A New Node Density Based k-edge Connected Topology Control Method: A Desirable QoS Tolerance Approach

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Abstract

This research is an ongoing work for achieving consistency between topology control and QoS guarantee in MANET. Desirable topology and Quality of Service (QoS) control are two important challenges in wireless communication networks such as MANETs.In a Mobile Ad hoc Network, MANET, nodes move in the network area; therefore, the network topology is randomly and unpredictably changed. If the network topology is not controlled properly, the energy consumption is increased and also network topology probably becomes disconnected. To prevent from this situation, it is necessary to use desirable dynamic topology control algorithms such as k-edge connectivity methods. This papertries to improvethe three following parameters according to the k-edge connectivity concepts: (1) network performance, (2) reduce energy consumption, and (3) maintain the network connectivity. To achieve these goals, as a new method, we enhance k-edge connectivity methods using an improved definition of node density. The new method is called as: Node Density Based k-edge connected Topology Control (NDB^{k}TC) algorithm. For the first time the node density definition is dynamically used. The new method, computes the node density based on a new equation which consists of the following factors: the relative velocity of nodes, distance between nodes, the number of nodes and the transmission range of nodes. The results show that our new method improves the network performance compared with the existing methods. Also we will show that the new method can holds QoS in a desirable tolerance range.

Keywords: Localtopology Control; k-edge Connectivity; Node Density; MANET; Optimizedenergy Consumption; QoS.

1. Introduction

Topology Control and QoS are two opposite functional services in the MANET because increasing in QoS will increase the number of links whereas topology control will decrease the number of links. This paper tries to present a new method which can hold these two functional services in the MANETs

1.1 Topology Control

A number of existing topology control algorithms including Local Minimum Spanning Tree (LMST) [5], Relative Neighborhood Graph (RNG) [6] and the Local Shortest Path Tree (LSPT) [7], guarantee 1-edge connectivity; meaning that, with removal of just one link, the network may lose its connectivity. Therefore, these algorithms are not practical for MANETs, due to changeable topology of them. For MANETs, many reliable topology control algorithms are introduced, including Fault-tolerant Local Spanning Sub graph (FLSS) [8] and Local Tree based Reliable Topology (LTRT) [9]. The mentioned algorithms can guarantee k-edge connectivity which means that with removal of (*k*-1) arbitrary edges, the network doesn't lose its connectivity [2]. Using same value of *k* for whole network in order to make redundancy is disadvantage of the algorithms. Because due to different moving speeds of the network nodes, an unnecessary redundancy maybe made in the network; in other words, a large value of *k* maybe not necessary in the parts of the network in which the average moving speed of nodes is low. The greater value of *k* for a node implies more directly connected neighbors, high energy consumption and high interference. Therefore, the value of *k* must be as small as possible.

In order to overcome the above issue, H. Nishiyama et al. [10] proposed a dynamic method, namely DLTRT which tries to compute the optimal value of *k*. The authors use the moving speed of nodes and probabilities to dynamically compute the appropriate value of *k* for each section of the network. The method supposes that all nodes in a part of the network move with the maximum speed existing in that part. This paper believes that always it is not necessary toconsider the worst cases, and the real situation is the best case must be used efficiently. Our idea is to use the concept of node density and introduce a new equation to compute it. The new proposed equation improves the previous definitions of node density in the context of mobile networks. Also, it is the first time that a new topology control algorithm uses the node density dynamically.

1.2 QoS Control

Against the best effort, on the Internet and in other networks, QoS (Quality of Service) is the idea that transmission rates, error rates, bandwidth, delay and jitter can be measured, improved, and, to some extent, guaranteed in advance. It is important that a topology

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control algorithm mustn't reduce QoS conditions. This research shows that the new algorithm, NDB^kTC, does not reduce the QoS stability [25, 26].

The remainder of this paper is organized as follows: at first the paper presents some of the well known existing topology control algorithms in MANETs and points their deficiencies, in section 2. Section 3 describe DLTRT algorithm, briefly. Section 4 explains our new node density based method. The experimental results and comparisons are depicted in section 5. Section 6 concludes the paper and finally the future works will be presented in section 7.

2. Related Works

Many of topology control algorithms in wireless ad hoc networks are based on minimum spanning tree, MST, and RNG [6] approaches [10]. The main goal in MST is to find a tree in the given graph so that includes all nodes of the graph while the total weight of edges is minimal. Li et al. [5] introduced an MST based algorithm referred to as LMST, which is the local version of MST. In LMST, each node sends a "hello" message contains its ID and current location, using the maximum transmission range. Note that the nodes inform their own location using GPS technology. Each node constructs its local graph afterwards receiving the same information and computes the minimum spanning tree using Prim's algorithm [11]. The vertices of this tree which aredirectly (one hop away) connected to the node, are remained as neighbors of the node. Li et al. [12] introduced an algorithm called k-localized minimum spanning tree ($LMST_k$) and claimed that the nodes degree is up to six; this can decreases the contention and interference in the MAC level.

