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Utility-based Location-Aware Data Forwarding Algorithm for Delay-Tolerant Mobile Ad-hoc Networks

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Abstract: Delay-tolerant Mobile Ad-hoc Networks (DT-MANETs) may dearth a continuous end-to-end connection between mobile devices. Data delivery in this network is a challenging endeavor since it must cope with network partitioning, dynamic topology, and long delays. Moreover, conventional data forwarding algorithms in DT-MANETs cannot perform well owing to the failure of its postulate that all the communication links are present forever. In this work, a Utility-based Location-aware Routing Algorithm (ULRA) is designed for DT-MANETs. We formulate a mathematical framework to derive the utility function of the nodes in order to implement a controlled packet duplication technique. For decreasing the overhead ratio due to packet flooding, we implement a criterion to assess the rate of packet duplication. Finally, a packet redundancy controlling technique is added to this algorithm. Extensive simulation studies have been carried out and the results reveal that the proposed ULRA outdoes the other existing data forwarding algorithms like Binary spray and wait, Epidemic, and FirstContact in terms of average hop count (AHC), packet delivery ratio (PDR) and with the acceptable overhead ratio in delay-tolerant network scenario.
Keywords: End-to-end delay; location aware; MANET; packet delivery ratio; routing;

I. INTRODUCTION

MANET is an outstanding distributed wireless network which comprises of randomly moving nodes. Any mobile device fortified with the wireless link can communicate with each other directly through single-hop or multi-hop fashion. Hence each hop (or host) acts as a wireless transmitter, receiver, router or gateway of the data packets. The ubiquitous access of MANET makes them suitable for emergencies like warfare, floods, and other disaster relief efforts as well as vast multimedia applications such as video conferencing, transfer digital information during traveling, etc., where static infrastructure networks are not imaginable to operate [1]. Practical DT-MANETs has developed from quite vague research efforts to a vigorous research subject enticing both software developers and network architects [2]. In an Internet protocol-based communication model, there are some intrinsic assumptions such as the availability of incessant link connectivity between hops, the symmetric data rates, the less end-to-end data latencies, and the minimum error rates [3]. These assumptions typically fail in DT-MANETs. Hence, TCP/IP protocol based routing algorithms do not perform well in delay tolerant network environments. Moreover, several real-time communication systems show delay-tolerant features, albeit of various types: from sparse MANETs to dense sensor networks. It is also observed that delay tolerance is also considered as the main parameter to define transmission performance and to develop appropriate tools to handle the issues in mobile ad-hoc networks [4].

Even though there are several research successes in ad-hoc networks, most of the algorithms expected that the link connectivity between two nodes always exists. Moreover, not all the internet services (e.g. electronic mail, news bulletin applications, and indoor temperature sensing system, and so on.) need a real-time communication and as a result, these services demand the networks ought to be relaxed with delay tolerance, consequently the idea of ad-hoc networks could become much closer to realism. In order to handle various types of heterogeneity in ad-hoc scenarios, there is a necessity for developing innovative algorithms. All these above-said services explore the significance of effective packet delivery rather than real-time transmission. This specific delay is defined as tolerance.

Most of the studies in delay tolerant networks mainly emphasis on the developing of data forwarding algorithms. Although there is something common of data delivery between Internet and delay tolerant networks, packet propagation in DT-MANETs still suffers from several issues. Mobile devices in DT-MANETs are more than static nodes and routers. Additionally, there are no predefined access points or controllers such as base stations in this network. Therefore data forwarding will be performed by a hop-by-hop basis. Each hop acts as a router and operates in a store-carry-forward fashion.

Though the nodes are not depending on access points or controllers and add many difficulties in the routing process. There are several motives for paying more attention to DT-MANETs. For instance, for communication in army battlegrounds, a mobile device has the maximum chance to be devastated. This may cause broken links in the communication system. Likewise, the mobility model will vary in line with the strategic plan. As a result, mobile devices need to construct the network spontaneously and then serve as routers to distribute the data packets. For communication in vehicular ad-hoc networks (VANETs), some base stations can be pre-deployed along the road at fixed intervals. But constructing access points is more costly than mount up the mobile nodes on the automobile itself and the process of data propagation depends on their mobility pattern. Most of the existing data forwarding algorithms hinge on collecting information from more than one neighbor node or the assumption of the existence of network topology information. Few algorithms use different packet propagation techniques in order to collect essential data for data delivery. On the one hand, some routing algorithms are impractical to realize owing to network splitting, dynamic topology and long communication latencies which may lead to communication failures. On the other hand, even though these packet propagation techniques performed well the obtained data may be expired or imprecise hence losing their real-time response for packet propagation. This study mainly contrasts previous works in the following facets:

1) The proposed algorithm depends on the information collected from only one neighbour hop. It is not required to distribute the connectivity information to the entire system or to store the history of link status at every hop.
2) Some existing routing algorithms intended to exploit a parameter assessing the link of the current hop with the receiver. But, this indirect method needs that all the hops have the information of its intended receiver node and it is not possible in DT-MANETs. This work proposes a novel idea to resolve routing issues in DT-MANETs that enable all the hops to guarantee uniform distribution of the packet replicas.
3) It is essential to handle network overloads due to that the packet duplication technique brings maximum packet redundancy in the DT-MANETs. In this work, we implement the concept of rate of packet redundancy to regulate the number of replicas.

The contribution of this paper is threefold:

4) A utility-based location-aware routing algorithm is developed according to the link status of a single neighbour node. Each node only needs to know the location of immediate neighbour nodes to choose the relay node for packet propagation. We assume that each host is fortified with a local positioning manoeuvre to find the locations of its neighbour's. The proposed algorithm is easy to deploy and does not add abundant computational complexities. Therefore the bounded network resources can be hoarded.
5) In this paper, we adopt a simple yet efficient factor called the rate of packet redundancy (RPR) to calculate the redundancy of the packet.
6) Finally, extensive simulation studies are provided to evaluate the performance of the proposed algorithm. The effectiveness of the proposed routing algorithm is compared with the other three recognized routing algorithms in terms of PDR, AHC and overhead ratio.

The remainder section of this article is arranged as follows: In Section II we discuss some prior studies which match our analysis. Section III describes the preliminary and motivation of the location-aware data forwarding algorithm. Section IV discusses the primary issues related to the packet propagation approaches in DT-MANETs. The working mechanism of ULRA is discussed in Section V. The implementation and evaluation details of the proposed strategy are given Section VI. Finally, we conclude this paper in section VII.

