Location-Based Utilization for Unidirectional Links in MANETs

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***Abstract*—Heterogeneous Mobile Ad hoc Network(HMANET) comprises different nodes with different capabilities. Hence, transmission and receiving capabilities are different. This causes unidirectionality problem. Avoidances is the most used strategy in researches to route data, e.g., Blacklist. In this paper, we proposed a strategy for on-demand routing protocols to detect unidirectional link and resolve it in timely fashion. This strategy is based on utilizing locations of nodes to filter and cache incoming RREQ packets to find reliable path to destination in the existence of unidirectional links. Simulation results show that our strategy outperforms Blacklist strategy in homogeneous and heterogeneous MANET.**

***Keywords*-MANET; routing protocol; unidirectional link; AODV;**

I. INTRODUCTION

Mobile Ad hoc NETworks (MANETs) are networks of wireless mobile nodes that have no fixed structure. Each node may act either as a router or an end-user node. In MANETs, node heterogeneity is one of the main network conditions that significantly affects the performance of the routing protocols [1]. Although most current MANET routing protocols assume homogeneous networking conditions where all nodes have the same capabilities and resources, in real life MANET may consist of heterogeneous nodes that have different capabilities and resources like military (battlefield) networks and rescue operations systems. Hence, the transmission reachability and quality of data reception among nodes are different. This can create a problem of unidirectional link between any two nodes. Unidirectional link problem is defined, where node B has a higher transmission range than node A (see Figure 1). Therefore B includes A in its transmission range while A does not include B. Consequently, the link between B and A is unidirectional from B to A only. However, most reactive routing protocols in MANET, assumes all links between two nodes are bidirectional, which gives incorrect routing information. Therefore, this incorrect information creates large delay and packet loss in heterogeneous networking [1]. In [2], suggested that unidirectional link can be utilised to increase packet delivery and hence increase reliability. In this paper, we investigate this issue by proposing a strategy that is Location-Based Utilization (LBU) to detect and utilise unidirectional links in route discovery process of on-demand routing protocols. This strategy utilizes locations of forwarding nodes of RREQ packets to resolve unidirectionality problem. All received RREQ packets are cacheed and filtered before they are processed or dropped.

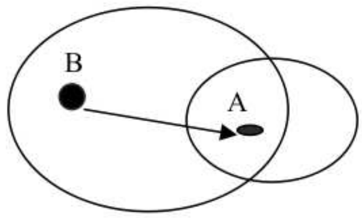

Figure 1: Unidirectional Link

The rest of this paper is organised as follows. Section II presents related works. In section III, the proposed strategy is described. The simulation parameters and scenarios that are used to investigate the performance of the proposed strategy are given in section IV. Then the results of the simulation study are summarised in section V. Section VI concludes the paper.

II. RELATED WORK

The common approaches to detect unidirectional link in MANETs are via MAC layer or network layer or both. Two way handshake Request-To-Send (RTS) and Clear-To-Send (CTS) is the common approach in MAC to avoid unidirectional links [3]. Network layer approaches use feedback mechanism either to detect and avoid unidirectional link or utilise it to improve routing processes. In heterogeneous MANET (HMANET), the issue of unidirectional links has been investigated. Different strategies have been developed to enhance the performance of routing protocols in presence of unidirectional links [2][3][4][5][6][7]. In AODV-Blacklist [8], when destination node sends RREP (or any node relays RREP) to next hop in the reserve path, it waits for ACK of receiving RREP. If it fails to receive ACK because of unidirectional link , then next hop is cached in blacklist. This means that when the node receives RREQ for second time from the node in blacklist, the packet will be dropped. AODV-BlackList avoids unidirectional link but with cost of high load of control overheads. Also, delay is increasing because source node may consume all RREQ_RETRIES to find path to destination.

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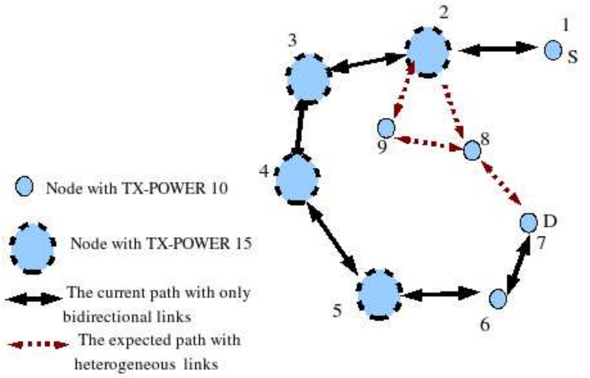

Figure 2: Routing through bidirectional links.

