

Effect of Route Length and Signal Attenuation on Energy Consumption in V2V Communication

Mahmoud Zaki Iskandarani
Faculty of Engineering
Al-Ahliyya Amman University
Amman, Jordan

Abstract—Simulation of Vehicle-to Vehicle (V2V) communication and connectivity is carried out. The main objective of the carried out V2V communication simulation is to study the effect of route length, number of hops per route, attenuation related parameter and message size on energy consumption of transmitted bits per sent message. Mathematical modeling (using the original radio energy model), and analysis, is carried out to quantify and approximate the effect of attenuation related parameter (α) and Route Length (LR) on energy consumption of transmitted Basic Safety Message (BSM) for both, 256 Bytes and 320 Bytes size. The original energy radio model is expanded to include not only message size, but also the effect of number of hops on energy consumption. The work successfully proved the critical effect of α and number of hops on energy consumption for a fixed BSM size and the effect of α on the transitional characteristics of routes as a function of number of hops. It is clear from the simulation that α has an adverse effect on consumed energy for transmitted BSMs and also has a marked effect on routes, where any value of α above 3 will lead to energy depletion among, other negative effects on communicating devices.

Keywords—Intelligent transportation systems; routing; connected vehicles; energy; V2V; multipath fading; BSM

I. INTRODUCTION

Advances in information and communication technologies and their applications to infrastructure and traffic under intelligent transportation systems generated much work on vehicular networking. Objectives for such work is to provide vehicles and roads with safe and reliable travelling infrastructure. Additional benefits from securing increasing the efficiency of roads and vehicles interaction is to enable a more relaxed and comfortable journeys. To achieve such objectives, a secure, efficient, effective, and reliable information need to be conveyed to vehicles concerning road conditions, accidents, incidents, congestion, weather conditions, alternative routes, alternative services on different routes and roads. This is for all travelling vehicles on the roads network, and for vehicles sharing the same road over a period of time, speed, distance, and location information need to be exchanged between vehicles as well as all other information that is received by vehicles from traffic management centers and from traffic control centers [1-4].

The delivered information to vehicles and information exchanged between vehicles, contributes to better and safer journeys, improves economic conditions and business efficiency, reduce pollution, fuel consumption, running cost.

To achieve intelligent transportation systems objectives, vehicular ad-hoc network (VANET) is devised based on the existing mobile ad-hoc network (MANET), to form a wireless communication infrastructure for information exchange among vehicles. In VANETS, vehicles are equipped through on board units (OBUs) with wireless communication capabilities, which prepare them to form temporary networks while sharing same road within a transmittable distance, without the need for infrastructure connections or road side units (RSUs) [5-9].

The main task of a VANET is to enable data exchange through wireless communication through an effective Basic Safety Messages (BSMs), covering Vehicle-to-Vehicle communication (V2V) for speed, distance, location and general safety applications. Vehicle-to-Infrastructure communication (V2I) for safety and information collection applications, and in some scenarios, when the vehicles are at a long distance, V2V can occur through V2I, or when internet access is required for cloud computing applications and for temporary vehicular networks through cloud, V2I and V2V is employed a blended way for vehicular networking applications [10-16].

Vehicles travel in different areas and undergo different traffic environments due to the infrastructure mapping, such as urban, rural and large cities roads. Thus, communication within a vehicular ad-hoc network should operate satisfactory in all these areas which, have different communication impairments, which affects transmission energy of BSMs.

For communication to operate successfully, the default signal propagation model (free-space), needs to be modified according to the existing types of interference and blockage that might exist. The existence of such obstacles that can cause signal fading due to many factors, such as reflection, refraction and adsorption due surfaces such as building, high traffic density, trees, among others, which can also cause shadowing of signal propagation and end with multi-path fading., hence, free-space model cannot be assumed due to general signal attenuation [17-20].

Vehicular networks have to communicate with nearby vehicles, road side units (RSUs) with different requirements. Thus, and regardless of mechanism of communication, consideration of multipath fading and frequency displacements due to dynamic movements of vehicles (nodes) during travelling on different road environments is essential. Radio waves V2V communication using different frequencies

and wavelengths are very much developed with energy consumption as a measuring factor of efficient data exchanged between vehicles in a vehicular network [21-22].

