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Theoretical Determination of the Effective Parameters Into the Carbon Nanotube networks behaviour

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Abstract. As a result of the high improvement rate of carbon nanotubes (CNTs) fabrication process and its tremendous important applications in various fields, the manuscript is devoted to the study of CNTs effective parameters for the case of nano-dimensional networks. It is also called Carbon nanotube networks (CANETs). Parameters such as density, allowable adjacent distance, phase angles and radius of CNTs are determined. Isotropy performance as a function of these CNTs parameters is discussed. This allows us to determine the suitable phase angles and adjacent distance between each one CNT and other in the case of random distribution. Also, the relation between the FET conductance and mobility between the transmitter and receiver destination as a function of different CNTs parameters are theoretically studied. From the results obtained, one can recognize that the CNTs properties play an important role for determining the CANETs behaviour. One of the effective CNTs parameters is the longitudinal length, L_{CNT} as it is commonly used in various CANETs figure of merit factors. According to the calculated values of CNTs length and radius, the allowable adjacent distance that achieves high FET conductance is between 3-15nm. The phase angle between CNTs is essential for achieving the intersections, nanonodes, in the path between the destination terminals. As a consequence of random distribution of CNTs in a specified area, the wide range of phase angles is studied from 1.5° to 75° with two degree increments in each step. The important fact that is concluded from the results is that the ability to apply phase angle modulation in the CANETs and its advantages to secure the data until it reaches to the terminal in shortest data path distance. Moreover, the obtained FET mobility values (50- 150 $cm^{٢}$/Vs) under considered conditions give the facility to fabricate the CNTs in nanodimensional practical phase processes.

Keywords*: carbon nanotube, networks, isotropy, phase encoding, mobility, CANET, FET conductance.*

1. Introduction

Engineering characteristics of graphene carbon nanotube (CNT) encourage the researchers to exploit them in various applications. This is due to the ability of CNT to gather the functions of more electronic devices at the same time. It can be adapted to work as four essential components in nanonetwork circuitry, i.e., modulator, demodulator, tuner, and antenna as shown in modern experimental and theoretical treatments [1- 8]. Logic applications such as inverter, NOR, and NAND gates can be obtained by utilizing CNTs network transistors [9-12]. Optical networks on-chip will have a good contribution for global interconnections accomplished with multi-core processors as considered in [13].

Also, the CNT has special optical proprieties that can be utilized for obtaining high performance nanoscale commutation networks. Moreover, CNTs' small sizes allow them for new applications such as nano-integrated tiny devices to go through a cell and operate in the blood stream without stirring the cell's defensive response. The CNTs open the way for solving the problems of emerging applications related to human body, such as early diseases diagnosis, drug delivery and directing and tracking of nanocapsules [14 -16]. The carbon nanotubes networks (CANETs) witness these multiple functions. The CNTs distributions denote the facility to carry the high data rate from one nanonode to other. Since the dimensions of CNT is 10^{-9} times lower than the traditional electrical networks, bandwidth will be increased inversely by the same factor, in THz range. The suggested CANET can be utilized in manufacturing devices in areas such as medicine, chemistry and physics, military, single-electron memories, and on-chip connection networks [17-20]. The power supply of these on- chip integrated devices nanonetworks can be saved by utilizing modified CNTs network as electrode in Li-ion batteries [21-24].

Any CANET can be specified according to the nature of the internal distribution of CNTs. The CNTs have the first priority for nanonetwork operation in various fields, because they enjoy unique mechanical, electric, and electromagnetic characteristics [25]. The main CNTs mechanical characteristics include a sharp resonance peak, high tensile strength, and elastic modules [26]. While the CNTs main electrical and electromagnetic characteristic is the high conductance, a high current density arises from its semiconducting and metallic properties. Consequently, the CNTs can be utilized as a gate between the source and drain in Field Effect Transistor (FET). The determination of short path in CANET essentially depends on the FET conductance value and mobility, which will be covered in more details in the following sections. Now the attention will be directed to how the CNTs can be constructed to establish nanonetwork. In this investigation, the CNTs are distributed randomly in the CANET. Their distribution, the phase angle, and the total numbers are studied to clarify and select appropriate values for these nanoscale networks. In recent research works and technologies, the CNTs networks are utilized as a semiconductor material to establish a single FET transistor [27].

The physical characteristics of each CNT will affect the network performance. The path of data, from the two destinations, depends essentially on the density, intersections, phase angle, radius and lengths of CNTs.