In [9], Early Unidirectionality Detection and Avoidance (EUDA) mechanism is proposed to detect and avoid unidirectional link in ad hoc network. This mechanism appends the forwarding node location only in RREQ packet to detect the unidirectionality. When node receives RREQ packet for the first time, it compares the transmission range to the distance to forwarding node using location information. If there is unidirectional link then the packet is dropped without any processing. This mechanism is used only to detect and avoid unidirectionality of links without utilizing it. In the worst case where there is no bidirectional route, all RREQ_RETRIES are consumed. Consequently, the control overheads increases and the packet delivery ratio decreases as the path to destination is not establishes. In [2], a powerful and simple strategy has been suggested to resolve unidirectional links in AODV-Blacklist. This strategy is developed to resolve the problem of unidirectional links by rebroadcasting RREP to first hop nodes as unidirectional link is detected and no nodes are blocked. To avoid insufficient exchanging ACKs during RREP rebroadcasting, TTL is set to 1. Also source node id and destination id are cached to avoid duplications of the same RREP packets. The simulation result shows improvement of AODV performance in term of packet delivery ratio and control overhead.

III. Description

In LBU, we use the concept of detecting unidirectional link using location information as in [9]. However, LBU differs from EUDA in [9] by utilizing the unidirectionality to improve routing process in on-demend routing protocols using 2 hops nodes locations . In Figure 2, there are different nodes with different transmission powers. Source node 1 initiates route discovery to find path to node 7. Node 2 will rebroadcasts the RREQ packet. Node 8 will receive the packet and has path to destination 7. However, it fails unicast its RREP to node 2 because of unidirectional link. As receiving a duplicated RREQ packet is ignored, then received RREQ from node 9 is ignored in node 8. In AODV-BlackList, rebroadcasting will continue until the destination is found or RREQ retries limit is reached. In Figure 2, node 8 will consider node 2 is unreachable and then inserts node 2 in its blacklist. Therefore, when node 8 receives any packet from node 2, it will be ignored. Source node 1 will have long path $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7$ to reach destination 7, which 3-hop far. This long path can degrade the reliability of network and delay data comparing to expected path $1 \rightarrow 2 \rightarrow 9 \rightarrow 8 \rightarrow 7$. One of the strategy to resolve this problem, when node 8 detects unidirectional link to previous forwarding node of RREQ, it rebroadcasts its RREP to its first hop neighbours. As node 9 hears rebroadcasting of RREQ and RREP packets, it will unicast RREP packet to node 2. This idea is similar to [2] (see more details in related work section). However, this may create large number of paths and increases control overheads, which may degrade the network performance. Instead of rebroadcasting RREP as in [2], each node (e.g., node 8) starts caching all RREQ packets of the same source and flood id to resolve any unidirectional links. The description of how to detect and utilize unidirectional links are described in below subsections.

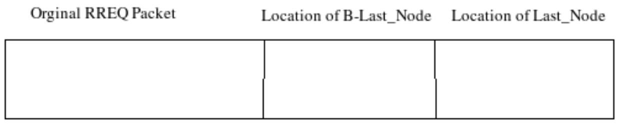

Figure 3: RREQ packet formate

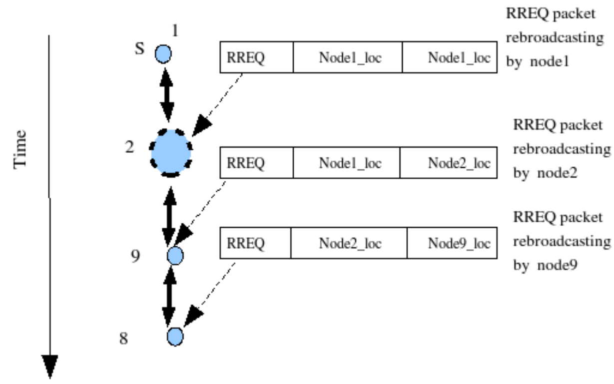

Figure 4: RREQ packet traversing

A. How is the unidirectionality detected?

Each RREQ packet will have two more fields, see Figure 3. These two fields carry locations of last two hops nodes, see Figure 4. When node receives RREQ packet,