II. RELATED WORK

Scheming data forwarding strategy for DT-MANETs is very problematic as well as stimulating tasks because it has to handle critical situations including dynamic topology, time-dependent links, and bounded energy sources. Recently, a considerable amount of investigations have been conducted to compact these challenges which lead to the introduction of different data forwarding approaches. Some algorithms are intended to handle very sparse networks with sporadic links and establish connections on demand. Few approaches bring other transmission technologies into the network such as satellites, drones, and other smart devices. Several routing algorithms have been developed to focus on different parameters but no specific protocol or method delivers a complete solution. In recent years, many eminent researchers carried out considerable research works to handle the problems of the data forwarding process in DT-MANETs. Most of them intended to handle very sparse networks or sporadic communication paths to support on-demand connectivity.

Zhao et al. propose a Message Ferrying (MF) method to handle the issues in the data forwarding process. This mobility-based method exploits a group of exceptional hosts known as *message ferries* to enable transmission among hosts in the network. The key notion of the Ferrying method is to add *non-randomness* in node mobility [5]. The data ferries use different movement models to enhance the performance of routing and decrease energy depletion in hosts. The authors extend this work by implementing multiple ferries and developing suitable paths to increase performance and decrease communication latency [6]. Until now, some congestion control algorithms have been designed for the delay-tolerant network which is generally employed in the static communication system or network with constrained mobility with a scheduled interruption period.

Cao et al. develop a dynamic congestion control based data forwarding scheme that drives the designated packet before the congestion occurs [7]. Thompson et al. suggest a new hop-based duplication controlling strategy which reduces buffer congestion by controlling the data duplication [8]. Dvir and Vasilakos exploit statistics about queue overflows, random walk, and transmission scheduling parameters to perform data forwarding verdicts deprived of the insight of complete routes [9]. Ryu et al. propose a two-level Back-Pressure with Source-Routing approach to decrease the number of queues needed at every hop and the dimensions of the queues, thus decreasing the overall latency [10].

In order to circumvent the packet flooding in the network, a direct method is to duplicate the packet based on the utility measure instead of copying blindly. Boloni and Turgut developed the Bridge Protection Algorithm (BPA) which alters the characteristics of a group of topologically significant hops [11]. Such approaches defend the bridge node by enabling a few hops to take over some of the duties of the sink. Though this approach considerably reduces the traffic in the critical zones, it has minimum impact on the performance of the network. Aruna et al. consider delay-tolerant packet forwarding as a resource allocation issue that interprets the routing measures into per-packet utilities that finds in what way data should be duplicated in the network [12]. A random variable is employed to denote the encounter between pairwise hops, consequently hops replicating data in the decreasing order based on a minimal utility. Liu and Wu propose multiple duplicate routing algorithm, namely optimal opportunistic forwarding (OOF), that increase the PDR and reduce the anticipated latency. At the same time, the number of forwarding processes per packet does not go beyond a specific predefined value [13]. El-Azouzi et al. relate the evolutionary games to non-cooperative forwarding control in DT-MANETs, of which the key focus is on methods to rule the contribution of the relays to the distribution of packets in delay-tolerant networks [14]. Abraham introduces a utility function as the difference between the predictable reward and the energy consumed by the relay to endure routing processes [15].

Additionally, there are few brilliant explorations for communication in Wireless Sensor Networks (WSN). Boloni and Turgut study the packet scheduling problem for WSN in the presence of portable sinks [16]. They designed an optimal algorithm based on dynamic programming and defined two algorithms that use only probabilistic frameworks and do not need any information about their upcoming network configurations. Turgut and Boloni propose three heuristic approaches to regulate the communication performance of the hops with portable sinks [17]. The authors also propose a graph-theory-based method for computing transmission parameters according to global information. Conversely, most of the studies do not consider the network configurations where hosts are movable and concurrently operate in an ad-hoc mode. To be precise, there is no secondary hop or predefined base station for data forwarding in dynamic ad-hoc networks. Further, most of the existing data forwarding algorithms extremely hinge on more than one-hop information. Some of them adopt a foreseeable mobility model or information oracle set recognized earlier. Some others use various data forwarding techniques to propagate the required information about network configuration.

All the above said approaches may upturn the difficulty to implement those algorithms in practice. The present study primarily contrasts the existing studies in two ways.

1) The proposed algorithm does not violate the ad-hoc nature of systems, therefore no controlled hops or access points are employed.
2) The data forwarding process is implemented only based on single neighbour-hop geographical information.

The experimental results demonstrate that ULRA has relatively high PDR and minimum AHC with a tolerable overhead ratio.

III. PRELIMINARY

A. Motivation

Distance vector routing (DVR), path-vector routing (PVR) and link-state routing (LSR) are renowned distributed routing approaches [18]. In a data forwarding approach using DVR or PVR, every hop selects its own relay based on the logged vectors obtained from its immediate neighbor hops Nevertheless, LSR assumes every hop preserves the link state information and then passes them to the network in order to make the entire network configuration visible to every hop. All these routing approaches generally need to collect the information of more than one adjacent hop. Besides, the network splitting and maximum packet latency may cause the obtained data obsolete and hence imprecise. Also, the repeated interruptions in DT-MANETs may cause the condition that updating packets flood in the entire network thus creating extreme overloads in the network.

To resolve the issues in existing data forwarding algorithms, we design a novel data forwarding algorithm based on the location of its immediate neighbor hop. The major goal of this research is to increase the PDR. Moreover, optimization of total packet latency is not of the vital emergency, high PDR may benefit from fast packet propagation in DT-MANETs, as hops need not preserve the replica of a packet consequently saving the constrained network resources. However, it is very difficult to select a parameter to optimize both PDR and delay. Fortunately, there is a perception that decreasing the distance among the sender and the receiver may increase the PDR.

This notion motivates many researchers to develop a routing algorithm to propagate the packet towards the receiving node as precise as possible. We agree with the authors in [19] who witnessed that packet replication rises the PDR and reduces the network delay. Nevertheless, the simple duplication technique presents awfully maximum traffic into the system. Therefore we need an approach to exploit replication cautiously and achieve a trade-off between decent performance and tolerable overhead ratio. In order to understand the objectives of our proposed work, we firstly define the primary parameters which influence the efficiency of the data forwarding algorithm, and subsequently, we list the assumptions of the DT-MANETs scenario. The proposed approach considers the following points to select network parameters.

1) The performance of some data forwarding algorithms greatly relays on the mobility pattern of devices.
2) Multiple copies of the packet can achieve concurrency in packet propagation by presenting more costs, which cause more traffic and subsequently decreasing the effectiveness of the algorithm.
3) Using different controllers can aid the data forwarding process by improving link stability at the cost of losing ad-hoc nature.
4) A real-world data forwarding strategy in DT-MANETs should perform in a distributed online manner.