The main feature of the CANET is how the data transfer is controlled from any nanonode to another one. From previous studies [28-30], the CNT properties play an important role for this transferring process. For example, the radius, length, and phase angle between different CNTs in a specified area will affect and control the way of data path. Especially, the value of phase angle and amount of deviations can be enrolled (exploited) to code and control the data flaw across the CANET. The length and radius of each individual CNTs has noticeable impact on phase angle and deviation. Because intersections between CNTs, which function of the considered two factors, will be established and then more nanonodes are assigned, it is evident to consider the figure of merits that are used to measure the probability of transferring the data via the nanonetwork. In this paper, other factors will be utilized such as isotropy, and FET conductance and mobility to determine the effective parameters in the CANET performance. Isotropy measures the directionality of CANET as a function of CNTs properties as described later. It is also more useful to depict and allocate the allowable phase angle to transfer the data via the nanonetwork. FET conductance between the source and drain is an important factor for any CANET, since it specifies the behavior according to the CNTs parameters. In other words, the data path length between the source and drain will affect the conductance value. So, when the CNT density increases, more vertices and edges will be established. And hence more intersections can occur if the allowed degrees of angles between them can be achieved. The allowed degrees of angles mean that each CNT angle in relation to other CNTs permits more intersections across the CNT length. In this study, more attention is given to cover most of angle degrees values with small predictable angles deviations.

Mobility is used to evaluate the momentum scattering rate and it is an essential part to investigate the scattering process in any system. Therefore, more descriptions are devoted to study the CANET charge carriers mobility in relation with CNTs parameters. In this treatment, it plays an important role for the determination of FET channel transconductance and deduced current. Then, the high-frequency behavior of the FET can be finally calculated by the mobility value [31 -32].

We now clarify how the CANETs work to transfer, control and secure the data between different users. The main point here is that CNTs carry out many functions at the same time. The random distributions of CNTs determine the network protocol between the two terminal destinations. The data routes will be different as it across different nanonodesand also it will be carried into different CNTs, which are represented as a channel of data. Also the phase angle and angle deviation will change depending on the data route length and nature of CNTs distribution. In our opinion, this wide variety of phase angle will contribute to the data encoding and will achieve the security while decreasing the interference along the data path. Another factor can also be involved in determining the CANET protocol is the conductance values between the terminals. This can be represented as the FET conductance and mobility between source and drain. Of course, more FETs will be represented if more nanonodes are incorporated for covering wide nano area. As a result of CNTs random distribution in a specified area, the intersection process and short path length between the terminals can be achieved.

In the following section, the mathematical model description and derivation of CANET are presented. Section (3) states the numerical results and discussions of the effective parameters into CANETs behaviour. The last section reports the important facts and consequences about the obtained results. Also, it assigns numerical values for the effective parameters into the proposed CANETs model representation.

2. Mathematical Model Description of CANET

In the beginning of this section, it is important to discuss the CANET distribution and how the data path can be varied according to internal properties of CNTs. The CNTs have a reduced size, in the scale of nanometers that contributes to more wide-range of bandwidth (in range of THz). As a result, the network capacity and then data rate will be increased (in range of 10^{14}b/s). Previously, some properties are distinguished for CNTs [28]. Here, more detailed discussions will be devoted to determine the effective parameters of CNTs that have a noticeable effect on the CANET performance. The essential part for the communication media is the CNTs network itself. The links of this network are the individual CNTs.

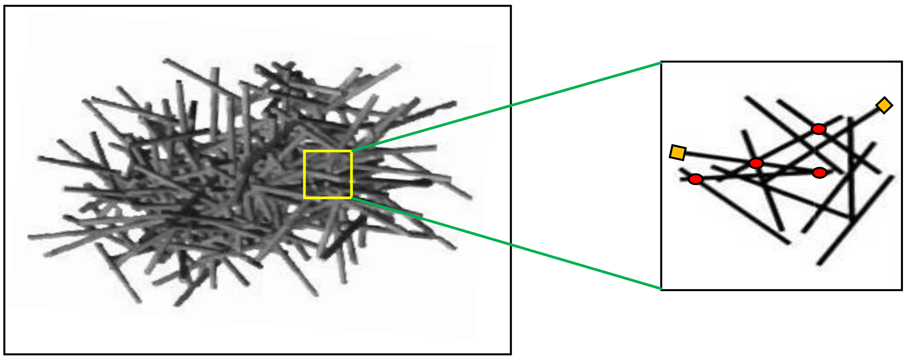
CNTs distributions determine the overall CANET distribution such as routes, coding method, nanonodes numbers, source drain conductance, and mobility. Of course, CNTs parameters such as length, diameter, and resistivity will determine the allowable angle and angle deviation between one CNT and others, intersections, vertices and edges. In this model, the CNTs are randomly distributed. In our opinion, this assumption is close to small nanosacle size practical implementation [32]. Also, the CNTs random distributions open the way to study the major probabilities of expected data routes between the source and drain. Accordingly, the angle increment and deviation between one CNT and others play an important role for encoding the data. Also, the angle value determines the required CNTs adopted parameters to achieve high conductance and accomplished mobility. In this proposed model, the numbers, lengths and radiuses of CNTs, in a specified constant area, are investigated.