The main idea of RNG [6] is to delete the redundant edges. An edge *(u, v)* is redundant if there is a node *w* so that the weights of both *(w, u)* and *(w, v)* are less than *(u, v)*. Cartigny et al. [13] proved that in a given graph *G*, the resulting topology of LMST is a sub graph of RNG. Li et al. [12] proposed a lower weighted structure called Incident MST and RNG Graph (IMRG) which utilizes both MST and RNG.

As another corporation of MST and RNG, two algorithms are introduced, namely RNG based Broadcast Oriented Protocol (RBOP), and LMST based Broadcast Oriented Protocol (LBOP) [14]. In these algorithms, the broadcast is initiated at the source, and is propagated following the rules of neighbor elimination, on the topology derived from RNG and LMST approaches.

Another spanning tree algorithm for topology control is the shortest path tree (SPT) [21]. R. Meng [22] presented an algorithm based on SPT, called LSPT. According to LSPT, an edge (*u*, *v*) is redundant if there is a two hop path such *[u, w, v]* between *u* and *v* such that weight $\{(u, w) + (w, v)\} <$ weight $\{(u, v)\}$. Li and Halpern [7] extended the algorithm to *k*-hop path using Dijkstra algorithm [16].

Although the above algorithms are simple and practical in wireless ad hoc networks, their resulting topology is 1-edge connected. That means the network may lose its connectivity with removal of just one link. Therefore, the next studies are focused on fault-tolerant strategies. A fault is the removal of some links in the network which can destroy the network connectivity.

k-edge connectivity is utilized to add fault-tolerance to topology control algorithms. The purpose of k-edge connectivity is to guarantee the network connectivity while some links of the network may be destroyed. Bahramgiri et al. [17] introduced CBTC (α) algorithm to guarantee k-edge connectivity which is based on cone based topology control algorithm [18]. In this algorithm, the transmission power of node *u* so determined that there is at least one node in each cone of degree α in the coverage area of node *u*. They demonstrate that if $\alpha < 2\pi/3k$, the algorithm guarantees k-edge connectivity. Li and Hou [8] proposed FLSS algorithm that its resulting topology is k-edge connected. Its main idea is to add an edge with the smallest weight into the set of edges until k-edge connectivity is guaranteed. The disadvantage of FLSS is its high complexity (see Table 1).

LTRT [9] is local version of tree based reliable topology, TRT, [19].The complexity of LTRT is $O(k(m + n \log n))$ and is better than FLSS, practically. LTRT uses the same value of *k* in whole network to guarantee k-edge connectivity that is a disadvantage. This results in unnecessary energy consumption in the parts of the network with low moving speed of nodes.

In order to eliminate this weakness of LTRT, recently Nishiyama et al. [10] proposed DLTRT algorithmthat is a dynamic version of LTRT. In DLTRT, an appropriate value of *k* is determined for a certain section of the network. This computation is based on the nodes moving speeds and the probability that a node moves out of coverage area of another node. R. Azzeddine et al. [12] introduced a k-edge connected algorithm, called SFL.In SFL, each nodeuses two broadcaststo determine its transmission range instead of (k+1) times broadcasting. Due to the few number of broadcasting, the complexity of SFL is lower than LTRT (see Table 1). It can be seen that the number of nodes (m) and links (n) can affect on the time complexity of algorithms.

Table 1. Time Complexity of Algorithms

Algorithm	Complexity
LMST	$O(m+n \log n)$
RNG	$O(n \log n)$
LSPT	$O(m+n \log n)$
FLSS	$O(m(m+n))$
LTRT	$O(k(m+n \log n))$
SFL	$O(2(m+n \log n))$

3. DLTRT Algorithm

H. Nishiyama et al. [10] proposed an algorithm namely dynamic LTRT, DLTRT. The basis of DLTRT is to consider the concept of k-edge connectivity and the fact of different moving speeds in the network. They compute three probabilities: the probability that a node moves out of coverage area of another node, ρ, the probability that the network be disconnected, ρ_{global}, and the probability that a node loss all its direct links, ρ_{local}. A network is disconnected if and only if there is a node that loses all links to its neighbors. The following equation is used to compute the value of *k*:

$$\rho^k \leq \rho_{local} \tag{1}$$

The smallest value of *k* satisfying equation (1) is the appropriate k.