Keeping all the above-mentioned points in mind, we made some simple assumptions as follows (i) every mobile device is fortified with a locating facility. We do not employ a global positioning system (GPS) for that since it may reveal the location of each node to the other nodes; (ii) once the node does not want others to identify its present location, it can turn off its locating facility. By considering the above-said parameters, we frame four significant rules of implementing data forwarding processes as follows:

a) The data forwarding algorithm does not make any assumption of the existing mobility model.
b) The amount of replicas for each packet is regulated by suitable methods to evade packet flooding.
c) There is no infrastructure or dedicated controller employed in DT-MANETs to preserve the ad-hoc nature of the entire network.
d) There is no assumption of existing global information and hence the proposed approach is more appropriate in real-world environments.

IV. PRIMARY ISSUES IN ROUTING

In this research, a utility-based location-aware data forwarding algorithm with one-hop information is designed and implemented. The key issues associated with ULRA are how to select relay hops and how many relay hops ought to be selected. Based on rule 1 and rule 4 given in the previous section, we are not aware of the location of the receiver, so the key objective of ULRA is to make uniform messages distribution to realize the maximum success rate of reaching the receiver. Also, we should try to certify that packets propagate as quickly as possible to realize minimum packet delay. In order to implement ULRA, the routing measures required by a hop X are the location of the hop X (L_X)and the locations of all immediate neighbors of X$(L_{in}(X))$.

A. Number of duplicate packets

When the network resources like buffer capacity and energy are adequate, employing more relays generally indicates maximum PDR and minimum delivery latency. Actually, whenever packet copies are propagated to many hosts, if some of these hosts vanish (e.g. link failures, energy depletion, switching among active and sleep modes, etc.) the process of packet forwarding is performed by the other enduring live hosts.

Thus the possibility of a host reaching the receiver increases with the number of of relay hosts. For instance, when node X duplicates the packet P to node Y, then node Y is also accountable for distributing message M. The node X and Y individually make their own routing verdict so that two concurrent routes to the intended receiver are created. However, network resources in DT-MANETs are constrained.

Hence the data forwarding process in DT-MANETs considers all the parameters stated above. The redundant packets consume large bandwidth and consequently lead to network bottlenecks. The buffering or processing of packets spent a considerable amount of power and hops often decide to halt communication when the power is small [20] or to discard the packet when sufficient buffer capacity is not possible. Therefore it is important to control the number of relay hops to circumvent unnecessary duplication [21].

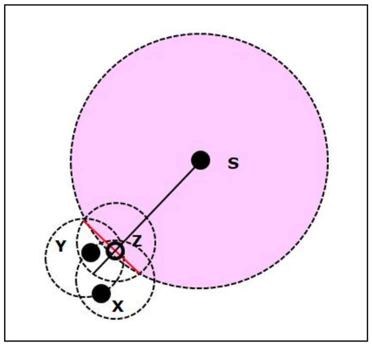

Fig.1. Selection of Two nodes for data propagation

In order to ensure the uniform packet distribution, one approach is to allow the source selects four hops to perform packet duplication. If these hops use the same routing method as source S, one of the routing paths of relay node would be on the way to S. Therefore one duplicate packet would be transferred again to a location near to source, which likewise causes that packets are detained by several hosts within the coverage region, therefore, killing the buffer capacity. Moreover, it is very difficult for a host to select four immediate neighbor hosts consistently in sparse DT-MANETs. In order to handle this problem, we ought to be allowed uniform packet distribution without losing the reliability of the data forwarding approach.

This algorithm enables the transmitting hop to select the adjacent hop and copy packets to it, and then enable both source and adjacent hop to pick their relay hops. The reason why ULRA selects the closest rather than the distant node is that although a remote hop can maximize the packet coverage region momentarily, the coverage region would nearly be an ellipse rather than a circle. To be exact, if the coverage region is non-uniform initially, it would become increasingly non-uniform therefore decreasing the effectiveness of the approach. Hence ULRA mainly attempts to preserve the coverage region analogous to a circle. Then, the transmitter and relay hops propagate the packet in the opposite direction to the transmitter in order to increase the coverage region. The source S of a particular packet and its coverage region are illustrated in Figure 1. The source is the hop currently selected to distribute the packet farther, and we draw a line perpendicular to the line SZ and therefore obtaining two zones where node X and node Y localize. When the process of data forwarding progress in this way ULRA can ensure that the packet coverage region would increase and eventually cover the receiver node.

B. Location of the Immediate Neighbor for Data Propagation

After deciding the direction, the selection of distant relay may decrease the redundant coverage region in order to exploit existing resources effectively. As given in Figure 2, assuming that node Q is the present hop to select the path, we can determine it intuitively that best relay node B, as it is the farthest hop to Q. The hop W discovers on the same location of Q and we consider this as the worst selection since duplicating the packet to W does not create any impact of the packet coverage region. As every host makes its own decision and not aware of its neighboring node's selections, a good technique to ensure the data forwarding process do well from the numerical point of view is to constantly achieve an optimum selection according to the selection of its neighboring hop.

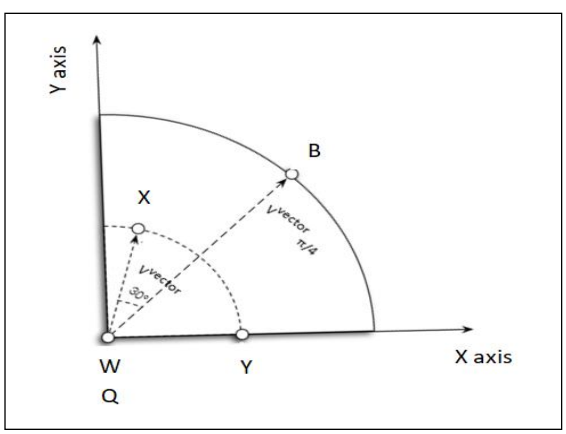

Fig. 2. The best and the worst location of relay hops

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V. DESIGNING OF DATA FORWARDING ALGORITHM