Other two factors that have important contributions in CANET distribution are the adjacent distance and expected distance deviation between the CNTs in the x and y directions, v and Δv respectively. Alignment of CNTs in this nanoscale is still very hard process, due to the difficulty to reduce the cost and to obtain the separation of impurities in metallic naotube [12]. So, the model studies various values of these two factors against conductance and mobility reliability.

Let us now discus how the data path can be varied according to CNTs properties. In fact, the shortest distance between the transmitter and receiver depends on CNTs random distribution. In other words, if the numbers of CNTs are adequate to compose multi intersections, the more nanonode will be found to exchange the data between the destinations. Hence the data path will be passed through the route which will have a minimum resistance (high conductance). Of course, the same data can go through different routes but the high SNR and desired encoding data, according to the required phase angle, will be picked in the destination terminal [1].

These phase angles are constructed due to the random distribution of CNTs into the CANET. An indication of the internal CANET distribution layout is considered in Fig. 1. To investigate the effect of phase angle of each CNT relative to other CNTs, the overall directionality of all CNTs will be determined. So, the quantity that is used to specify or measure the global directionality of all CNTs is the isotropy.

To describe of isotropic and anisotropic properties, the orientation distribution function is usually used; see for example [33].



Terminals in the carbon nanotube networks

Nanodes internal connections via the information passes

Fig. (1). Schematic diagram of the Carbon Nanotubes Network (CANET) with its random pass lengths, angles and density of distribution.

The anisotropy of electromagnetic response of CNT-based polymer composite in terahertz range is studied experimentally and theoretically in details in [34]. There, the dispersion and alignment of multiwall CNTs (MWCNTs) in polystyrene matrix were achieved by the forge rolling method.

The simple form of isotropy is considered in [12]. For convenience in the proposed CANET model, the isotropy can be denoted by the following expression [28]:

$$I(\theta, n) = d_t n\, w_{CNT} L_i \sum_{k=1}^{n} \frac{\cos(\theta_k + \Delta\theta)}{\sin(\theta_k + \Delta\theta)} \quad (1)$$

Here, d_t is the density of nanotube, n is the number of carbon nanotube in specified area, w_{CNT} and L_i are the width and length of nanotube respectively, and θ_k and $\Delta\theta$ are phase angle and angle deviations respectively. In this treatment, various phase angles with small increment step and most probabilities of angle deviations are covered. Adoption of two latter parameters, θ_k and $\Delta\theta$, is essential to determine the adequate CNTs arrangements as considered before. Consequently, the conductance and mobility will be determined, as depicted in the results and discussion section. One can notice from equation (1) that parameters of the CNTs control the obtained value of isotropy. Also, the effect of various CNTs parameters such as lengths, radius, and densities into isotropy are studied.

It is important to determine the suitable path that the data will travel between the transmitter and receiver destinations. This path is dependent mainly on the CANET properties and distribution. Normally, the route that has small distance and resistance will be the most suitable candidate for the data signal transmission. The connection procedure of the nanonetwork between the two destinations can be measured by the FET conductance. It depends on the CANET specifications and can be given by:

$$G_{SD} = \left\{\frac{\rho_{CN}}{A} \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} P_{ij} \left\{ |v_i - v_j| + \left(\frac{L_i}{2}\cos(\theta_i + \Delta\theta) + \frac{L_j}{2}\cos(\theta_j + \Delta\theta)\right)\right\}\right\}^{-1} \quad (2)$$

$$G_{SD} = \left\{\frac{\rho_{CN}}{A}\left[\left(\left(P_{12}|v_1 - v_2| + \left(\frac{L_1}{2}\cos(\theta_1 + \Delta\theta) + \frac{L_2}{2}\cos(\theta_2 + \Delta\theta)\right)\right) + \left(P_{13}|v_1 - v_3| + \left(\frac{L_1}{2}\cos(\theta_1 + \Delta\theta) + \frac{L_3}{2}\cos(\theta_3 + \Delta\theta)\right)\right) + \cdots + \left(P_{n(n-1)}|v_n - v_{n-1}| + \left(\frac{L_n}{2}\cos(\theta_n + \Delta\theta) + \frac{L_{n-1}}{2}\cos(\theta_{n-1} + \Delta\theta)\right)\right) + ..\right)\right]\right\}^{-1}$$