In this paper, the extent of influence of the attenuation dependent parameter (α) and Route Length (RL) is analyzed and modeled using the basic radio energy model. The effect of fading and route length is also related to the number of hops per route and to energy consumption for 256 Bytes and 320 Bytes BSMs.

II. METHODOLOGY

The purpose of this work is to use simulation of connected vehicles under different communication conditions, to assess V2V connectivity through energy consumption and its relationship with both route length and fading factors. The results of the simulation is used to develop the energy radio model to explicitly show effect of route length, hops, and fading factors (attenuation) in the consumed energy.

Modeling of energy consumption through data exchange between vehicles through routing using radio model is expressed by the general equation (1) and is derived as the energy per bit as a function of single hop.

$$E = E_{tx} + E_{rx}. \quad (1)$$

Where;

E_{tx} : Energy consumption of transmitter electronics.

E_{rx} : Energy consumption of receiver electronics.

The components of equation (1) are:

$$E_{tx} = E_{elect} + E_{tx(d)}(d)^\alpha. \quad (2)$$

$$E_{rx} = E_{elect}. \quad (3)$$

E_{elect} : Energy consumption of radio dissipation.

$E_{tx(d)}$: Energy consumption of the amplifier in the free space channel model used to transmit 1-bit over 1-meter distance, which can be substituted with the term $E_{(initial)}$.

α : Attenuation dependent parameter, function of communication environment usually between 2 and 5.

d : Transmission range or distance.

To account for size of exchanged data in bits, equation (4) needs to be taken into consideration.

$$k = N * packetsize * 8. \quad (4)$$

Where;

N : Number of transmitted packets.

Thus; equations (2) and (3) become:

$$E_{tx} = k * (E_{elect} + E_{(initial)}(d)^\alpha) \quad (5)$$

$$E_{rx} = k * E_{elect}. \quad (6)$$

It is assumed in this work that both E_{elec} and $E_{(initial)}$ have fixed values of ($E_{elec} = 50\text{nJ/bit}$, $E_{(initial)} = 0.105\text{nJ/bit/m}^2$). Thus the variation in consumed energy is mainly due to the factors of distance and the attenuation factor α .

Energy for transmitted bits is a function of distance, as more energy is needed for longer distances, due to fading and attenuating factors, and distance between transmitter and receiver (which is varying in real time). Energy is also related to the number of hops required to pass a message from vehicle A to vehicle B under consideration. The number of hops and consequently route length (RL) indicative of traffic condition and smoothness of traffic flow.

Thus, energy will be consumed more in relation to route length (RL), which is related to the number of hops. This means that, the distance (d) can be replaced by Route Length (RL), which will enable measuring distances as a function of hops based on the following assumptions:

1) Each vehicle will transmit to a fixed range such that route length for each hop does not exceed that range.

2) The range of transmission for each vehicle is widened if no communication achieved with the current range within a period of time T .

3) Route length will increase as more hops are needed for V2V connection, which will require longer communication time and more energy consumption. Hence, equation (5) becomes:

$$E_{tx} = k * (E_{elect} + E_{(initial)}(Route\ Length)^\alpha) \quad (7)$$

As Route length (RL) is related to the number of hops, then, Route length can be approximated and represented as shown in equation (8), which presents the effect of average hop length (AVH) or in general shows the effect of hop length as hops constitute travelled message route.

$$Route\ Length(RL) = (M * Average\ Hop\ Length). \quad (8)$$

Where M represents number of hops per specific route. So, equation (7) can be fairly represented as shown in equation (9).

$$E_{tx} = k * (E_{elect} + E_{(initial)}(M * AHL)^\alpha) \quad (9)$$

As the number of hops increases, the average hop length decrease, indicative of more traffic and more consumed energy.

To obtain a good approximation for Average Hop Length (AHL), the average of all routes length with different number of hops should be computed.

Thus, number of hops and average hop length need to be reduced in order to preserve consumed energy, at the same time, such hop count can be used to indicate traffic conditions.

III. RESULTS AND DISCUSSION

Tables I to IV present the initial simulated results for road traffic and V2V communication using BSMs.

