS A FUNCTION OF NUMBER OF CONNECTIONS FOR 440 VEHICLES

Connections Sequence	Hops Count	Message Travelled Distance (m)	Consumed Energy Per Route (J)
1	3	67.32	0.0013
2	3	65.98	0.0012
3	3	64.73	0.0012
4	2	63.59	0.0012
5	2	58.77	0.0010
6	2	57.32	0.0010
7	2	55.87	0.0009
8	2	54.49	0.0009
9	2	53.20	0.0009
10	2	52.00	0.0008
11	2	50.91	0.0008
12	2	49.95	0.0008
13	2	49.13	0.0007
14	2	48.47	0.0007
15	2	47.98	0.0007
16	2	47.69	0.0007
17	2	47.59	0.0007
18	2	47.69	0.0007
19	2	47.98	0.0007
20	2	48.47	0.0007
21	2	49.13	0.0007
22	2	49.95	0.0008
23	2	50.91	0.0008
24	2	52.00	0.0008
25	2	53.20	0.0009
26	2	54.49	0.0009
27	2	55.87	0.0009
28	2	57.32	0.0010
29	2	45.39	0.0007
30	2	40.86	0.0006
31	2	41.28	0.0006
32	2	41.78	0.0006
33	2	42.34	0.0006
34	2	42.96	0.0006
35	2	43.66	0.0006
36	2	44.42	0.0006
37	2	45.26	0.0007
38	2	46.18	0.0007
39	2	47.18	0.0007
40	2	48.26	0.0007
41	2	49.43	0.0008
42	2	50.69	0.0008
43	3	52.04	0.0008
44	3	55.22	0.0009
45	3	56.11	0.0009
46	3	57.25	0.0010
47	3	58.59	0.0010
48	3	60.07	0.0011
49	3	61.65	0.0011
50	3	63.31	0.0012
51	3	65.04	0.0012
52	3	66.81	0.0013

53	3	68.61	0.0013
54	3	70.44	0.0014
55	3	72.30	0.0015
56	3	74.18	0.0015
57	3	75.32	0.0016
58	3	76.03	0.0016
59	3	77.91	0.0017
60	3	78.08	0.0017
61	3	79.89	0.0018
62	3	81.86	0.0018
63	3	83.99	0.0019
64	4	86.27	0.0020
65	4	92.70	0.0023
66	4	94.70	0.0024
67	4	96.70	0.0025
68	4	98.24	0.0026
69	4	100.24	0.0027
70	4	102.24	0.0028
71	4	103.00	0.0028
72	4	104.32	0.0029

V. ANALYSIS AND DISCUSSION

Fig. 3 shows the relationship between increasing number of vehicles (nodes) and the average message travelled distance by a transmitted signal from one vehicle to another vehicle. It is clear from the plot that as the traffic density and volume increases per same area size, the travelled distance will decrease, due to vehicles or nodes becoming closer to each other, as their number increases and their speed drops. Hence, the number of 2 hops routes will increase, while 3 hops, and 4 hops routes will decrease, thus reducing the average message travelled distance. This is supported by the detailed hops count and comparative plot shown in Fig. 4.

Fig. 4 present detailed hops distribution that count for each simulated volume of vehicles (nodes) travelling the same areas size. As the plot and associated table present, at 40 vehicles volume, 2 hops routes are not used as the vehicles (nodes) are very far apart (very low traffic), hence only 3 hops and 4 hops connectivity routes are available. As the traffic volume increase to 280 vehicles (nodes), traffic density increases per area size and more vehicles are now able to communicate through 2 hops routes, thus the overall hops count increases in relation to traffic volume with 2 hops routes having larger percentage of the communication routes. However, as the traffic flow is smooth and congestion state is not reached, 3 hops routes and 4 hops routes are almost equally distributed.

With number of vehicles reaching 440 vehicles (nodes) per same area size, the simulated results show a decrease in the 4 hops routes and a large increase in 2 hops routes, with slight increase in 3 hops routes. This is due to the increase in volume and traffic density above normal conditions (optimum level), which lead to vehicles or communicating nodes become closer, slowing down to a limited speed as a result of traffic build up. These observations, which are supported by the carried out MATLAB simulation proves the presented hypothesis and is further backed by the presented plots and associated data in Fig. 5 where, a clear indication of the

reduction in the average consumed energy as the number of hops per route is reduced going from 40 vehicles (nodes) through a smooth (optimum) traffic density per area size (280 vehicles), and up to the start of congestion, where the number of vehicles reached 440 vehicles or nodes.

Such deduction is further proved in Fig. 6, where the corresponding reduction in the average consumed energy per route is shown to correlate with the increase of the 2 hops routes and the reduction of 3 hops routes and 4 hops routes. All plots and analysis are based on data in Tables I to III.