$$P_{ij} = f(x, y, L_i, L_j, \theta_j + \Delta\theta) \quad (3)$$

Here ρ_{CN} is the CNT resistivity, P_{ij} is probability of the carbon nanotube (*i*) to intersect, connect, with another one (*j*) , $|v_i - v_j|$ is the difference in distance between vertices in *x* or *y* direction, L_i and L_j is the CNT length for the CNT number *i* and *j* respectively into the specified area, *A*. One can notice that the FET conductance is mainly a function of CNTs properties and distributions. Also, the P_{ij} internally is a function of CNTs properties. Various values of CNTs lengths, radiuses and phase angles are discussed to obtain a high conductance. From the considered equation, there are two parameters that influence the conductance value directly. The phase angles and angle deviations (θ_k and $\Delta\theta$), and the distance difference, $|v_i - v_j|$, between CNTs and each other are functions of the random distribution, properties and numbers of CNTs in a specified area respectively. Consequently, the CNTs intersections and nanonodes will be constructed in the data path. The data can be transferred via different paths and nanonodes between the two destinations. In each path, different FET gates conductance will be included. This means that different induced current will flow for carrying or transmitting the data in each path between the destination terminals. The effective one is the path which has a high FET gates conductance to carry the data between the source and drain [35- 37].

Determinations of charge-carrier mobility in semiconducting carbon nanotubes are essential part for CANETs behavior. Charge density, impurities, and scattering mechanisms can be assigned when studying the effects of the applied voltage, temperature and other physical quantities on the mobility [31, 38]. Mobility can be determined by different methods depending on the device type. i.e., the Drude model of the mobility can be applied in the case of carbon nanotube FET rather than Hall mobility method [32, 38]. In the intrinsic mobility model of a nanotube, many assumptions are considered when discussing the FET mobility. For example, there is no injection for non-equilibrium carriers from source and drain, quantum capacitance and thermally activated carriers may be neglected. However, the following approach allows us to probe different aspects of the CNTs device behavior. The formula that measures the FET mobility, μ can be denoted by:

$$\mu = \frac{t_{CNT}}{20\epsilon w}\left(\frac{I_{on} - I_{off}}{V_{SD}}\right)\sum_{i=1}^{n}\sum_{j=1, j\neq i}^{n} L_{sd}\,(i,j)$$

$$=\frac{t_{CNT}}{20\epsilon w}\left(G_{SD-on} - G_{SD-off}\right)\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n} L_{sd}\,(i,j) \quad (4)$$

where, $L_{sd}(i,j)$ is the different longitudinal length paths between the FET source and drain, gate length, t_{CNT} is the CNT center location, ϵ is the carbon nanotube dielectric constant, *w* is the FET gate width, $(I_{on} - I_{off})$ the gate current on-off at a specific source drain voltage, V_{sd}. The last term can be represented by the difference between the gate conductance value in “on” state and “off” state, $(G_{SD-on} - G_{SD-off})$. By substituting the values of different $L_{sd}(i,j)$ from equation (2) into equation (4), the induced FET mobility values can be determined.

The main goal in the derivations of the previous mathematical model is to distinguish the main CNTs parameters that enhance CANETs behaviour. This will be presented in details when obtained results are described and discussed in the following section.

3. Results and Discussions

In the consequence of the previous mathematical model derivations, the results will be processed. The CANETs isotropy measures the directionality of the nanonetwork.

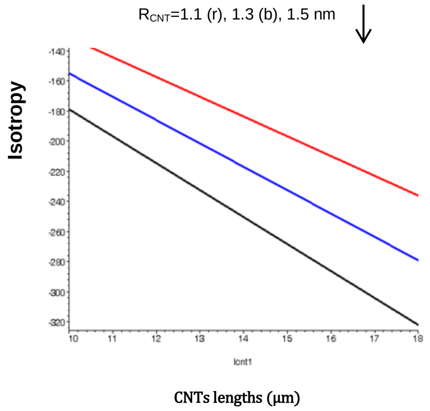


Fig. (2). The CANET isotropy vs CNTs lengths at different CNT radius. For CNT numbers; N=100, initial angle; θ= (40°), Δθ=2-200°.

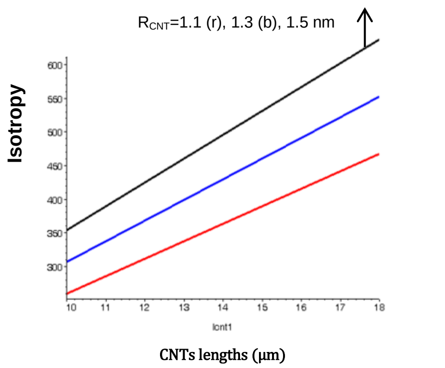


Fig. (3) The CANET isotropy vs CNTs lengths at different CNT radius. For CNT numbers; N=100, initial angle; θ= (π/4°), Δθ=2-200°.