A. Selection of the relay node

As we are not aware of the receiver node information such as the direction or the distance, the only tactic to increase the possibility of reaching the receiver node is to distribute the packets as uniformly as possible. In order to explain our algorithm effectively, first we define the term peer hop. For a particular hop X, its peer hop represents the hop also selected as the relay by the direct ancestor of X. As illustrated in Figure 2, hop Y is a peer of X and vice versa, as that both X and Y have been selected as relay hops by their ancestor hop Z. To keep a uniform distribution, the selection of next-hop of each node hinges on the selection of its peer node. Nevertheless, a hop could not depend on a query process to find its peers, else rule 4 is violated, since if that we could not ensure the hop and its peer to be in the consistent coverage area of each other. On the other hand, the query is not a single-node process, therefore violating the rule. The only option to get the peer selection information is to enable every hop to predict the direction that its peer is most liable to select. But, the location of the potential relay hop is calculated by its likelihood to emphasize in every position of the sector. Therefore ULRA aims to obtain the most promising direction for the potential packet delivery. Also from the statistical significance, it is known that the prediction of the direction is the optimal technique and causes less variance. Consequently, we try to predict the shown up direction for a hop in the sector. The set of locations is denoted as L and the cooperation system is constructed as given in Figure 2. Since every hop has an equal chance of showing up in any location of the sector, L_X follows a uniform distribution and consequently, the probability density function (pdf) is derived as

$$pdf - \frac{1}{4\pi D^2} \qquad (1)$$

Now the expected direction can be estimated as π /4. So it is advisable to keep uniform packet distribution in order to let every hop to select the neighbor hop to the anticipated direction (i.e., π /4). Similar to other routing algorithms in DT-MANETs, ULRA is also delineating the utility function to describe the suitability of the routing process for a particular packet. The utility function is defined as

$$U(Q,X) = \frac{1}{2D} dist(Q,X) + \left(1 + \frac{1}{\sqrt{2}}\right)\left(\cos\left(V_{QX}, V_{\frac{\pi}{4}}\right) - \frac{1}{\sqrt{2}}\right) \qquad (2)$$

For all the nodes N, $\cos(V_{QQ}, V_{QN}) = \frac{1}{\sqrt{2}}$. As illustrated in Figure 2, the direction from node Q to node X and the direction of the bisector of the sector are defined by V_{QX} and $V_{\frac{\pi}{4}}$ correspondingly. In equation 2, $\frac{1}{2R} dist(Q,X)$ is the constraint for measuring the distance. The remainder part of the equation defines the degree of approximation between V_{QX} and the expected optimal direction $V_{\frac{\pi}{4}}$. Thus the range of either part is [0, 1/2], and then the value of $U \in [0,1]$. Considering the two hops B and W in Figure 2, the direction of node B is $V_{\frac{\pi}{4}}$ and the distance between B and node Q is D. Now, we can calculate the cosine value of the angle formed by these two vectors as $\cos\left(V_{QB}, V_{\frac{\pi}{4}}\right) = 1$. Then, we can get the maximum utility value from equation 2 as

$$U(Q,B) - \frac{1}{2D} \times D + \left(1 + \frac{1}{\sqrt{2}}\right)\left(1 - \frac{1}{\sqrt{2}}\right) - 1 \qquad (3)$$

In the meantime, node W finds on the same location as node Q, and so we have $dist(Q,W) = 0$, and $\cos\left(V_{QB}, V_{\frac{\pi}{4}}\right) - \frac{1}{\sqrt{2}}$. Under this case, we get the minimum utility as

$$U(Q,W) = \frac{1}{2D} \times 0 + \left(1 + \frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}\right) = 0 \qquad (4)$$

Similarly, $U(Q,X)$ and $U(Q,Y)$ are calculated as follows.

$$U(Q,X) = \frac{1}{2D} \times \frac{D}{2} + \left(1 + \frac{1}{\sqrt{2}}\right)\left(\frac{\sqrt{3}}{2} - \frac{1}{\sqrt{2}}\right) = 0.52 \qquad (5)$$

$$U(Q,Y) = \frac{1}{2D} \times \frac{D}{2} + \left(1 + \frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}\right) = 0.25 \qquad (6)$$

Now, we have the sequence of the choice priority:

$$U(Q,W) < U(Q,Y) < U(Q,X) < U(Q,B) \qquad (7)$$

Equation 2 ensures that while localizing in a similar direction, a distant probable relay hop causes the maximum utility value. The equation also guarantees that when the distances are the same, a direction being more imprecise to the expectation has a maximum value of utility. Consequently, the utility (U) can be calculated by either direction or distance of the relay hop and these are considered to make routing decisions. Consequently, the location of neighbor hops is exploited effectively.

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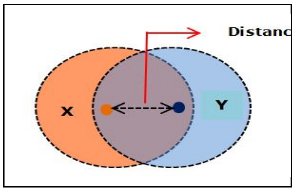

Fig.3. Overlapping region of packet P_X

B. Controlling Packet Redundancy

Assume P_S is the group of all packets in MANET and P_X is the packets generated by the node X. Any location within the transmission range of node X can be considered as a coverage area and node X is accountable for communication within the coverage region. Assume that node Y is also preserving a replica of P_X and the distance among the nodes X and Y is smaller than D. In this case, there is an overlapped region where both nodes X and Y have the capacity to achieve communication for P_X. If the overlapped region is too big, then it is not necessary for both nodes X and Y to preserve the identical replica of P_X. To be precise, both X or Y takes responsibility for communication and hence killing the network resources. In order to describe the redundancy, a variant called the rate of packet redundancy (RPR) is defined. Consider N^{OL} is a group of hops that are all preserving the copy of packet P_X. The k[th] order rate of packet redundancy (k-RPR) of N^{OL} for P_X by $Area^{OL}(k, N^{OL})$, and it is represented by

$$\text{The region covered by k hop in } N^{OL} = Area^{OL}(k, N^{OL}) \quad (8)$$

where $k \le |N^{OL}|$. Figure 3 represents a 2-order RPR of X and Y for P_X defined as $Area^{OL}$. The correlation of $Area^{OL}$ and $dist(X, Y)$ can be defined as

$$Area(dist) = Area^{OL}(2, \{X, Y\}) \quad (9)$$

and

$$Area(dist) = 2D^2 \left| arccos \frac{dist}{2R} \right| - dist \times D\left(1 - \frac{dist^2}{4D^2}\right) \quad (10)$$

If $dist - \frac{D}{2}$, then $Area(\frac{D}{2}) - 2.167\ D^2$. The overlapping region is about 70% of a consistent coverage region, and it is defined as 2-Margin. If there exists a $2 - RPR > 2 - margin$ between any two hops, then a redundant copy of the packet from both hop is discarded to exploit the resources effectively and reduce the congestion overheads.

C. Routing Protocol

As ULRA does not depend on any global knowledge or beyond single-hop status, we do not require any data forwarding methods including DVR or LSR and therefore simply enable every hop to distribute a HELLO packet when it enters into the network. Hence the control overhead for all the hops is simply related to the hop intensity of the network. A control HELLO packet contains some details of its source such as node_ID, location and a summary vector of all the packets preserved in it [22]. For every hop, all the adjacent hops within its coverage area will get the HELLO packet and then append the corresponding location information to their neighbor's table. Also, ULRA allows the data packet contains its source location being referred by other relay hops.