In the beginning, each node periodically broadcasts a "hello" message, contains its ID and current location and speed, to the maximum transmission range. Subsequently, each node *u* receives the same messages from its neighbors and constructs its local graph. It is assumed that all neighbors of *u* move with the maximum speed of the neighborhood. The maximum distance r that a node *v* can move throughthe slut timeΔt, can be obtained using $r=2V_{max}.\Delta t$ (see Fig. 1). If *R* represents the transmission radius of node *u*, according to [5] the probability that node *v* moves out of coverage area of node *u* after Δt seconds, ρ, is computed using one of the following three equations:

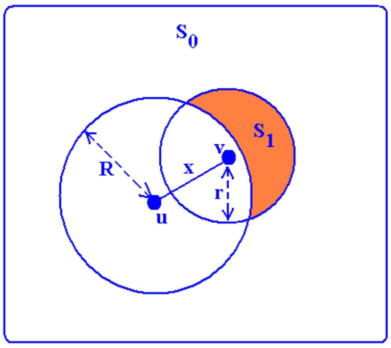


Fig. 1. Calculation of the probability that node v moves out of coverage area of node u [10].

if $0 < r < R$:

$$\rho = \int_{R-r}^{R} \frac{2xS_1}{S_0 r^2} dx, \tag{2}$$

if $R < r < 2R$:

$$\rho = \frac{\pi(r+R)}{S_0 r^2}(r-R)^3 - \int_{r-R}^{R} \frac{2xS_1}{S_0 r^2} dx, \tag{3}$$

if $r \geq R$:

$$\rho = \frac{\pi(r^2 - R^2)R^2}{S_0 r^2}. \tag{4}$$

4. Proposed New Method Based on Node Density

In the previous section, DLTRT algorithm was explained briefly. Although this algorithm resolves the weakness of previous algorithms, it has another weakness. Authors of [10] use the worst situation in their computations; this means that, they suppose that all nodes in a certain part of the network move with the maximum speed existing in that part. In such a case, the probability that the neighbors move out of the coverage area of node *u*, see Fig. 1, is increased. Therefore, node *u* has to increase its transmission range more and as a result, the energy consumption in node *u* is increased.This research believesthat the new algorithm can use more real situation of the environment and increase the network performance.

To understand the worst and real cases of the environment around the nodes and their impact on the performance, consider Fig. 2. As it can be seen, Fig. 2(a) shows a node *u*, in time t, which three neighbor nodes *v1*, *v2* and *v3* are in its transmission range, R_u. Suppose that the moving speed of neighbors is as $V_{v1}>V_{v2}>V_{v3}$. Now the new location of the neighbor nodes after Δt seconds must be known and determined the transmission of node u such that it does not lose all links to the neighbors. If the worst situation is considered, i.e. it can be supposed that all neighbors move with the maximum speed, V_{v1}, and in opposite direction of node *u*, the new situation of nodes is similar to Fig. 2(b). As mentioned in the previous section, the distance *r* that the nodes can get away from node *u* is equal to $r=2*V1*\Delta t$. Therefore, with a high probability, all neighbor nodes would move out of transmission range of node *u* after Δt seconds. Therefore, node u must increase its transmission range to R'_u, that here is equal to distance between u and v3, in order to maintain some of its connections with neighbors.

Now consider the real situations, i.e. each neighbor has its own moving speed and direction. As the moving speed for every neighbor is lower than the previous case, the probability that they move out of the transmission range of nod *u* becomes less. So, the new locations of the neighbor nodes will be similar to Fig. 2(c). Similar to the previous case, node u increase its transmission range to R'_u. The difference is that in this case, real situation, the amount of increasing is low. Therefore, the energy consumption and interference are less than the worst case has.

In order to utilize the real situations and improve the network performance, the concept of node density is used in the network. Our new method use arguments of [10] to compute the value of *k* while the difference is the addition of computation and broadcasting of *k* to the proposed algorithm. In fact, using of node density is our main idea and innovation. The main idea behind utilizing the node density concept is that in the dense sections of the network, the topology is more stable. As a result, the nodes can decrease energy consumption by decreasing their transmission range. The new method introduces a new equation to compute node density which presented in the following subsection. Furthermore, SFL [20] is used as k-edge connected algorithm, because its complexity is lower than LTRT (see Table 1).

4.1 Node Density: Identification and Application

Before description of proposed algorithm, we investigate the concept of node density and the method of its calculation. The studies which use the concept of node density, such as [21] and [22], identify node density as $\frac{n}{N}$ or the network density as $\frac{n\pi R^2}{A}$. In these identifications, n depicts the number of neighbor nodes, N is the total number of nodes in the network, R is the average transmission range, and A stands for the network area. There are two major disadvantages in these identifications:

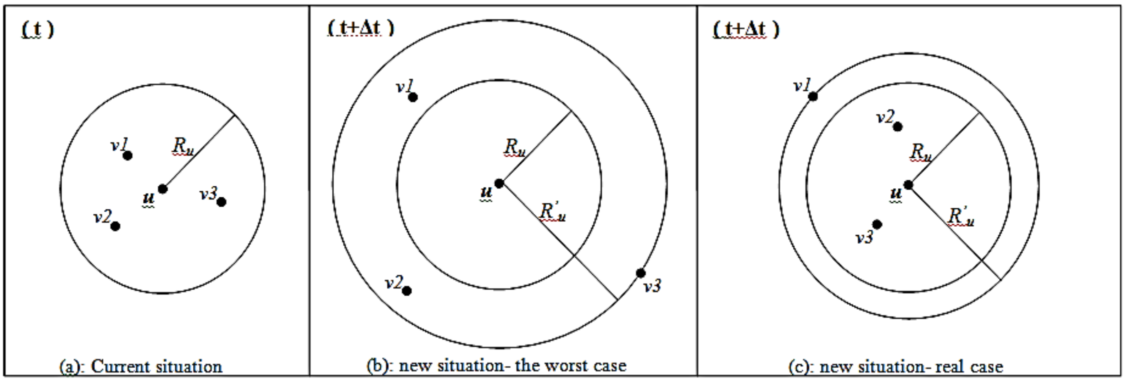


Fig. 2. The worst and real situations of environment around node u

The methods which use above identifications for computation of node density consider density as a constant value and use it globally. However, similar to moving speed, the node density is not equal in different sections of the network.