Equation 1 determines the different CNTs parameters that have effects on the isotropy behavior. Figs (2 and 3) depict the isotropy as a function of different lengths and at various CNTs radius value

The number of CNTs and phase angle deviation between them in these two Figs are kept constant, N=100, Δθ=2-200° respectively. Meanwhile, the initial phase angle value between CNTs is changed from θ= 40° to π/4 (45°) respectively. From these Figs, one can notice that the trend of isotropy is changed inversely at different value of initial phase

angle. In Fig. 2, isotropy reached higher values at longer values of CNTs. The higher obtained isotropy value is for wider CNTs radius, 1.5nm, and vice versa for Fig. 3. But higher positive values of isotropy are recognized in Fig. 2 in comparison with Fig. 3. The origin of principal difference between dependencies in Figs 2-3 is referred to the change of the initial phase angle values from 40° to π/4. This will occur periodically depending on the cyclic values of phase angle. From nanonetwork point of view, it is normal to obtain various isotropy value and direction because the intersections are distributed randomly. This distribution is dependent on each CNT length, radius and phase angle with other CNTs. To clarify more the effect of CNTs parameters on the isotropy behavior, Figs (4, 5 and 6) show the relation between the isotropy and each of initial phase angle and length of CNTs. The order of various CNTs radius is the same as in Figs (2, and 3). The difference between these three Figs is that the number of CNTs are varied as 10, 50, 100 CNTs respectively. In each Fig., the isotropy trend, as mentioned in the previous Figs (2, 3), appears periodically according to the initial value of phase angle, θ. It is clear that at small length of CNTs, the isotropy variations are not recognized as at higher values of CNTs length, from 4 to 18μm in Figs (4, 5) and from 13-19μm in Fig. 6.

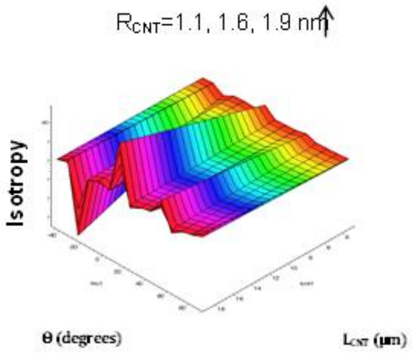


Fig. (4). The CANET isotropy vs CNTs lengths; L_{CNT}, and Initial angle values; Θ, at different CNT radius. For CNT numbers; N=10, Δθ=2-200°.

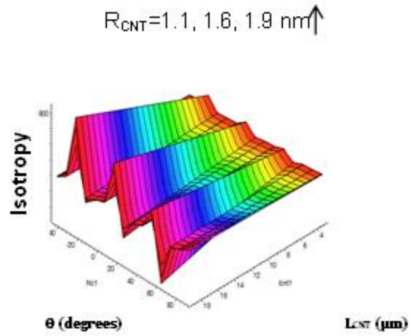


Fig. (5). The CANET isotropy vs CNTs lengths; L_{CNT}, and Initial angle values; Θ, at different CNT radius. For CNT numbers; N=50, Δθ=2-200°.

The reason to change the CNTs length range, L_{CNT}, in Fig. 6 to determine the allowable range which can give a similar behavior of the isotropy in short and long nanotube length. From the obtained results in Figs (2-6), one can notice that when the CNTs radius increases the absolute values of isotropy also increase. The high isotropy values are mainly function of the proper value of CNT radius at simultaneous phase angle values between CNTs for the same CNTs length for an assigned nanonetwork area. The high isotropy peaks values will contribute more into the data exchange between transmitter and receiver. Also from these Figs, in addition to the effects of previous parameters, (initial phase angle, CNTs radius), the number of CNTs has a recognizable effect in isotropy value, as in Fig. 6. It is predictable that when the number of CNTs is increased, the intersections and corresponding nanonodes will be realized. Hence, the isotropy, directionality will be high in positive and negative values. From the obtained results, the CNTs initial phase angle and numbers play an important role for selecting the required CANETs isotropy range. For certain CNTs number, the phase peaks can be utilized to exchange the data between various nanonodes. Also, different peaks value can be utilized as a nano-communication technique for encoding the transferred data between the source and drain. In another word, the phase angle value that has a peak can be assigned. Hence it can be used to transfer data between different nanonodes till the data reaches the destination terminal point.

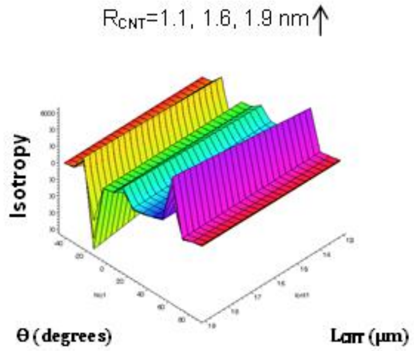


Fig. (6). The CANET isotropy vs CNTs lengths; L_{CNT}, and Initial angle values; Θ, at different CNT radius. For CNT numbers; N=100, Δθ=2-200°.