1) The node calculates the distance to the forwarding

source id	flood id	forwarding node address	B_last_loc	last_loc	isUnidirLink

Figure 5: Seen_Data_Table formate

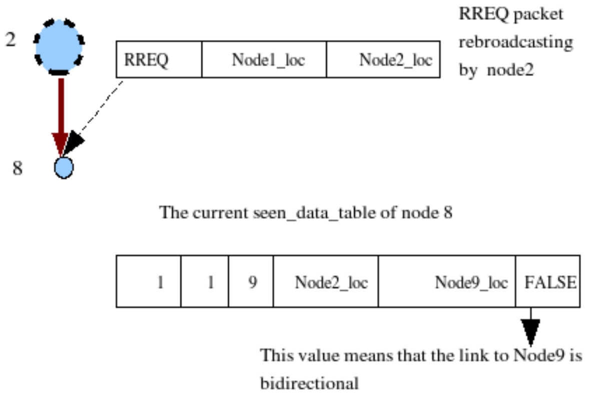

Figure 6: Incoming RREQ packet through unidirectional link

node by using locations information in RREQ packet.
$curr_{loc}$=(x_{curr}, y_{curr})
$lastloc$=$getLastLoc(Recived\_RREQ\_Packet)$
$Distance$=$\sqrt{(x_{curr} - x_{lastloc})^2 + (y_{curr} - y_{lastloc})^2}$

2) The node calculates its transmission range. In QualNet, the function PHY_PropagationRange calculates an estimated radio range for a given interface.

Transmission_Range_CurrNode=
PHY_PropagationRange(node, 0, FALSE)

3) The node compares its transmission range to the distance in step1:
if (Distance > Transmission_Range_CurrNode)
link is unidirectional
else
link is bidirectional

B. How is the unidirectional link fixed?

Unidirectional link here means that the current node can not reach the forwarding node while the forwarding node can reach it. Instead of dropping all RREQ packets of the same flood id and source id, the node caches the information in RREQ packet to detects and resolve the unidirectionality during the flooding of the same RREQ packet. These information is stored in a table called "seen_data_table",

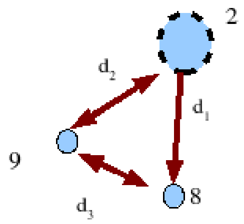

Figure 7: The triangle inequality in distance between nodes

which is similar to seenTable in AODV. seenTable is used to avoid duplication of the same RREQ packet where it keeps the id of source and flood number of the first incoming RREQ packet. seen_data_table is used to resolve unidirectionality. The formate of this table is shown in Figure 5. Each node receives RREQ packet, detects the type of the link. Each type of link has different process as following:
Unidirectional Link:
If the link is unidirectional (see Figure 6) then node searches seen_data_table for a record, which can resolve the problem where:

1) source id and flooding number are the same as the current received RREQ packet. This guarantee the freshens of nodes locations information and updates unidirectionality situation in timely fashion within neighbourhoods nodes.
2) The value of isUnidiLink is false, which means the forwarded node has bidirectional link to the current node.
3) Location value of B_last_loc field of the record is same as Location of Last_Node in received RREQ packet. In Figure 6, node 8 looks in its seen_data_table for a node that can reach the forwarding node of the current RREQ packet.
4) To avoid long path and replace unidirectional link with only 2-hop link, node is selected based on its location to form triangle inequality with current and forwarding node . In other words, we prefer the situation where the length of unidirectional link is less than the sum of lengths of other 2 links as shown in Figure 7 where $d1 < d2+d3$ and di is the distance between node pair of nodes.

If a record is found that satisfies above conditions then the "forwarding node address" in seen_data_table is used as next hop to the current forwarding node of the current received RREQ packet. Otherwise, information about the RREQ packet and unidirectionality are inserted in seen_data_table. Also if the received RREQ packet has not been process yet, then the packet will be processed after unidirectional link is fixed where node 9 will be the source of the packet. To utilise

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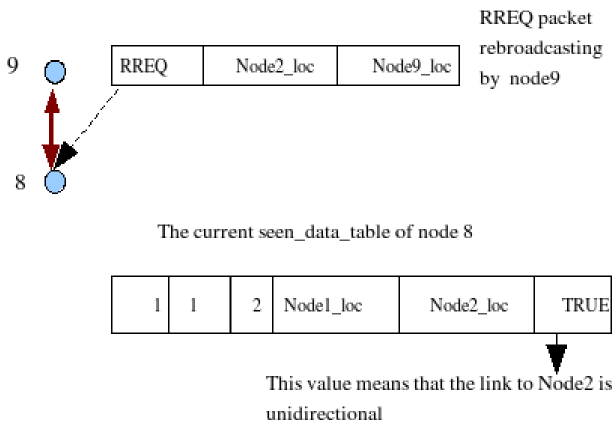

Figure 8: Incoming RREQ packet through bidirectional link

node memory, each record that have been used to solve unidirectionality in seen_data_table is deleted. Therefore, the record about node 9 in seen_data_table is deleted because it has already been used to solve the unidirectional link between node 8 and node 2. Consequently, as this problem has been solved, it is inefficient to insert information about node 2 in seen_data_table.