TABLE II. BSM COMUNICATION FOR $\alpha = 1$

M	RL (m)	E _{tx} (J)	
		BSM=256 Bytes	BSM=320 Bytes
2	50.62	0.0001128	0.0001410
2	55.00	0.0001137	0.0001421
2	55.64	0.0001138	0.0001422
2	55.81	0.0001138	0.0001423
2	55.88	0.0001138	0.0001423
2	56.21	0.0001139	0.0001424
2	56.34	0.0001139	0.0001424
2	56.82	0.0001140	0.0001425
2	56.99	0.0001141	0.0001426
2	57.63	0.0001142	0.0001428
2	57.84	0.0001142	0.0001428
2	58.87	0.0001145	0.0001431
2	59.82	0.0001147	0.0001433
3	61.17	0.0001149	0.0001437
3	61.86	0.0001151	0.0001438
3	62.43	0.0001152	0.0001440
3	62.66	0.0001152	0.0001440
3	63.33	0.0001154	0.0001442
3	64.30	0.0001156	0.0001445
3	64.47	0.0001156	0.0001445
3	65.81	0.0001159	0.0001448
3	66.05	0.0001159	0.0001449
3	67.28	0.0001162	0.0001452
3	67.91	0.0001163	0.0001454
3	68.87	0.0001165	0.0001456
3	69.87	0.0001167	0.0001459
3	70.53	0.0001168	0.0001461
3	71.91	0.0001171	0.0001464
3	72.26	0.0001172	0.0001465

TABLE III. BSM COMUNICATION FOR $\alpha = 2$

M	RL (m)	E _{tx} (J)	
		BSM=256 Bytes	BSM=320 Bytes
2	50.62	0.00063	0.00078
2	56.91	0.00077	0.00096
2	56.99	0.00077	0.00096
2	57.30	0.00077	0.00097
2	58.04	0.00079	0.00099
2	58.05	0.00079	0.00099
2	58.21	0.00080	0.00100
2	59.07	0.00082	0.00102
2	59.17	0.00082	0.00102
3	63.27	0.00092	0.00115
3	64.60	0.00096	0.00120
3	64.89	0.00096	0.00121
3	64.93	0.00097	0.00121

3	66.02	0.00099	0.00124
3	67.61	0.00104	0.00130
3	68.83	0.00107	0.00134
3	68.92	0.00108	0.00134
3	68.96	0.00108	0.00135
3	69.29	0.00109	0.00136
3	69.78	0.00110	0.00137
3	69.80	0.00110	0.00138
3	70.22	0.00111	0.00139
3	70.50	0.00112	0.00140
3	70.57	0.00112	0.00140
3	70.91	0.00113	0.00142
3	71.31	0.00114	0.00143
3	71.36	0.00115	0.00143
3	71.75	0.00116	0.00145
3	72.24	0.00117	0.00146

TABLE IV. BSM COMUNICATION FOR $\alpha = 3$

M	RL (m)	E _{tx} (J)	
		BSM=256 Bytes	BSM=320 Bytes
2	51.93	0.02878	0.03597
2	51.96	0.02883	0.03604
2	52.01	0.02892	0.03614
2	52.11	0.02908	0.03635
2	52.21	0.02925	0.03657
2	52.37	0.02953	0.03691
2	52.53	0.02980	0.03724
2	52.76	0.03017	0.03772
2	53.26	0.03104	0.03879
2	53.26	0.03104	0.03879
2	53.57	0.03159	0.03949
2	53.93	0.03222	0.04027
2	54.32	0.03293	0.04116
2	54.76	0.03373	0.04217
3	66.55	0.06045	0.07557
3	71.39	0.07461	0.09326
3	72.65	0.07863	0.09828
3	72.99	0.07975	0.09968
3	73.42	0.08115	0.10144
3	74.20	0.08377	0.10471
3	74.35	0.08428	0.10536
3	74.55	0.08494	0.10618
3	74.60	0.08513	0.10642
3	74.89	0.08611	0.10764
3	75.06	0.08671	0.10839
3	75.19	0.08716	0.10895
3	75.52	0.08830	0.11037
3	75.54	0.08837	0.11046
3	75.93	0.08974	0.11218