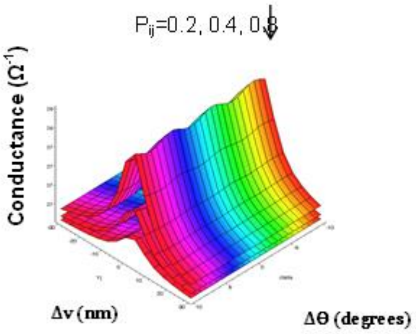


Fig. (7). The CANET conductance vs CNTs adjacent distance deviation; Δv, and CNTs angle deviation; ΔΘ, for CNTs numbers; N=50, resistivity=0.13 mΩcm, adjacent distance, v=1-12 nm, Angle step 2°.

Now we describe more on how the initial phase angle and angle deviation can be utilized for encoding data. The proposed model covers almost expected values of phase angle range. Moreover, the allowable phase angle range $\theta_j \pm \Delta\theta = \left\{(0,9,18,27,\dots.\frac{\pi}{2}) \pm \Delta\theta\right\}$ is manipulated, as additionally considered in [28]. The $\pm\Delta\theta$ predicted tolerance values, phase angle deviation, open the way to more accurate determination of the total effective phase angles. From the obtained results till now, the phase angle and CNTs density are effective parameters for the CANETs model representation.

To investigate the influence of other parameters such as the adjacent distance between the CNTs, and the allowable gate widths into the CANETs performance, the FET gate conductance and mobility are theoretically determined as considered in Equations (3 and 4). The FET conductance is a very important parameter and its dependency on the CNTs parameters such as length, radius, and adjacent distance is practically studied in [39- 42]. Therefore, the dependence of conductance in each of the angle and adjacent distance deviations is illustrated in Fig. 7. Highest peak is achieved at the minimum value of connection probability, 0.2. To find the main cause for getting the highest FET conductance values at lowest connection probability, P_{ij} , refer to equations (2 and 3). The higher values of P_{ij} occurred when the longer nanotube length and adjacent distance between them are utilized. This means that less intersection and nanonodes will occur in the way of the data path between two user terminals. In turn, the corresponding conductance value will decrease. For attaining higher values of conductance, more intersections and small adjacent distance between CNTs should be achieved. From Fig. 7, one can notice that multi-separated FET conductance peaks occur for different connection probabilities and also can repeat periodically for other angle phase period. It indicates the importance of the determination of phase angle as many peaks appear along the phase angle deviation range. This means many encoded data can be transferred via nanonodes from the transmitter to the receiver terminal. This ensures the ability to exploit the phase angle values to make a phase modulation for transferring data between the user terminals. Moreover, the conductance semi Gaussian distribution is notified along the adjacent distance deviation, Δv. One can notice that as the adjacent distance deviations increase, conductance values decrease as discussed in [43]. The highest peaks of conductance are achieved at Δv range from +2nm to +5nm for adjacent distance, v, from 1-12 nm. So, the maximum peaks of conductance occur at total adjacent distance (v±Δv) in the range from 3- 15nm. These adjacent distance assigned values will be declared more when the mobility is studied as shown in Figs (8, 9).

The minimum values of FET mobility, μ, are achieved at the same adjacent distance deviation considered before, Δv from +2nm to +5nm. It is noticed also from Figs (8, 9), at the same CANETs conditions and for P_{ij}= 0.8 and Δv=3nm, when the gate width, *w*, is expanded from 5μm to 10μm, the mobility value will decrease from 150cm^2/Vs to 50cm^2/Vs. These predictable obtained values of FET mobility demonstrate the ability to precisely assemble the CANETs by utilizing available manufactural process [44]. The various angle ranges from 1.5°-75° with step increment 2° are utilized. This implies and confirms the scanning smoothly of all possible phase angle values in the range. The mobility behavior takes a semi-parabolic shape, reciprocal of FET conductance behavior, and has higher values for specified higher connection probabilities. The obtained results give appropriate behavior when compared with the discussion considered in the experimental results in [44].

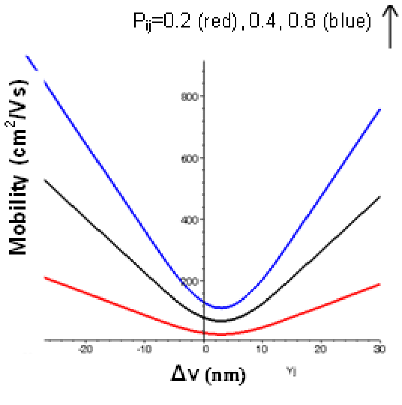


Fig. (8). The CANET mobility vs CNTs adjacent distance deviation, Δv (nm) at different CNT radius. For CNT numbers; N=50, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=5μm.