Algorithm 1 demonstrates two types of duplication approaches used in ULRA called simple duplication and utility-based duplication. Every hop will first check its packets in sequence, and propagate all the deliverable ones. For the remaining packets, the hop will use either of the two duplication policies for packet propagation. Let Z is the node making the duplication decision. If there is only one active relay node, then Z will check its neighbor's table and then employ the naive duplication policy. Otherwise, node Z will implement the utility-based duplication approach to evade the packet flooding.

Algorithm 1:

```
If new packet entered
    If more than one active relay node available
        Copy to two relay nodes selected by the utility value
    Else copy to the only one relay node
        Go to step:1
Else go to step :1
```

The pseudocode for redundancy coping technique and table updatation is given in Algorithm 2. Both mechanisms are achieved by enabling interactions of the "HELLO" packets between hops. As the energy is bounded in DT-MANETs and there is a tradeoff between the energy consumption and listening frequency and of "HELLO" packets [23], ULRA takes full advantage of every "HELLO" packet, and accordingly, it appends the packet duplication policy with the "HELLO" packet. The redundancy handling technique will remove the packet from both hops. ULRA transfers the packet to a hop whose distance from X is less then D/2. In this study, we plan to divide the redundancy handling technique from the duplication process to make the algorithm more simple and clear. Moreover, a "present bad hop" might be a "future good relay", because hops might travel to a distant location where no hop can cover now. Accordingly, if we did not duplicate the packet to the hop in this condition, we would in some sense miss a chance to propagate the packet further.

```
Algorithm 2:
    If "Hello" is received from a relay node X
        Update the table of neighbors
        If Distance from X is more than half of the
signal range
            Remove the redundant packets based on the
"Hello"
            vector
        Else go to step:1
    Else go to step :1
```

Furthermore, even the present bad hop is also "a future bad hop". This problem will be addressed by the redundancy handling technique since every two arrived "HELLO" packet will trigger it. In this case, the hop will check the summary vector contained in the "HELLO" packet with its own, and remove the redundant packets in order to protect the buffer capacity. The "HELLO" packet can help a hop in informing its neighbor(s) presence, and therefore we enable every hop to preserve its neighbor's table by sending "HELLO" packets. Nevertheless, an adjacent node can be considered exist only if it is alive, which means that we should also have an announcement method for hops to remove the unacceptable neighbors. To handle this, every hop removes the corresponding neighbor entry when its anticipated "HELLO" packet has been lost more than two times. The reason is that one-time "HELLO" missing due to some reason including MAC conflicting or unpredictable latency etc. Though we can recover the removed neighbor entry to the table when a new "HELLO" packet reaches, operations on the table will take some time and consume a considerable amount of energy. Thus a fault-tolerant technique for the "HELLO" packet stated above is essential for resolving this issue.

VI. PERFORMANCE EVALUATION

A. Network model and parameter settings

In this work, ONE simulator is used to evaluate the results. ONE is a clock-stepped simulator and the precision of a result is depending upon the topology-based time-step [24]. A smaller time step causes a faster simulation task. In our experiments, we set the time-step as 0.1 sec.

For compute-intensive circumstances, we marginally rise the time-step to get a suitable processing time. In order to reimburse the imprecision presented by reducing the simulating particle size, each test is performed 5 times. Finally, the results are averaged. Once again, we underline that the global network knowledge or more than single-node status is problematic to achieve. Therefore we select three algorithms, viz.

Binary Spray and Wait (BSW), Epidemic (EPI) and FirstContact (FC) to relate ULRA. All these data forwarding algorithms are not depending upon any global information or any propagation method. EPI takes advantage of system resources as much as possible to realize the maximum PDR; however, its furious flooding presents maximum traffic overhead. If the system resource is adequate, EPI performs the trick. BSW [25] can be considered as a flooding routing bounded in a number of hops and the number of packet replicas. FC [26] is the simplest one-copy data forwarding strategy, which enables all the nodes to route packets to the first faced adjacent node.

By relating ULRA to all these three strategies, we evaluate its efficiency. The parameters used in the simulation study are given in Table 1.

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TABLE I
Parameter Settings for The Simulation Study

Parameter	Default	Range
Number of hops	120	-
Network size (m^2)	1000	-
Packet size (KB)	500	-
Packet TTL (min)	20	-
Packet interval (s)	40	20–60
Mobility pattern	Random Walk	-
Node mobility (m/s)	0.5	0.2–0.8
Data rate (kbps)	250	-
Coverage distance (m)	100	20–180
Node buffer capacity (MB)	6	2–10
Tickets in BSW	18	-
Simulation time (hours)	5	-

The communication nodes are implemented randomly for each run and move all the nodes based on the Random Walk mobility pattern. We set the speed of the node to be a comparatively low value, for the purpose of studying the performance of ULRA with less assistance supported by node mobility. It is observed that ULRA outdoes the other routing strategies when the mobility is comparatively low, which shows that a location-based data forwarding approach might be a good solution for the network set-up where node position is relatively constant. In this work, PDR, average hop count (AHC) and overhead ratio (OR) are considered as the performance metrics and these measures are defined as follows

$$PDR = \frac{Number\ of\ packets\ delivered}{Number\ of\ packets\ created}$$

$$AHC = \frac{Number\ of\ relay\ nodes}{Number\ of\ packets\ created}$$

$$OR = \frac{Number\ of\ packets\ relayed - Number\ of\ packets\ delivered}{Number\ of\ packets\ delivered}$$

The experiments are carried out by changing the interval of packet generation, buffer size of the node, node mobility, and coverage range. First, the performances of four routing strategies are evaluated in terms of performance measures and then the stability of ULRA is analyzed by varying the simulation time and density of mobile hops. Then, the parameters that might affect the performance of ULRA are studied by varying the mobility and coverage range.

B. Results and Analysis

The packet delivery ratios of all four algorithms are given in Figure 4. From the figure we can observe that all the four algorithms have a comparatively low PDR when the packet interval is small, since that there are a large amount of generated packets that completely occupy the buffer of the node, hence causing the maximum packet discarding possibility [27]. With the increase in packet interval, the PDR of both EPI and ULRA increases. ULRA almost has the same high PDR as EPI, whereas BSW and FC exhibit poor performance than the first two algorithms. EPI and ULRA achieve maximum PDR by employing a utility-based duplication technique. The results show that the redundancy handling technique only reduces a little for packet forwarding possibility.