Bidirectional Link:

If the link between forwarding node of the current received RREQ packet is bidirectional (see Figure 8) then information of this packet is used to solve any unidirectional link in seen_data_table if:

1) Conditions 1 and 4 are satisfied as above described.
2) The value of isUnidiLink is true, which means the forwarded node has unidirectional link to the current node.
3) Location value of last_loc of the record is same as location of B_Last_Node in received RREQ packet. In Figure 8, node 8 looks for a node where the forwarding node of the current RREQ packet can reach it while node 8 can't.

If a record is found that satisfies above conditions then the address of current forwarding node is used as next hop to the forwarded node of the recorded packet. In Figure 8, node 9 will be the next hop to node 2. Otherwise, information about the RREQ packet and bidirectionality are inserted in seen_data_table to be used to solve any incoming unidirectional link. To utilise node memory, each record of the unidirectionality that has been solved seen_data_table is deleted. Therefore, the record about node 2 in seen_data_table is deleted. Each node receives second flood of the same RREQ packet will delete all records about the first flood in the seen_data_table.

IV. Simulation Models

The performance of LBU for unidirectional link is compared to BlackList and RTS/CTS strategy. AODV[8] and OTRP[10] are used as routing protocols. OTRP combines the idea of hop-by-hop routing such as AODV with an efficient route discovery algorithm called Tree-based Optimized Flooding (TOF) to improve scalability of Ad hoc networks when there is no previous knowledge about the destination. To achieve this in OTRP, route discovery overheads are minimized by selectively flooding the network through a limited set of nodes, referred to as branching-nodes. Those protocols have been simulated using the QualNet4.5 package. The simulations ran for 200s with 100 different values of seeds. Nodes density of 100 were randomly distributed on 1500 x 1500 grids. Random way point was used as mobility model with five different values of pause times that were 0s, 50s, 100s, 150s, and 200s. Speeds of the nodes were varied from 0 to 20 m/s. The simulated protocols have been evaluated with 10 data traffic flows. Constant Bite Rate (CBR) was used to generate data traffic at 4 packets per second. Each packet was 512 bytes. IEEE 802.11b was used as MAC protocol with constant transmission bandwidth of 2Mbps. The strategy has been evaluated in homogeneous and heterogeneous MANET where transmission power of all node was 15dbm in homogeneous MANET. In heterogeneous MANET, there are two different types of nodes where 50% of nodes have transmission powers as 15dbm and other 50% has transmission powers as 10dbm. Packet Delivery Ratio (PDR), End-to-End Delay, and Normalized Control Overhead (NCO) were used as performance metrics of each protocol. In addition, we introduce new metric called Retried Ratio (Ret_Ratio), which is ratio of the number of RREQ packets retried to the number of RREQ packets initiated. This ratio calculates the number of RREQ retries that has been consumed to find routes. As this ratio is high indicating that more RREQ retries have been consumed to find path to destination. Confidence interval of 95% is used to scale the data.

V. Results

LBU is applied on top of AODV and OTRP where Blacklist and RTS/CTS are disabled, see (Figure 9- Figure 10).

The problem of the unidirectionality affects routing process of on demand routing protocols, where the forwarding node of the RREQ may have unidirectional links to its neighbours nodes. In other words, rebroadcasting nodes stores incorrect information about the first hop, which is unreachable because of unidirectionality. Consequently, source node does not received RREP packet and then the route may not found. This will increase the number of route discovery occurrences and consequently increases Ret_Ratio.