TABLE V. BSM COMMUNICATION FOR $\alpha = 4$

M	RL (m)	E_{tx} (J)	
		BSM=256 Bytes	BSM=320 Bytes
2	53.54	1.68287	2.10359
2	54.18	1.76491	2.20614
2	54.88	1.85787	2.32234
2	55.46	1.93788	2.42235
2	55.47	1.93882	2.42352
2	55.49	1.94197	2.42747
2	55.53	1.94739	2.43423
2	55.64	1.96315	2.45394
2	56.04	2.01967	2.52459
2	56.18	2.03995	2.54994
2	56.34	2.06309	2.57886
2	56.47	2.08235	2.60294
3	63.08	3.24238	4.05298
3	64.76	3.60191	4.50239
3	66.56	4.02014	5.02518
3	67.52	4.25767	5.32208
3	67.63	4.28495	5.35618
3	67.91	4.35545	5.44432
3	68.03	4.38557	5.48197
3	68.49	4.50628	5.63284
3	69.60	4.80694	6.00867
3	70.54	5.07095	6.33869
3	71.35	5.30825	6.63531
3	72.72	5.72646	7.15807
3	73.14	5.86081	7.32602
3	74.03	6.15081	7.68851
3	74.96	6.46646	8.08307
3	75.02	6.48689	8.10862
3	76.58	7.04254	8.80317

Fig. 1 to 4 show effect of the attenuation related parameter (α), Route Length (RL), BSM size on energy consumption during transmission (E_{tx}). From the figures, it is realized that:

- 1) The clear increase in the energy consumption of the transmitted messages as a function of Route Length (RL).
- 2) The expected increase in the energy consumption of the transmitted messages as a function of message size.
- 3) A marked increase in the energy consumption of the transmitted messages as a function of increasing the attenuation dependent parameter (α).
- 4) The increase in (α) caused a change in the energy consumption function behavior from linear to quadratic, which has an ability to increase in a dramatic manner causing communication failure due to energy depletion.

Tables V and VI present statistical data regarding average hops lengths (AHL), attenuation dependent parameter (α), and average consumed energy (ACE) during BSM transmission. From the tables, the following is noted:

- 1) As α increases, AHL is also affected.
- 2) AHL (2 Hops) changes dynamically with AHL (3 Hops), so if one increases the other decreases.
- 3) For all α values, AHL (2 Hops) is larger than AHL (3Hops).
- 4) The number of hops forming a route is independent of BSM size.
- 5) The average consumed energy per hop (ACE) is inversely related to the number of hops with overall average consumed energy directly proportional to route length (RL) and to the transmitted message size (BSM).
- 6) The average consumed energy per hop is directly proportional to the attenuation related parameter (α).

From the observations on data presented in Tables V and VI, equation (10) shows a reasonable representation of obtained data within the radio model context.

$$ACE = k * (E_{elect} + E_{(initial)}(M * AHL)^\alpha) \quad (10)$$

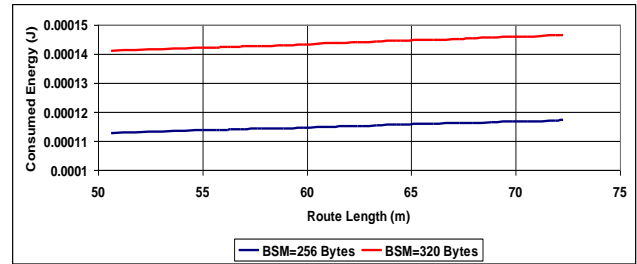


Fig. 1. Consumed Transmission Energy as a Function of Route Length ($\alpha=1$).

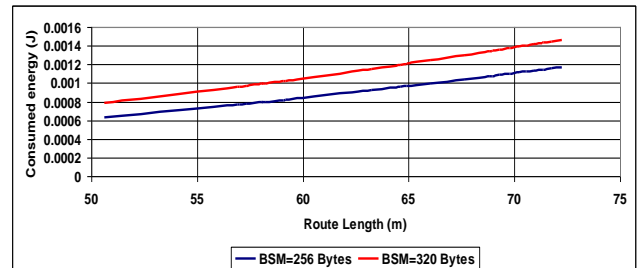


Fig. 2. Consumed Transmission Energy as a Function of Route Length ($\alpha=2$).