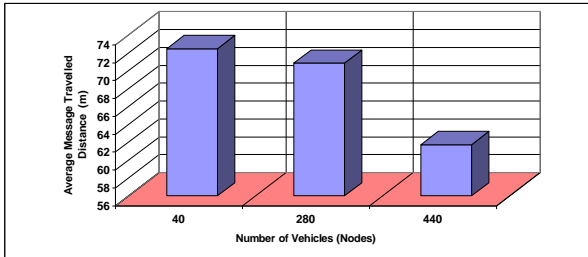


Fig. 3. Effect of Number of Vehicles (nodes) on Average Travelled Distance (Route).

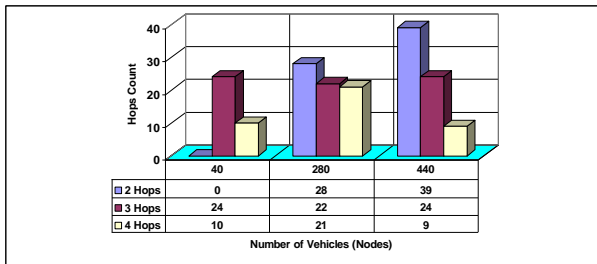


Fig. 4. Relationship between Number of Vehicles (nodes), Hops Distribution and Hop Count.

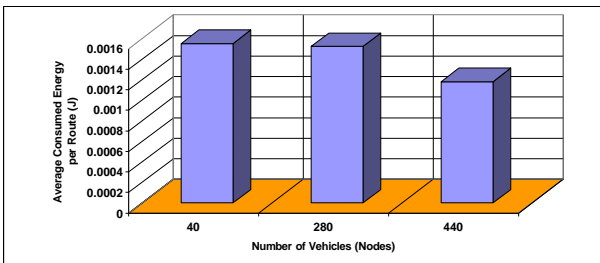


Fig. 5. Effect of Number of Vehicles (nodes) on Average Consumed Energy for Transmitted Bytes.

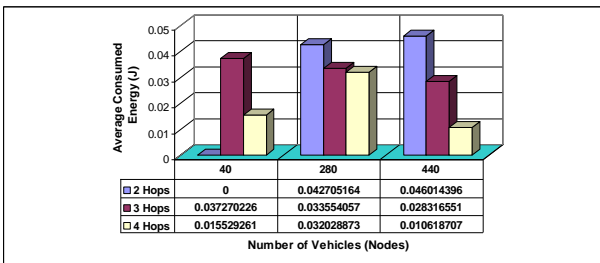


Fig. 6. Relationship between Number of Vehicles (nodes), Hop Distribution and the Average Consumed Energy for Transmitted Bytes.

Based on the previous analysis, the normal pattern for optimum number of vehicles (nodes) in relation to the available area size that results in smooth traffic flow, is related to the sequential hops pattern through symmetrical analysis. A symmetrical transition between routes with different number of hops, indicates smooth traffic with optimum mobility, any deviation from that present the extreme low traffic or very high traffic (congestion). Three cases are depicted by Fig. 7 to 9:

1) If the number of vehicles (nodes) are too low (low traffic flow) in relation to area size: the sequential hops pattern is shown to be [3, 4], (Fig. 7).

2) If the number of vehicles (nodes) are optimum (smooth traffic flow) in relation to area size: the sequential hops pattern is shown to be [4, 3, 2, 3, 4], (Fig. 8).

3) If the number of vehicles (nodes) are high (High density traffic flow (congestion) in relation to area size: the sequential hops pattern is shown to be [3, 2, 3, 4, 3], (Fig. 9).

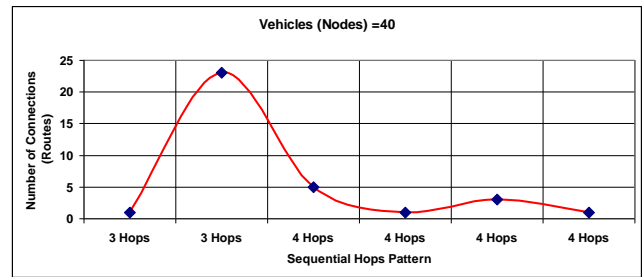


Fig. 7. Hops Distribution Dynamics as a Function of Connections (Routes) for Low Traffic Density.

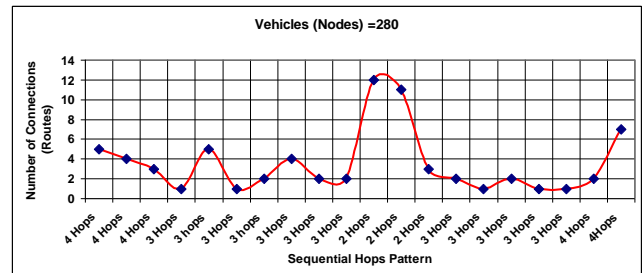


Fig. 8. Hops Distribution Dynamics as a Function of Connections (Routes) for Optimum Traffic Density.