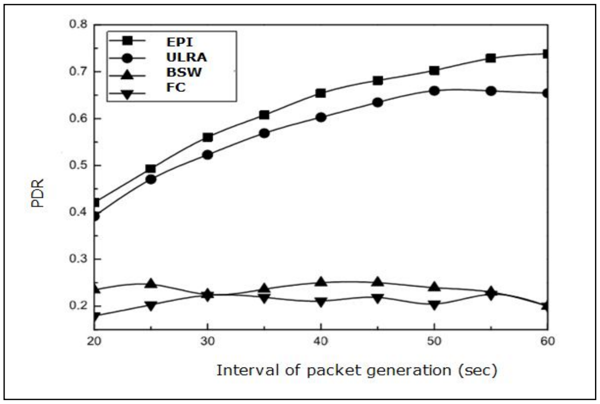

Fig.4. PDR versus Interval of packet generation

From Figure 5 we can observe that EPI has the maximum PDR when the buffer size is adequate. When the buffer dimension is around 4 MB, the PDR of ULRA is approximately equal to EPI, and both of them do well with the existing buffer capacity.

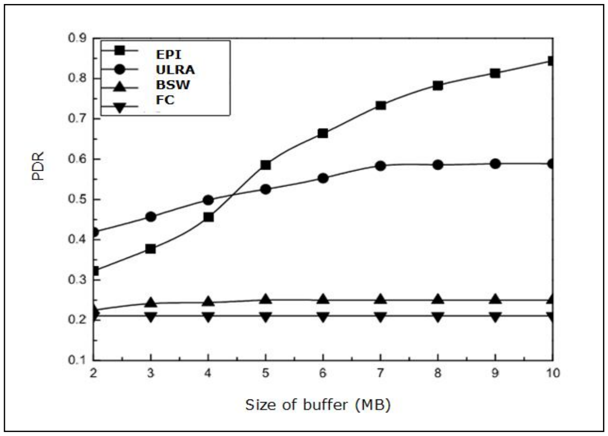

Fig.5. PDR versus the size of the buffer

Conversely, when the buffer capacity is severely limited, the PDR of ULRA is greater than that of EPI due to the exploitation of a utility-based duplication technique rather than an original one. Moreover, ULRA has a redundancy handling technique, so protecting the constrained buffer capacity. BSW and FC still have a non-optimum performance. Figure 6 displays that the PDR of all the four data forwarding approaches marginally increases with the increase in node mobility. If the mobility is comparatively low, BSW and FC do not have optimal performance. Specifically, FC uses the one-copy mechanism and hence it routes packet in a non-concurrent manner. Therefore it has poor performance.

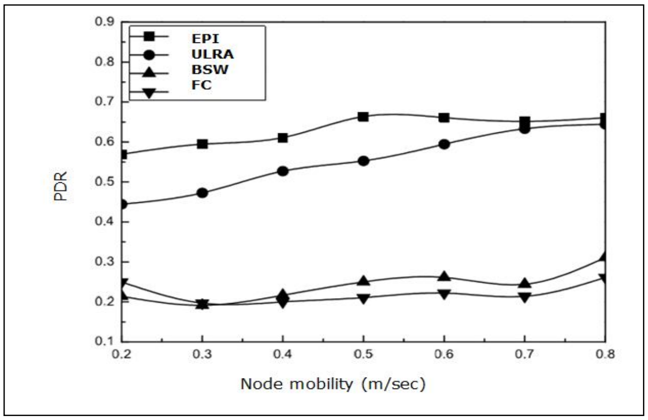

Fig.6. PDR versus node mobility

Moreover, it is observed that the multi-copy method can be considered as an effective approach for increasing the packet forwarding possibility. Figure 7 shows the PDR performance of all four algorithms against the transmission range. From the figure it is observed that all the four strategies have the minimum PDR due to limited existing links employed in the network. With the increase in the transmission range, the link contact of the entire network remains improving and the PDR of EPI and ULRA increases much more rapidly than BSW and FC. Because both approaches produce a sufficient amount of packet replicas and exploit the network resources completely.

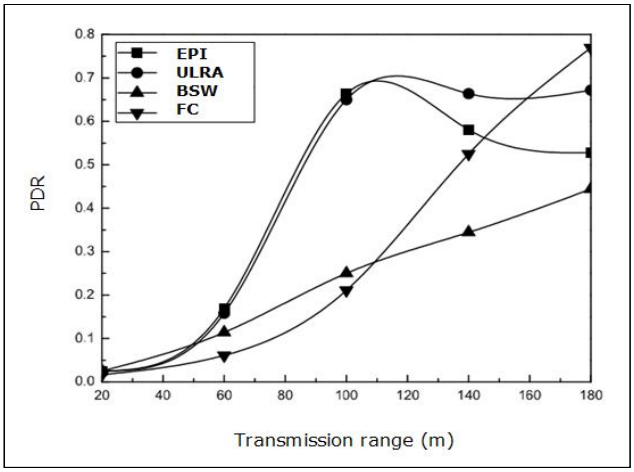

Fig.7. PDR versus transmission range

BSW realizes a reasonable performance if the link connectivity is relatively robust. By employing the technique of the single-copy data forwarding, FC achieves optimum performance in terms of minimum resource consumption. From the study, it is observed that the multi-copy approach is comparatively useful for improving the possibility of packet propagation for low node mobility. Further, ULRA has the maximum PDR as EPI and ULRA is a good choice as compared to EPI when the buffer capacity is limited.

Figure 8 shows the performance of the four algorithms in terms of AHC. The minimum AHC indicates a more competent relay procedure. But, things become very different when considering BSW, for that the higher AHC per packet is bounded by the particular network topology. As we fix the tickets is 18 for the BSW algorithm, the upper bound of the node count for every packet is smaller than $\lceil log_2 18 \rceil = 5$. Consequently, we relate the other three approaches in the AHC assessment. From Figures 8 - 11, it is observed that ULRA has the minimum AHC among the three algorithms due to location-based relay hop selection. Hence, the packet is transferred decisively toward the receiver. In the meantime, when the network capacity is reasonably adequate, the performance of EPI is similar to ULRA. However, in our experiments, the buffer capacity is constantly fixed in a limited range similar to actual network implementations. Therefore, the recurrent packet loss adds extra relay nodes into the data forwarding task. Besides, we can observe that FC always has the maximum AHC owing to its inherent single-copy and original relay node selection strategies.