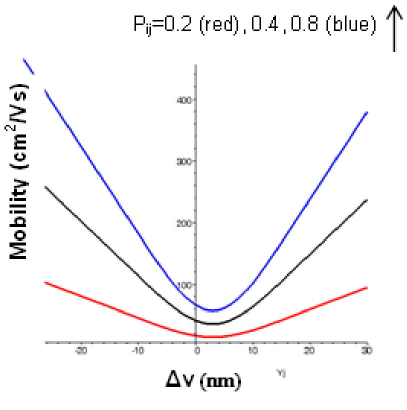


Fig. (9). The CANET mobility vs CNTs adjacent distance deviation, Δv (nm) at different CNT radius. For CNT numbers; N=50, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=10μm.

To explain the effect of adjacent distance and phase deviations (Δv, $\Delta\theta$) into the mobility, analogous to the FET conductance, Figs (10, 11) are depicted for the same condition considered in previous two Figs (8, 9). One can notice that there are multiple peaks of the FET mobility along the variation axis of the phase deviation, $\Delta\theta$. It ensures the fact that the phase angles can be utilized for encoding the data into the carbon nanotube network. Also, it is more obvious in the last two Figs (12, 13). Many multi periodical peaks can be recognized when exploring the change of the mobility with phase angle deviations. Also it is clear that the peaks can be utilized for interchanging the data between the nanonodes. One can notice that, from the mobility behavior as a function of gate conductance deviations, ΔG, the mobility has a semi stable behavior in comparison with its augmented vales at low and high connection probabilities respectively. But in all cases of the connection probabilities, there is an increment of FET mobility with the increase in the ΔG value that agrees with the obtained results considered in [31]. When comparison is held between Figs (12, 13), the multi-peaks of the mobility is more sharp in the case of small adjacent distance deviation than in high adjacent distance deviation, Δv =5, and 10nm respectively. Determining suitable connection probabilities and then stable mobility behavior depends essentially on the specified CNTs parameters.

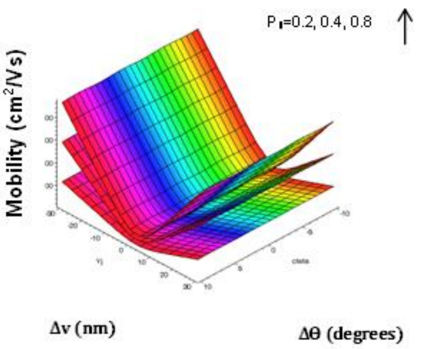


Fig. (10). The CANET mobility vs CNTs adjacent distance deviation; Δv, and CNTs angle deviation; ΔΘ, for CNTs numbers; N=50, resistivity=0.13 mΩcm, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=5µm.

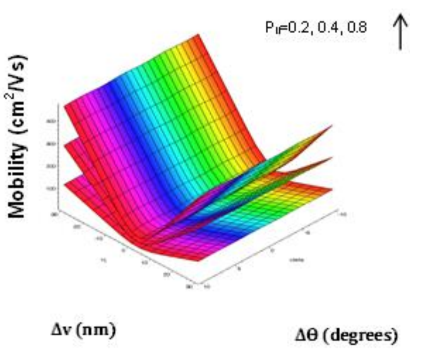


Fig. (11). The CANET mobility vs CNTs adjacent distance deviation; Δv, and CNTs angle deviation; ΔΘ, for CNTs numbers; N=50, resistivity=0.13 mΩcm, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=10µm.

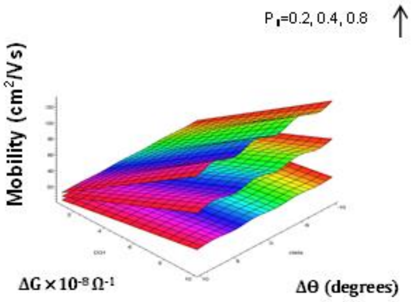


Fig. (12). The CANET mobility vs CNTs gate conductance deviation; ΔG, and CNTs angle deviation; ΔΘ, for CNTs numbers; N=50, resistivity=0.13 mΩcm, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=5µm, Δv=10nm.