Blacklist_RTS/CTS strategy with AODV and OTRP detect unidirectional links after it occurs then avoids unidirectional links without solving. This strategy may

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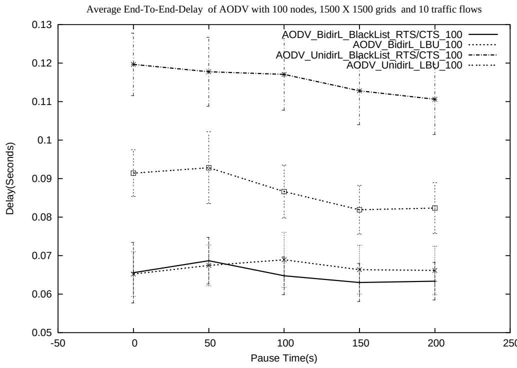
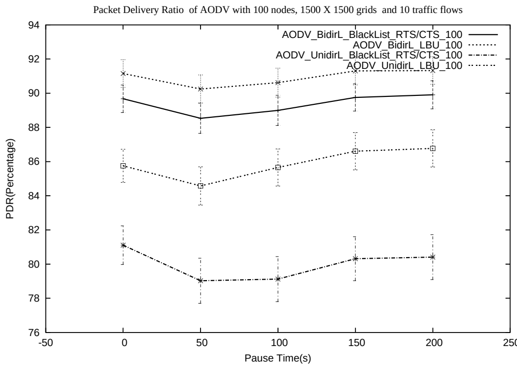
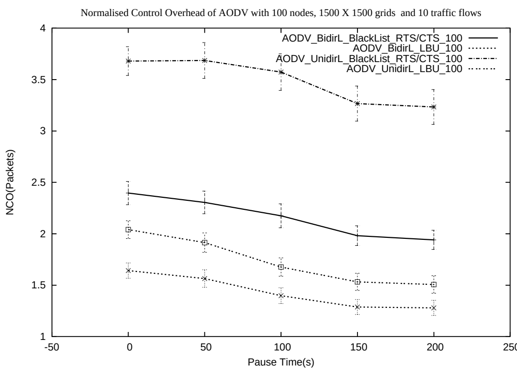


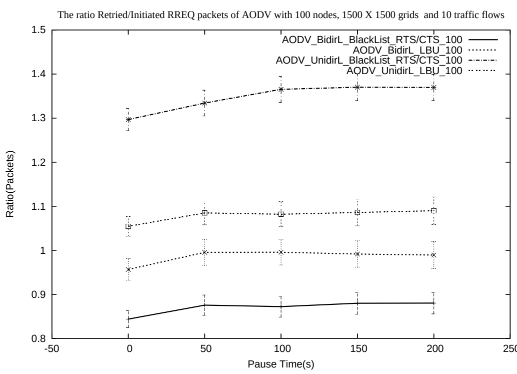
(a) Delay



(b) PDR

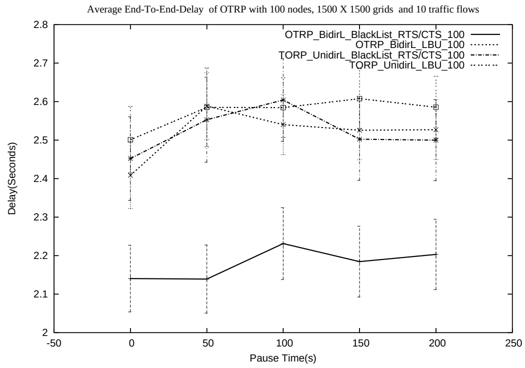


(c) OH

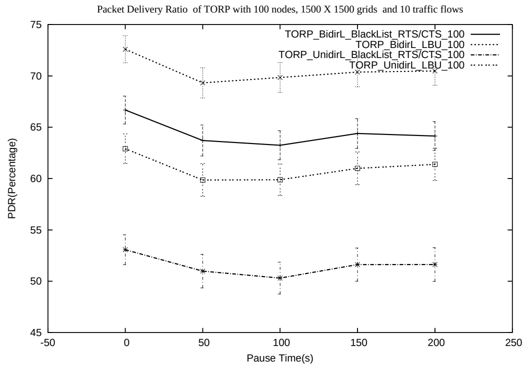


(d) Ret

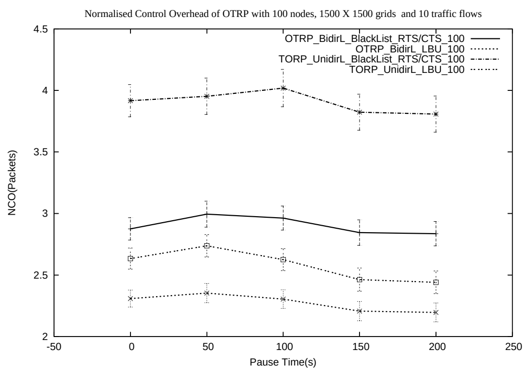
Figure 9: compare LBU to BlackList_CTS/RTS under both bidirectional and unidirectional links with AODV and 100 nodes