In these identifications, the distance and relative velocity of nodes are not considered, while these two factors have a significant effect on stability of the local topology.

In this paper, for the first time , the new method uses the concept of node density dynamically in local topology control problem. Also the above disadvantages will be addressed. First, the local density is dynamically computed for each node. This means that in each topology update, the node density is computed regarding the new situation and available information. In addition, we introduce an equation to compute node density which considers all items affecting the node density and stability of topology.

Our proposed equation uses the following factors in computation of node density: the number of neighbors of the node, the distance of neighbors from the node, the relative velocity of the neighbors in the rest frame ofthe node, and the transmission range of the node. There is a direct relationshipbetween node density and the number of neighbors; in other words, as the number of neighbors becomes larger, the density value will become greater too.

The node density has an opposite relationship with distance, the relative velocity of neighbors and the transmission range of the node; that means, if the node covers its neighbors by a smaller transmission radius, and the distance and relative velocity of the neighbors are smaller, the node density will be increased.

Based on the above analysis, the new following equation is proposed to compute the node density:

$$D_u = \frac{n_u^2}{(N-1)\sum_{i=1}^{n_u}(x_{iu}+v_{iu})}.(\frac{R_{\max}-R_u}{R_{\max}})^2 \qquad (5)$$

where n_u is the number of neighbors of node u, N is the total number of nodes in the network, x_{iu} is the distance between nodes i and u, and v_{iu} is the relative velocity of nodeiin the rest frame of node u. Also, R_u is the transmission range of node u and R_{max} is the maximum transmission range. As it can be seen in equation (5), the node density will be increased if the number of nodes is increased; the distance of neighbors from the node, relative velocity of the neighbors in the rest frame of the node, and transmission range of node are decreased. Therefore, the density of node u is maximized when all nodes are located in the transmission range of u, the nodes relative velocitiesin the rest frame of u are zero, they have the minimum distances from u, and transmission range of the u is small asfar as possible.

Now suppose that there are two nodes A and B in the network, as shown in Fig. 3. As it can be seen , the number of neighbors is identical for A and B. Suppose that the transmission radius of A and B are equal and the average speed of the neighbors for node B is greater than for node A. If the node density be computed regarding the number of neighbors, the density of A and B are equal, while this is not logically true; because it is clear that the local topology of node B is more unstable than node A, due to the greater distances and speeds of the neighbors of node B.

Therefore, this is necessary that the new method changes and improves the identification of node density in the mobile networks. The procedure of the new proposed method and its algorithm are investigated in the following subsection.

4.2 The Algorithm and Steps of the New Method

Procedure 1 shows the algorithm of our proposed method which is explained it as the following.

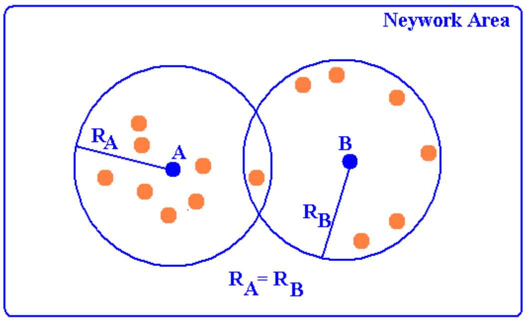


Fig. 3. Two Nodes with same transmission range and number of neighbors and different density.

Steps 1-6: At the beginning, each node broadcasts a "hello" message to the maximum transmission range. This message contains ID, current location, current speed and moving direction of the node. When a node *u* receives the same.

Procedure 1: Density based topology control in each node

1: **loop**
2: Calculate the current moving speed and direction.
3: Broadcast a "hello" message.
4: Build the local graph similar to Fig.4.
5: Calculate ρ based on the local graph by using one of Eqs. (2) - (4).
6: Determine the optimal value of k by using Eq. (1) withcalculated value of ρ.
7: Calculate node density using Eq. (5).
8: Broadcast the density and k in a message.
9: select the nearest neighbor in terms of density.
10: if the value of k related to the selected neighbor is smaller than the calculated k, replace it as new k.
11: Run a k-edge connected algorithm with the optimalvalue of k.
12: Keep the determined transmission range during theperiod of topology update.
13: end loop

messages from its neighbors, it constructs the local graph as Fig. 4. The vertices of this graph are node *u* and the neighbor nodes which their messages received by node *u*. There is an edge between every two vertices of this graph while its weight equals to the Euclidian distance between its vertices. The distance can be calculated using the current location of the nodes.