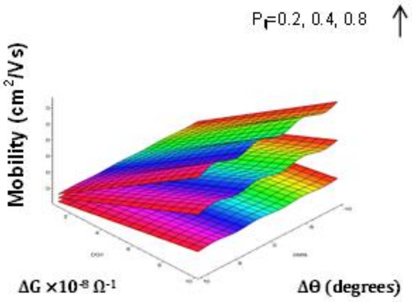


Fig. (13). The CANET mobility vs CNTs gate conductance deviation; ΔG, and CNTs angle deviation; ΔΘ, for CNTs numbers; N=50, resistivity=0.13 mΩcm, angle range (1.5°-75° with step increment=2°, v=1-12nm, w=5µm, Δv=5nm.

As seen from the previous results, when connection probabilities values are low, high conductance and low mobility values can be achieved. The low FET mobility values mean that it matches with the practical rules for fabrication of the nano-dimensional devices like CNTs [44].

4. Conclusion

As a result of increasing demand of nanodevices that can be fabricated into the same nano-integrated chip, the development of new nanonetworks techniques to transfer, encode, store, and read data have become more interesting for any nanofabrication designer. Among these techniques, the carbon nanotube networks (CANETs) can be exploited for versatile applications. The main focus of this paper is to determine the main effective CNTs parameters that influence the behavior of CANETs. From the obtained results, the phase angle and angle deviation between various random CNTs play an important role in determining the CANETs properties such as isotropy, FET conductance and mobility. Other important factors include the adjacent distance and deviation values that are common sensitive parameters for improving the CANETs behviour. These two essential factors depend mainly on the CNTs density, radius, and length. Certain values of these parameters are assigned into the obtained CANETs behviour. For example, the appropriate values of numbers, radius, and length range of the CNTs that denote high isotropy are 100, 1.5nm, and 13-19µm respectively. As a result, the allowable adjacent distance between different random CNTs ranges from 3 to 15nm. The other effective parameter that can enhance CANETs performance is the gate width. When the gate width, *w*, is expanded from 5µm to 10µm, the FET conductance will increase, while the mobility value will decrease from 150cm^2/Vs to 50cm^2/Vs.

Accordingly, any increment into the FET conductance difference, ΔG, will affect positively on FET mobility. Finally, as the adjacent distance deviation decreases, the multi peaks of the FET conductance and mobility will be become sharper. These peaks can represent the data transfer, encoding, reading and storage between nanonodes and also between the nano-transmitter and nano-receiver.

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تحديـد نظـري للمعاملات المؤثرة في سلوك شبكات الأنابيب النانوية الكربونية

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مـلخص البحـث: نتيجة معدل التطور العالي في عملية تصنيع الانابيب النانوية الكربونية (سنتس) وتطبيقاتها المهمة الهائلة في المجالات المختلفة، فإن البحث قد كُرس لدراسة المعاملات المهمة لسنتس وذلك في الشبكات ذات الابعاد النانوية. وهذه الشبكات تسمى شبكات الانابيب النانوية الكربونية (كانيتس). هذه المعاملات المثمرة مثل كثافة، المسافة المتجاورة المسموحة، طور الزاوية ونصف قطر السنتس وقد تم حسابها. أداء الايزتروبى كدالة في معاملات السنتس السابقة قد نوقشت. وهذا بدوره يسمح بحسابة طور الزاوية المناسب والمسافة المتجاورة لكل سنتس موزع عشوائي والآخرين.

ايضا العلاقة بين توصيلية ال (فت) والتحركية بين محطتي المرسل والمستقبل كدالة في معاملات مختلفة للسنتس قد درست نظريا.

من النتائج المحصول عليها، يمكن ملاحظة ان خواص السنتس تلعب دور مهم لحساب سلوك الكانيتس. من المعاملات المؤثرة هو الطول الطولي لأنه عامل مشترك يستخدم في مختلف عناصر رقم الجدارة للكانيتس. وطبقا للقيم المحسوبة لطول السنتس ونصف قطره، القيم المسموح بها للمسافات المتجاورة والتي تحقق اعلى توصيلية للفت تكون ما بين (٣–١٥) نانومتر.

طور الزاوية بين السنتس يعتبر اساسي لتحقيق التقاطع والعقد النانوية وذلك في الطريق مابين محطتي الوصول. ونتيجة التوزيع العشوائي للسنتس في مساحة محددة، نطاق عريض من طور الزوايا قد درس من1.5° الى

°75 مع درجتين زيادة في كل خطوة. إن الحقيقة المهمة والتي يمكن ان تستنتج من هذه النتائج انه امكانية تطبيق تعديل طور الزاوية في الكانتس وميزتها في امن المعلومات حتى تصل الى الاطراف وسلوك أقصر طريق بينهم. علاوة على ذلك، فإن قيمة التحركية للفت المحصول عليا تكون ما بين (٥٠ الى ١٥٠ سم/فولت ثانية) تحت الظروف المذكورة والتي تعطي امكانية تصنيع السنتس في الابعاد النانوية عمليا.