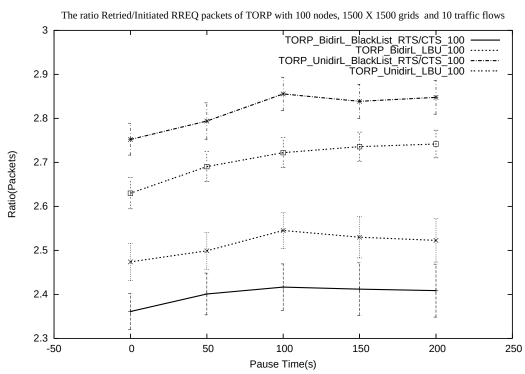
(a) Delay



(b) PDR



(c) OH



(d) Ret

Figure 10: compare LBU to BlackList_CTS/RTS both bidirectional and unidirectional links with OTRP and 100 nodes

work with homogeneous MANET where nodes have similar transmission power and the occurrence of unidirectionality is low. However, LBU outperforms Blacklist_RTS/CTS strategy in term of PDR and NCO under both unidirectional and bidirectional links, see(Figure 9(b-c) and Figure 10(b-c)). This is because LBU strategy supports AODV and OTRP by filtering incoming RREQ packets where not all incoming packets are processed. In other words, incorrect information about first hop neighbours is avoided using LBU. Moreover, our strategy provides sufficient routing information about 2-hop neighbours by solving unidirectional links. In homogeneous MANET where bidirectional links are assumed to exist between any pair of nodes, LBU performs more efficiently than Blacklist_RTS/CTS. AODV_LBU increases PDR by 2% and (see Figure 9(b)) while OTRP_LBU increases PDR by 10% (see Figure 10(b)). Although locations of last 2 hops are attached with RREQ packet in LBU, NCO is improved comparing to Blacklist_RTS/CTS as shown in Figure 9(c) and Figure 10(c) where AODV_LBU and OTRP_LBU reduces NCO by 0.8. However, delay with LBU is higher than Blacklist_RTS/CTS for both protocols where the number of unidirectional link is low under bidirectional links, as shown in (Figure 9(a) and Figure 10(a)) . This is because if unidirectional link is exist between forwarding node and its relay, this will reduce rebroadcasting area, which may increase Ret_Ratio and then consequently increases delay as shown in Figure 9(d) and Figure 10(d). However, detecting unidirectional links and resolving it immediately can guarantee a reliable path to route data, which explains the improvement in PDR and NCO. In heterogeneous MANET, nodes with different transmission are exist. Therefore, high percentage of unidirectional links occur. In both protocols, LBU resolves this problem without any increasing of NCO or delay comparing to Blacklist_RTS/CTS strategy or other strategies as you can see in Figure 9 and Figure 10. This is because LBU detects and immediately resolves any unidirectional links that may occur in the first RREQ_RETRIAL (see Figure 9-(d) and Figure 10-(d)) comparing to Blacklist strategy where unidirectional links are avoided and some nodes are blocked. Therefore, AODV_Blacklist_RTS/CTS and OTRP_Blacklist_RTS/CTS consume nearly 2 and 3 respectively out of 3 RREQ_RETRIALS to find bidirectional paths to route the data. This will increase delay as shown in Figure 10(a). Unlike AODV, the number of rebroadcasting nodes is eliminated in OTRP, which reduce rebroadcasting area and hence OTRP requires more RREQ_RETRIAL. Therefore, generally the delay with OTRP is sightly higher than AODV but OTRP_LBU has constant delay. As RTS/CTS is used too, Blacklist_RTS/CTS consequently increase NCO by 1.5 and decrease PDR by at least 6% as in Figure 9-(b and c) and Figure 10-(b and c) respectively.

VI. Conclusion

In this paper, LBU is proposed to resolve unidirectional link in MANET. Instead of dropping duplicated RREQ packet, each incoming RREQ packet is used to filter routing information of neighbours under unidirectionality. LBU and Blacklist_RTS/CTS are applied on top of AODV and OTRP. LBU outperforms Blacklist with RTS/CTS strategies under homogeneous and heterogeneous MANET in term of PDR and NCO, and without increasing delay.

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