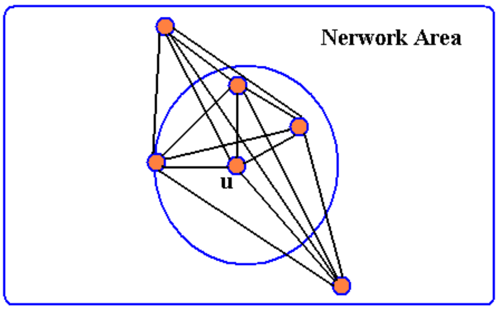


Fig. 4. Local graph of node u.

In computation of the minimum spanning trees for a given graph, if the weights of some edges are equal, the resulting tree may not be unique. This can affect performance of the algorithm. To prevent this, the following weight function is used in order to compute the weights of the network links. Here, *w* is the weight function and *d* is the Euclidian distance function. It is supposed that the nodes know their own position using GPS technology.

w (u1,v1) > w (u2,v2)

$\Longleftrightarrow$ d (u1,v1) > d (u2,v2)
or (d (u1,v1) = d (u2,v2)
&& max {id(u1),id(v1)} > max {id(u2),id(v2)})

or (d (u1,v1) = d (u2,v2)
&& max {id(u1),id(v1)} = max {id(u2),id(v2)}
&& min {id(u1),id(v1)} > min {id(u2),id(v2)})

The probability ρ and the value of k are calculated using the method explained in section 3.

Steps 7-10: Each node computes its density using Eq. (5) and broadcasts it along with the calculated k using maximum transmission range. When node *u* receives the same information from its neighbors, compares its own density with them and selects the nearest neighbor in terms of density. If the value of k related to the selected neighbor is smaller than the calculated k, node *u* replaces it as new k. Now, a k-edge connected algorithm is run using the new k in order to determine the new transmission radius. In the proposed procedure, every k-edge connected algorithm can be used. Therefore SFL algorithm [20] is used because its complexity is low (see Table 1). After running the algorithm, each node uses the determined transmission radius until the next topology update procedure is started. The topology update is completed when the Procedure 1 is performed once.

5. Compare: Simulation Calculations and Numerical Results

In this section, the new method, NDB^{k}TC, according to Procedure 1 introduced in the previous section will be simulated. Afterwards, the new method will be compared with DLTRT [10]. The following metrics are employed for the comparison: connectivity rate, average transmission range and the node degree.

Simulation computations are done according to the parameters of Table 2, in Matlab R2012a on a Core i5-4200M-2.5 GHz laptop with 4 GB of RAM and in windows 8 environment. According to [10] for the beginning, it is supposed that ρ_{local}=0.0022, as the excepted connectivity rate is considered equal to 80%. 100 nodes are placed uniformly in an square area of 1000*1000 (m^2). The maximum transmission range is set to 250 m. Each node can move with speed of 0-25 m/s in random direction. The expected connectivity rate is 80%. The topology update interval is set to 10s for all nodes.

Random way point [23] is used as mobility model. Simulation results are presented in the following.

Table 2. Simulation parameters and related values.

Simulation Parameter	Value
Simulation area	1000*1000 m
Maximum transmission range	250 m
Number of nodes	100
Topology update interval	10 s
Average moving speed	0~25 m/s
Expected connectivity rate	80%

5.1 Comparison of Connectivity Rate

Two nodes are connected if there is at least one path between them. A network is connected if and only if every two nodes of it are connected [2]. According to this identification, the following equation is used to compute the connectivity rate [10]; assuming that N is the total number of nodes in the network.

$$C = \frac{\sum_{u,v \in N} c_{uv}}{|N|(|N|-1)} \tag{6}$$

where,

$$c_{uv} = \begin{cases} 1, & \text{if } u \neq v \text{ and } (u, v) \text{ is connected,} \\ 0, & \text{otherwise.} \end{cases}$$

Suppose that graph G (N, E) is as Fig. 5-left [10]. As it be seen,the graph$G$is connected; so according to Eq. (6) the connectivity rate of G in this case is 100%. If one of the links from G is deleted, as shown in Fig. 5-right, the connectivity rate of G will be 40%.

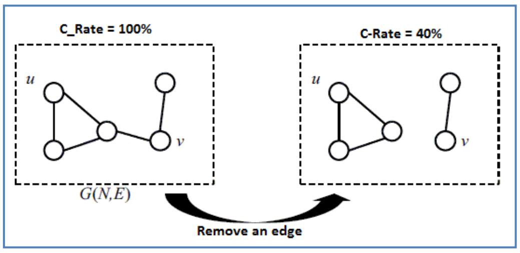


Fig. 5. Change The connectivity rate with removal of one edge.