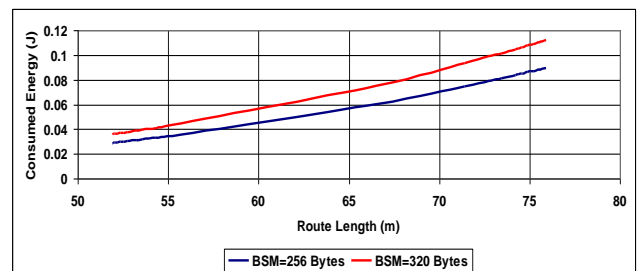


Fig. 3. Consumed Transmission Energy as a Function of Route Length ($\alpha=3$).

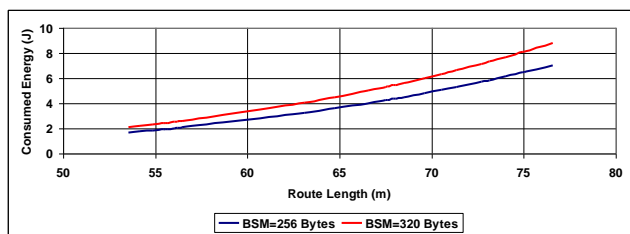


Fig. 4. Consumed Transmission Energy as a Function of Route Length ($\alpha=4$).

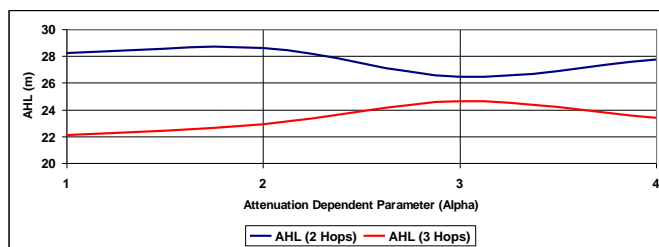


Fig. 5. Effect of α on Route Characteristics.

TABLE VI. EFFECT OF α AND AHL ON AVERAGE ENERGY CONSUMPTION (ACE) FOR BSM=256 BYTES

α	AHL (m)		ACE (J)	
	2 Hops	3 Hops	2 Hops	3 Hops
1	28.21	22.10	0.00006	0.00004
2	28.60	22.93	0.00039	0.00036
3	26.46	24.60	0.01525	0.02754
4	27.72	23.37	0.96830	1.67793

TABLE VII. EFFECT OF α AND AHL ON AVERAGE ENERGY CONSUMPTION (ACE) FOR BSM=320 BYTES

α	AHL (m)		ACE (J)	
	2 Hops	3 Hops	2 Hops	3 Hops
1	28.21	22.10	0.00007	0.00005
2	28.60	22.93	0.00048	0.00045
3	26.46	24.60	0.01906	0.03442
4	27.72	23.37	1.21000	2.09741

IV. CONCLUSIONS

This work presents a new approach to analyze energy consumption by transmitted BSMs during V2V communication. The analysis showed a marked and non-linear effect of the attenuation dependent parameter (α) on both route length and consumed energy. Route length also has an effect of increasing the energy consumed in a transmitted message as a function of number of hops. The conventional energy radio model is used to analyze such effects and successfully showed that the original distance term in the model can be replaced with route length and further with an expression relating number of hops and average hops length. Based on this work, traffic movements and congestion can be estimated as energy consumption is related to the number of BSMs exchanged and to number of hops per route. Energy harvesting in BSM exchanges with advanced information and communication technologies with smart cities traffic applications and internet of things IoT will much benefit from such approach, as routing algorithms always search for shortest route with minimum number of hops and energy dissipation and consumption.

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For large values of α , E_{elec} can be ignored as most of the consumed energy is influenced and affected by route length (RL), which contains hops. Thus, equation (10) can be reduced and simplified to obtain equation (11).

$$ACE = k * (E_{(initial)} (M * AHL)^\alpha) \tag{11}$$

The differential change in ACE in response to AHL will also follow a power law representation affected by both BSM and α .

Fig. 5 shows the behavior of 3 Hops routes versus 2 Hops routes as a function of the attenuation dependent parameter α . The figure clearly shows an opposite dynamic behavior, which points towards a dependence relationship between α and its effect on the differential characteristics of routes. Such effect of α is critical in routing considerations for BSMs exchanged between vehicles and for vehicular ad-hoc networks under communication networks affected by transmitting frequency and processing speed within environmental parameters with associated multi path fading factors.

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