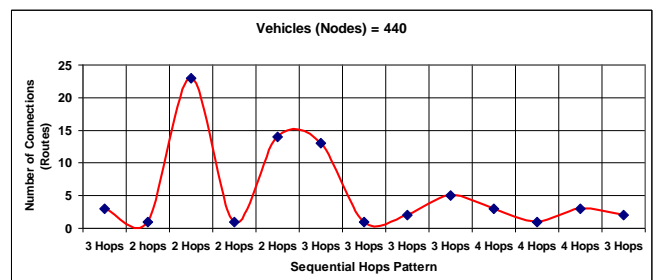


Fig. 9. Hops Distribution Dynamics as a Function of Connections (Routes) for High Traffic Density (Congestion).

Thus, the symmetric case only occurs when the traffic is optimum (case 1), while when it is very low, the 2 hops connectivity does not exist, as the vehicles are far apart (also taking into account speed). In the case of congestion, a shift in the 2 hops is observed as they swap places and a switch also occurs in places between 4 hops and 3 hops routes (case 3). The swapping, switching, and deviation from symmetry implies a serious change in the traffic flow pattern, which is proved through simulation to indicate congestion. The route sequential hops pattern (RSHP), discussed above can be generalized as in equations (6) to (8), assuming maximum allowed number of hops is H_{max} .

$$RSHP_{low\ traffic} = [(H_{max} - 1), \dots, (H_{max})] \quad (6)$$

$$RSHP_{smooth\ traffic} = [(H_{max}), \dots, (H_{max} - 1), (H_{max} - n), (H_{max} - 1), \dots, (H_{max})] \quad (7)$$

$$RSHP_{congestion} = [(H_{max} - 1), (H_{max} - n), (H_{max} - 1), \dots, (H_{max}), \dots, (H_{max} - 1)] \quad (8)$$

$(H_{max} - n)$: The minimum number of hops per route, which is assumed to hold a value of 2.

The expressions in equations (6) to (8) with their associated patterns are correlated to the following variables as indicated in the proposed system in Fig. 1:

- 1) Hops Count (H)
- 2) Message Travelled Distance (MTD)
- 3) Energy Consumed per Route (ECR)

Thus, eliminating any errors that might result when a vehicle is moving at slow speed not because of traffic density, but as a matter of choice.

VI. CONCLUSIONS

This work presented a new concept in congestion control as a function of hops count and route energy variation. The work attempted to solve a critical issue in traffic management and smart cities, namely, congestion. Congestion is a result of inefficient transportation policies, or a consequence of road incidents, will adversely contribute to the economic, environmental, and societal beings. Hence, it is of prime importance to control congestion and work towards smooth traffic flow. As a result of this work, a final correlation can be made between:

- 1) The consumed energy per used route and traffic density.
- 2) The number of connections during vehicle's trip and traffic density.

Fig. 10 and 11 illustrate the relationships with fitted polynomial curves.

The fitted curves mathematical expressions are given in equations (9) and (10).

$$M = 4x10^{-4} N^2 + 273x10^{-3} N + 0.237x10^2 \quad (9)$$

$$ECR = 5x10^{-9} N^2 + 2x10^{-6} N + 15x10^{-4} \quad (10)$$

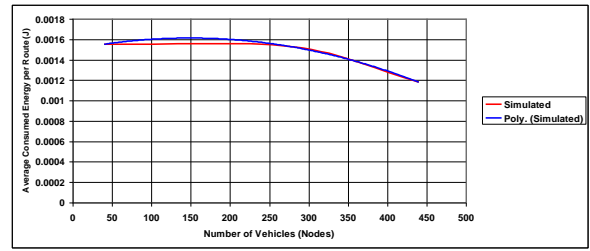


Fig. 10. Effect of Increasing Traffic Density on the Average Consumed Energy Per route.

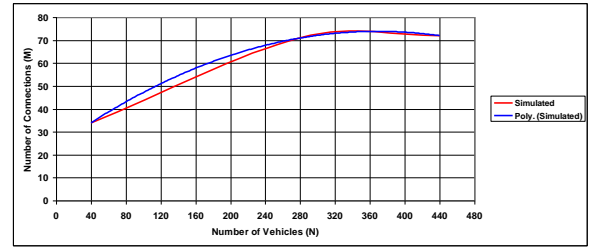


Fig. 11. Effect of Increasing Traffic Density on the Number of Connections Per Trip.

Where;

M: Number of Connections.

ECR: Energy Consumed per Route.

The reduction in energy as nodes number increases is due to slower motion and mobility, which indicates congestion and fewer available connections at the horizon. Also, 2 hops connections are shown to increase as vehicles (nodes) become closer to each other within the available range contributing to lower energy consumption.

Finely, this work achieved the following:

- 1) Establishing a relationship between congestion and number of hops per communication route as a function of travelling vehicles.
- 2) Enabling the correlation between physical travelled distance and communication route length.
- 3) Deducing a relationship between consumed energy and congestion.
- 4) Proving that energy consumed is a function of number of hops, which is also related to the consumed energy that can be correlated to congestion.
- 5) Proposing a correlative algorithm that supports traffic management system.

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