Fig. 6 shows the connectivity rate in both our new method and DLTRT algorithm. It is clear that the connectivity of new method is lower than DLTRT algorithmin some cases. But, it still satisfies the expected connectivity rate, 80%. The reason of low connectivity rate of our new method is decreasing the value of k. With decreasing the value of k in the node, the number of times k-edge connected algorithm is run, step 11 in procedure 1, is decreased. So, the determined transmission range to the node is decreased. This results in decreasing the number of edges and reducing the connectivity rate.

5.2 Comparison of Average Transmission Range

As previously mentioned, decreasing the value of k reduces the determined transmission range. Fig. 7 shows the average transmission range in both DLTRT and NDB^{k}TC. It can be seen that with increasing the average moving speed, the difference between DLTRT and NDB^{k}TC is increased. This is because, in the lower moving speeds, the difference of value of k between the neighbors is low and as a result the value of k has not an impressive change. But, when the average moving speed is increased, the difference of value of k is increased; so, the change of k in node density based method will be greater. According to [24] the amount of energy consumption in the network can be obtained from the following equation:

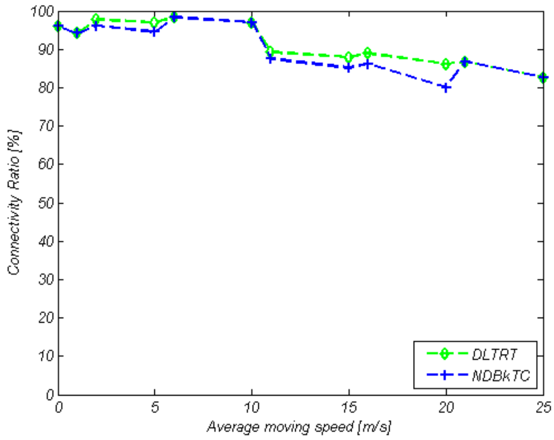


Fig. 6. Connectivity rate in new method compared with DLTRT.

$$E = \sum_{u \in N} (R_u)^{\alpha} \tag{7}$$

where R_u is the node u transmission radius and α is distance-power gradient or the path loss element. In an environment without obstacles, α is considered equal to two [24]. According to equation (7) when transmission radius is decreased, the amount of energy consumption is decreased at least with power of 2, and vice versa. Therefore, our new method decreases energy consumption by reducing the transmission range.

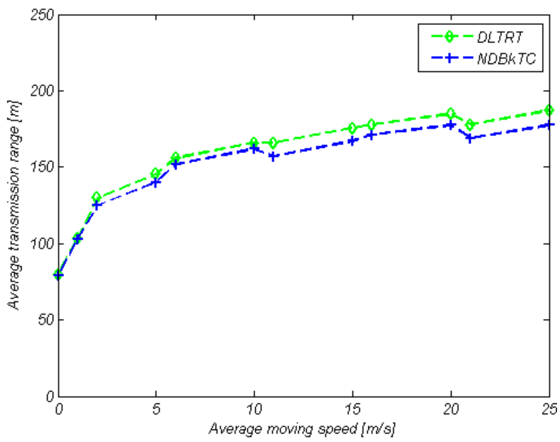


Fig. 7. Average transmission range in new method compared with DLTRT.

5.3 Comparison of Node Degree

Node degree is the number of direct neighbors of the node; in other words, the neighbors which are connected to the node with one direct link. The node degree can be studied as logical node degree and physical node degree [1]. The logical node degree equals to the number of nodes determined by the algorithm; in fact, the number of logical neighbors. The physical node degree is the number of neighbors in the transmission range of the node. Interferences are decreased with decreasing in the node degree. Fig. 8 shows the logical node degree in both DLTRT and NDB^{k}TC.

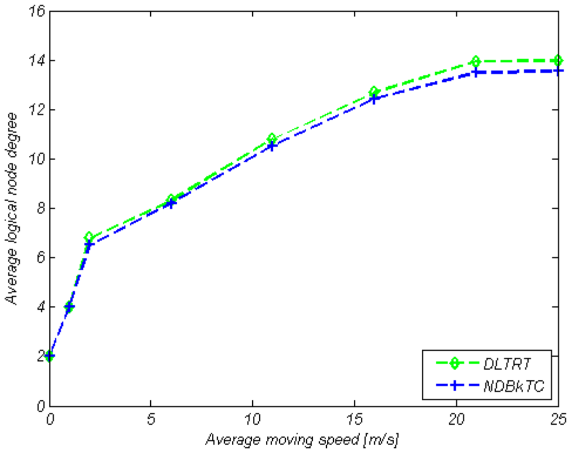


Fig. 8. Logical node degree in new method compared with DLTRT.

As it can seen from Fig. 8, the logical node degree in our new method is lower than in DLTRT. This difference is increased when the average moving speed is increased. This is becausein this casedue to increasing the difference of moving speed related to the nodes which are located in a same section, the difference of computed *k* for the nodesis increased. Therefore, it is more probable to change (decrease) *k* values computed to the nodes, based on the analogy of their densities. As a result, the times to repeat the k-edge connected algorithm and the number of logical neighbors is decreased.