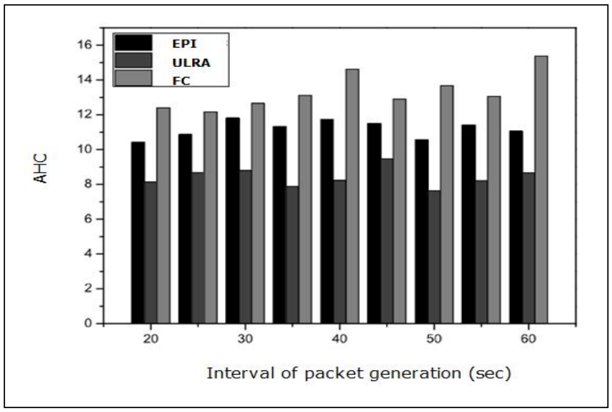

Fig.8. AHC versus Interval of packet generation

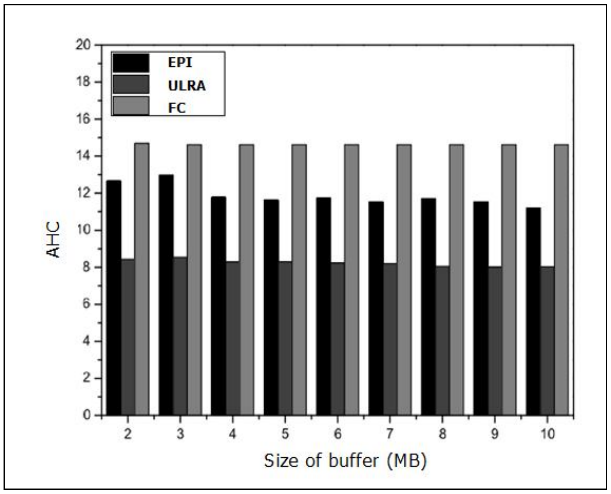

Fig.9. AHC versus size of the buffer

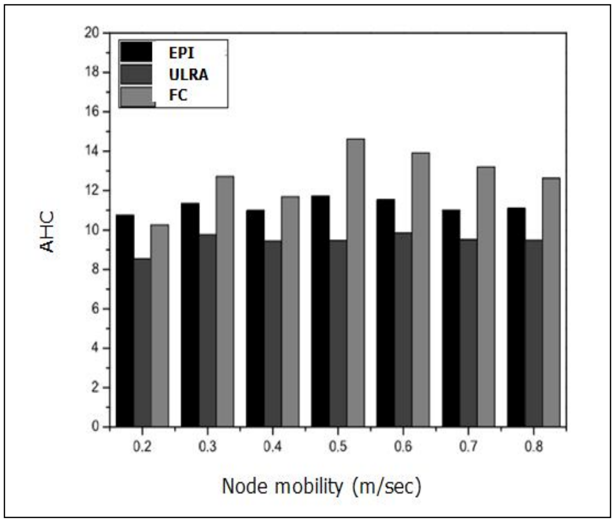

Fig.10. AHC versus node mobility

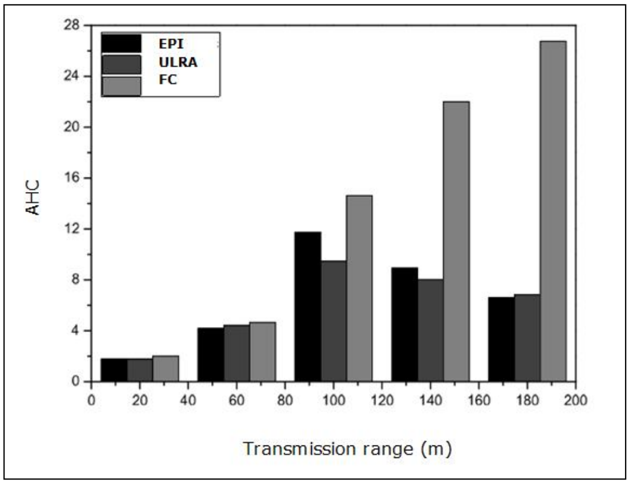

Fig.11. AHC versus transmission range

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The performance of all the four routing algorithms in terms of the overhead ratio is shown in Figures 12 - 15. The overhead ratio is a measure that reveals the performance of packet propagation. The direct delivery has a zero-overhead ratio as the number of packets relayed is always equal to the number of packets delivered [28].

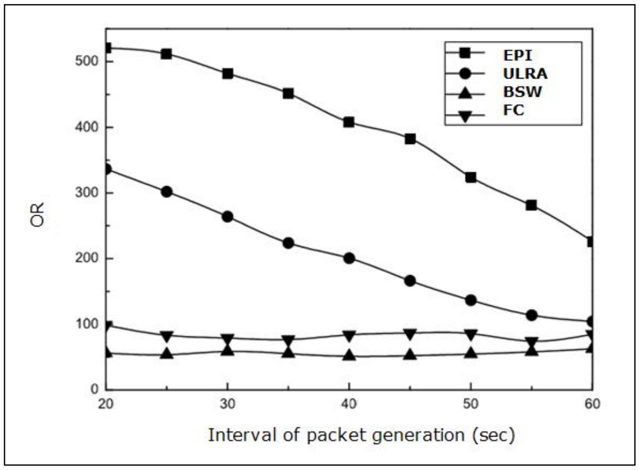

Fig.12. Overhead ratio versus Interval of packet generation

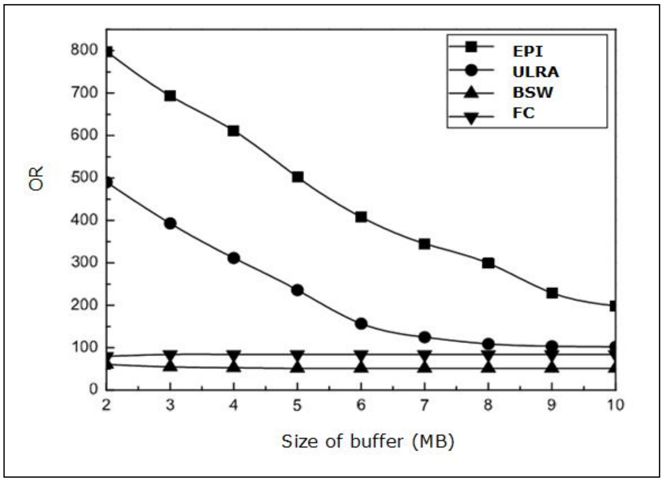

Fig.13. Overhead ratio versus the size of node buffer

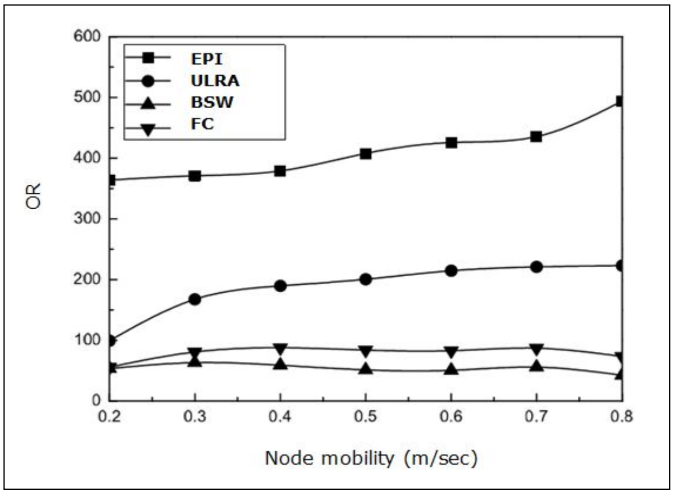

Fig.14. Overhead ratio versus node mobility

In the BSW algorithm, a similar propagation approach is implemented in the "wait" phase. However, the "spray" phase confines the higher amount of replicas of the packet. Consequently, it can be concluded that spray and wait processes should have a less overhead ratio. FC is a single copy data forwarding algorithm and exploits record vector to evade network loops, so $umber\ of\ packets\ forwarded \leq |maximum\ HC| \times Number\ of\ packets\ produced$. The overhead ratio of FC can be calculated from this inequality and the result shows that its overhead ratio is as low as that of BSW. From Figures 12 – 15, we can observe that ULRA has the maximum overhead ratio than EPI, BSW, and FC.