The simulation results show that the new method decrease physical node degree up to 1.3 nodes compared with DLTRT. In fact, in NDB^{k}TC due to decreasing the transmission range, physical node degree is decreased.

5.4 QoS Analysis

Figure 8 shows some mechanism for controlling QoS which we consider 3 parameters delay, bandwidth and lost rate in this paper.

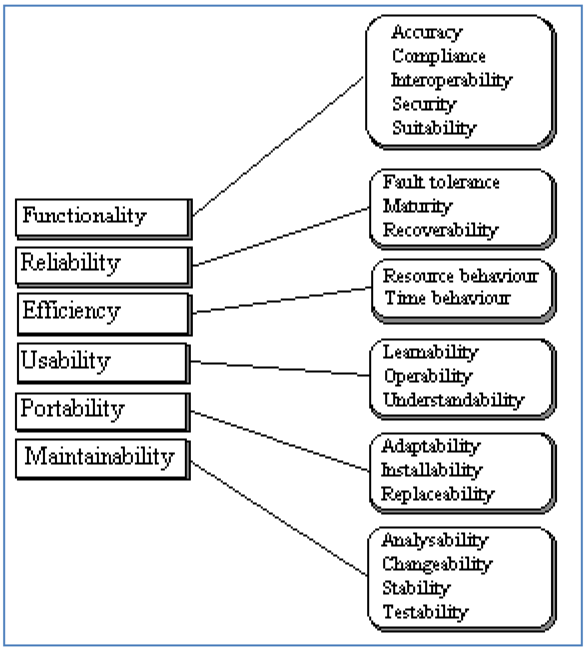


Fig. 9. Some mechanism for controlling and improving QoS in networks [25, 29].

Also in Figure 9 we can see some new and modern mechanism for controlling QoS in networks such as Differential Services Networks [25, 27].

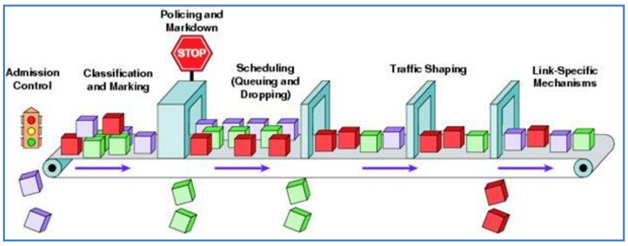


Fig. 10. some new and modern mechanism for controlling QoS in networks such as Differential Services Networks [25, 28].

For analyzing the situation of QoS in NDB^{k}TC and DLTRT, we consider the following heuristic formulation:

$$F_{QoS} = \frac{\text{Used Band}}{\text{Available Band}} * \left(1 - \frac{\text{Lost Rate}}{\text{Total packets}}\right) * \left(1 - \frac{\text{delay}}{\text{total time}}\right) \quad (8)$$

If F_{QoS} vanishes, this means that lost rate or delay has been increased and so QoS will be failed, whereas, if F_{QoS} limits to 1, this means that QoS has a desirable situation. $F_{QoS} = 0$ shows that all available bandwidth has been used and delay and lost rate are equal to 0. Figure 10 shows values of F_{QoS} before and after applying NDB^{k}TC to the network. This figure shows that however NDB^{k}TC reduces the number of links and bandwidth, it maintains F_{QoS} in a desirable range and does not fall QoS conditions. Before applying NDB^{k}TC, DLTRT transmits and delivers packets.

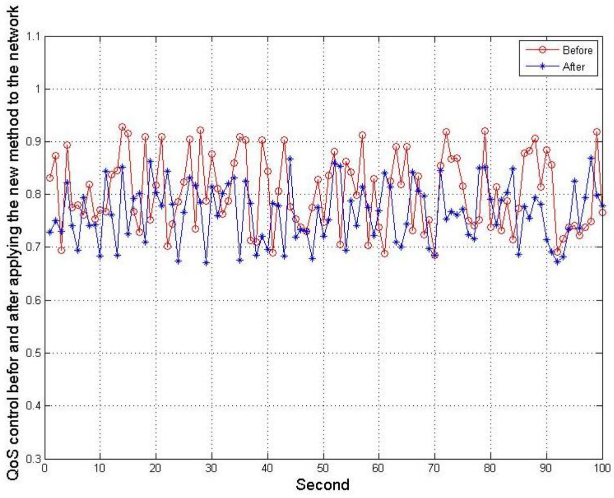


Fig. 11. NDBkTCdecreases the number of links but can holds QoS conditions (F_{QoS}) in a desirable ranges.