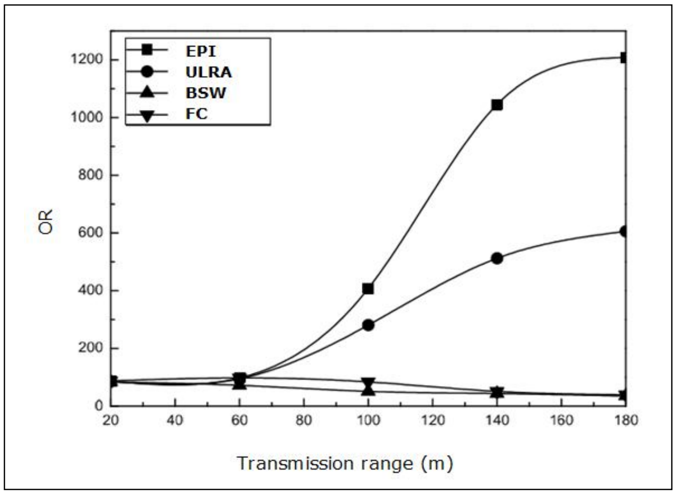

Fig.15. Overhead ratio versus transmission range

VII. CONCLUSION

In this work, a Utility-based Location-aware Routing Algorithm is designed for DT-MANETs. We formulate a mathematical framework to derive the utility function of the nodes in order to implement a controlled packet duplication technique. For decreasing the overhead ratio due to packet flooding, we implement a criterion to assess the rate of packet duplication. Finally, a packet redundancy controlling technique is added to this algorithm. Extensive simulation studies have been carried out and the results reveal that the proposed ULRA outdoes the other existing data forwarding algorithms like Binary spray and wait, Epidemic, and FirstContact in terms of packet delivery ratio (PDR) and average hop count (AHC) with an acceptable overhead ratio in delay-tolerant network scenario.

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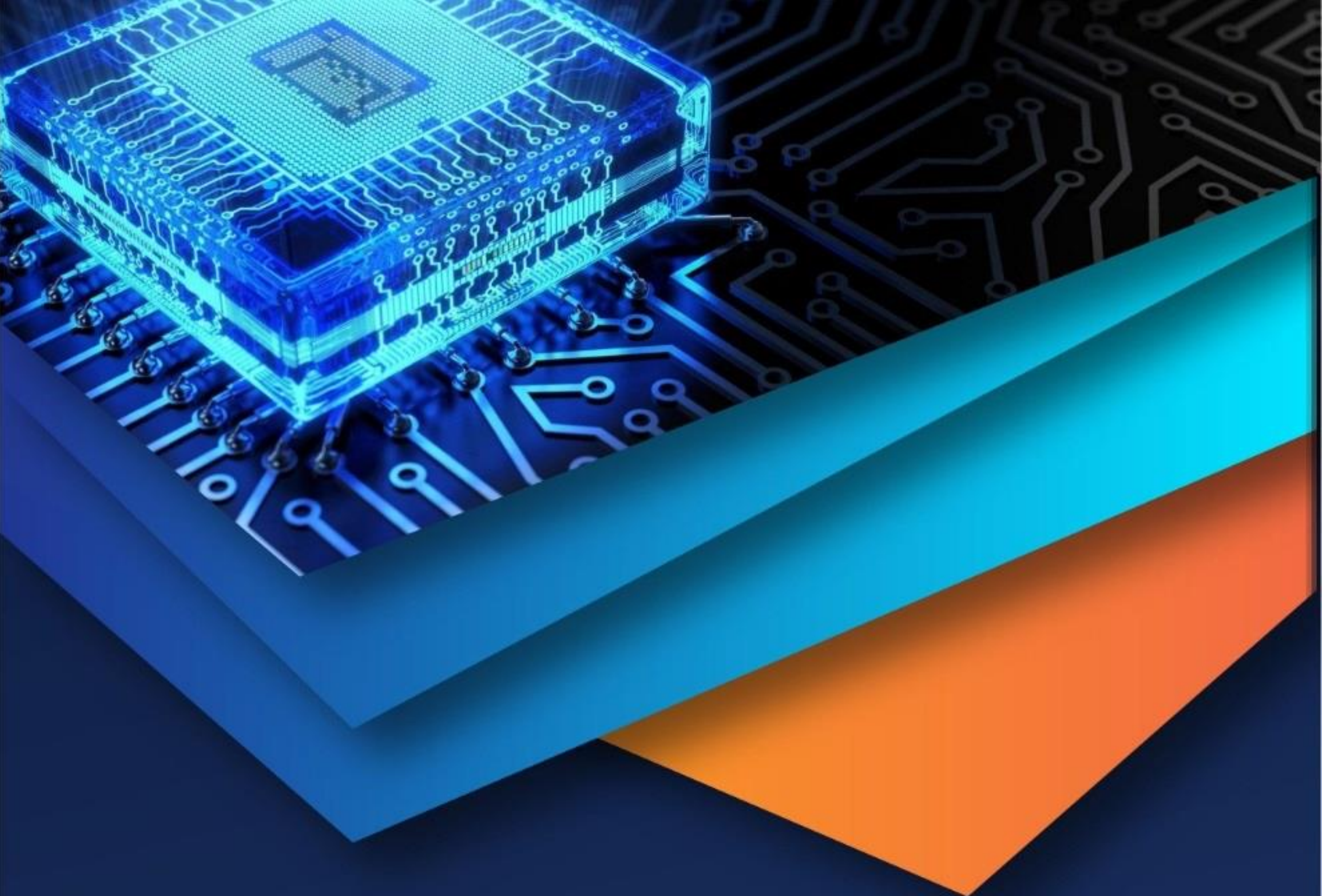

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