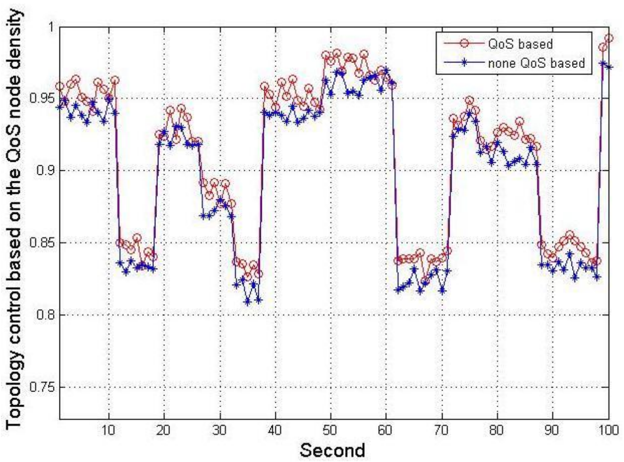
6. New QoS k-edge Connected Algorithm

In this paper in the subsection 4.1 a new node density definition has been presented and used. Now this definition is improved using F_{QoS}in order to increase the QoS guarantee of the new method NDB^kTC which has been presented in the section 4. We call this new node density formulation as QoS Node Density factor which is as the following:

$$D_u^{QoS} = F_{QoS} \times D_u \quad (9)$$

As we see formulation (9) shows that F_{QoS} can affect on the D_u. In fact if two nodes have the same D_u, D_u^{QoS}selects that node that has the better QoS conditions. Based on the formulation (9) we compare results of NDB^kTC in two states: using D_u^{QoS} and D_u. For achieving these results we re-run the simulation shown in Table 2. Figure 11 shows that D_u^{QoS} as compared to D_u increases stability and consistency of QoS in

NDB^kTC. D_u^{QoS} as compared to D_u increases the average of QoS parameter as %5.17.



7. Conclusion

This paper has investigated the effect of the nodes movement over the mobile ad hoc networks connectivity, network QoS, and analyzed the algorithms which guarantee k-edge connectivity. We outlined disadvantages of the algorithms and proposed a new node density based method in order to overcome the disadvantages. In this method, for the first time, the concept of node density was used in local topology control, dynamically. In order to improve existing identifications of node density which was used as a constant in the previous studies, a new equation was proposed to compute it. In this new formula, all factors affecting the node density and stability of topology have been used. In fact, our purpose is to efficiently utilize available information in the computations, instead of using the worst cases.

The new method has been compared with DLTRT. The criteria used for comparison are as follow: connectivity rate of the network, average transmission range and the logical and physical node degree. The results show that our new method with maintaining the expected connectivity rate, improves the performance factors.

Simulation results show that however NDB^kTC reduces the number of links and bandwidth, it maintains F_{QoS} in a desirable range and does not falls QoS conditions. Before applying NDB^kTC,DLTRT transmits and delivers packets.

8. Future Works

This paper used the concept of node density in order to improve the performance factors in MANETs. Although the new proposed method is better than the existing ones, but it can be improved by using other techniques. We will try to improve our new method in the future studies. Some of these techniques include the following:

1. Combination of node density with clustering:The new proposed method uses the density of the neighbor nodes to determine the optimal value of *k* related to k-edge connectivity. Density based clustering is one of the clustering techniques. In density based clustering, a node can construct a new cluster or can be a member of another existing cluster. The condition required to construct a new cluster by a node is that the node has a certain number of neighbors in its coverage area. This procedure runs in each node and obtainedclusters are merged as far as possible.The local versions of density based clustering are introduced which we can use them to improve our new method. The new idea can be using the information of clusters in order to determine the optimal value of *k*.
2. Neural networks: As shown in section 5, the new proposed method in this paper improves the factors of the network performance compared with the existing methods. Therefore its determined

transmission range for every node of the network is better than the previous methods. The neural network technique can be used as the following.

In order to use neural networks a data setmust be provided for training the network. To construct this data set, the following steps must be done: In the beginning, we simulate a MANET according to this paper and run it using the proposed new algorithm. When a node computes its density, a feature vector is constructed for it. This vector consists of the following elements: the computed density for the node, current transmission range, the average distance of the neighbors from the node, and the number of the neighbor. Afterwards, the remaining of the algorithm is run and the transmission range is determined for the node. This determined transmission range must be saved in the target vector, as the related element of the node. This procedure is repeated for all nodes until termination of the simulation.

Suppose that the number of the network nodes is N, the simulation time is T, and topology update interval is Δt. The number of the existing samples in data set in the end of each simulation will be equal to (T / Δt)*N. So, if we repeat the simulation for M times, the number of samples will be M*(T / Δt)*N samples. We can train the neural network using 80% of the data set samples as training set. The remaining of samples is used to test the correction of the trained network.

Now new simulation must be done using the trained neural network. If the results have a performance as well as the proposed method in this paper, the algorithm can reduce the computation overhead impressively, in topology control.

3. Inserting new factors in the node density equation: the new proposed equation in this paper for node density, uses four various factors: the moving speed of nodes, the distance between nodes, the number of nodes, and transmission range of nodes. We proposed this new equation to use in MANETs and for topology control problem. In the other types of networks such as Mobile IP and VANETs, or in the other problems, e.g. routing, it is maybe required to use other factors in the equation. Therefore, we can allocate a part of the future studies to use the concept of node density in other types of network and other problems. It is clear that a new equation must be presented to compute the node density.

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