ISSN:2249-5789
Shobha Rani et al , International Journal of Computer Science & Communication Networks,Vol 3(2), 126-133

E-CARP: efficient-Cross Layer Congestion Control Adaptive Routing Protocol for Mobile Ad hoc Networks in Constrained Environment

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Abstract

Mobile Ad hoc Networks (MANETs) shows unexpected behavior when multiple data streams with heavy traffic load such as multimedia data and data is sent to common destination. The main reason for packet loss in mobile ad hoc networks is due to congestion. In the current design, the routing protocols are not congestion adaptive. The way in which the congestion is handled results in longer delay and more packet loss. When a new route is needed the routing protocols take significant overhead in finding it. In this paper we propose an adaptive congestion control algorithm using cross layer design, which out-performs even during constrained situation. For analyzing the performance we have chosen four popular routing protocols such as AODV, DSR, DSDV and TORA. We also observe through simulation in NS-2 that AODV out-performs other routing protocols in normal situation and DSR out-performs in constraint environment. We strongly argue that routing should not only be aware of but also be adaptive to network congestion.

Keywords: Mobile Ad hoc Networks, routing, congestion control, performance, constraint situation

1. Introduction

Ad hoc wireless networks are composed of mobile stations communicating solely through wireless channels [1, 2]. Ad hoc wireless networks are expected to play an increasingly important role in future civilian and military setting. Ad hoc networks are useful for providing communication support where no fixed infrastructure exists or the deployment of a fixed infrastructure is not economically profitable, and movement of communicating parties is allowed.

In ad hoc wireless networks, a message sent by a mobile may be received simultaneously by all of its *neighbors*. Messages directed to mobiles not within the sender's transmission range must be forwarded by neighbors, which thus act as *routers*. Due to mobility it is not possible to establish fixed paths for message delivery through the network. Therefore, a number of routing protocols have been proposed for ad hoc wireless networks [3, 4, 5, 6, 7, 8, 9, 10], derived from *distance-vector* [11] or *link-state* [12,13] routing algorithms. Such protocols are classified as *proactive* or *reactive*, depending on whether they keep routes continuously updated, or whether they react on demand. This approach is not suitable for large networks because many unused routes still need to be maintained and the periodic updating may incur overwhelming processing and communication overhead.

The on-demand approach is more efficient in that a route is discovered only when needed for a transmission and released when the transmission no longer takes place. However, when a link is disconnected due to failure or node mobility, which occurs often in MANETs, the delay and overhead due to new route establishment may be significant. To address this problem, multiple paths to the destination may be used as in multipath routing protocols ([14], [15], [16], [17]). The alternative path can be found immediately in case the existing is broken. The multipath has lot of overhead in maintaining the multiple paths.

The routing protocols can also be categorized based on congestion-adaptive versus congestion-unadaptive routing. The congestion unawareness in routing in MANETs may lead to the following issues.
Maximum delay to find a new route: Traditional routing protocol takes maximum time for congestion to be detected by the congestion control mechanism. In severe congestion situations, it may be better to use a new route. The problem with an on-demand routing protocol is the delay it takes to search for the new route.
Huge routing overhead: In case a new route is needed, it takes processing and communication effort to discover it. If multi-

ISSN:2249-5789
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path routing is used, though an alternate route is readily found, it takes effort to maintain multiple paths.

Heavy packet loss: Many packets may have already been lost by the time congestion is detected. A typical congestion control solution will try to reduce the traffic load, either by decreasing the sending rate at the sender or dropping packets at the intermediate nodes or doing both. The consequence is a high packet loss rate or a small throughput at the receiver.

The above problems become more visible in large-scale transmission of traffic intensive data such as multimedia data, where congestion is more probable and the negative impact of packet loss on the service quality is more of significance. Our proposed Efficient Congestion Control Adaptive Routing Algorithm (e-CARA) protocol tries to prevent congestion from occurring in the first place and be adaptive should a congestion occur. The ns-2 [18] simulation results show that e-CARA significantly improves the packet loss rate and end-to-end delay while enjoying small protocol overhead and high-energy efficiency as compared to AODV [19], DSR [20], DSDV [21] and TORA [22].

The rest of the paper is organized as follows. In the following section II, we briefly review AODV, DSR, DSDV and DSR Routing Protocols. In section III, we present detailed observation in constrained environment. We present the algorithms for e-CARA protocol in Section IV. The performance study and result analysis is discussed in Section V. The paper is concluded in Section VI with directions to the future work.

II. Review of Routing Protocols

A. AODV

AODV (Ad hoc On-demand Distance Vector) is a dynamic, self-starting, multi-hop on-demand routing protocol for mobile wireless ad hoc networks. AODV discovers paths without source routing and maintains table instance of route cache. This is loop free and uses destination sequence numbers. The mobile nodes to respond to link breakages, changes in network topology in a timely manner. AODV also maintains active routes only while they are in use and delete the stale (unused) route. AODV performs Route Discovery using control messages Route Request (RREQ) and Route Reply (RREP) whenever node wishes to send packet to destination. The source node in network broadcasts RREQs to neighbors and use an expanding ring search technique. The forward path sets up in intermediate nodes in its routing table with a lifetime association using RREP. When a route is broken, either destination or intermediate node moves RERR to the source node. When RERR is received, source node reinitiate discovery is still needed.

B. DSR

DSR (Dynamic Source Routing) is reactive, simple and efficient routing protocol for multi-hop wireless ad hoc networks of mobile nodes. DSR uses source routing and protocol is composed of two main mechanisms: Route Discovery and Route Maintenance, which works together entirely, on-loop-free routing, rapid discovery when routes in the network change, designed for mobile ad hoc networks of up to about two hundred nodes and to work well even with high rates of mobility. The source route is needed when some nodes originate a new packet destined for some node by searching its route cache or initiating route discovery using RREQ and RREP messages. On detecting the break, DSR sends RERR message to source for new route.

C. DSDV

The Destination-Sequenced Distance-Vector (DSDV) Routing Algorithm is based on the idea of the classical Bellman-Ford Routing Algorithm with certain improvements. Every mobile station maintains a routing table that lists all available destinations, the number of hops to reach the destination and the sequence number assigned by the destination node. The sequence number is used to distinguish stale routes from new ones and thus avoid the formation of loops. The stations periodically transmit their routing tables to their immediate neighbors. A station also transmits its routing table if a significant change has occurred in its table from the last update sent. So, the update is both time-driven and event-driven.

The routing table updates can be sent in two ways: - a "full dump" or an incremental update. A full dump sends the full routing table to the neighbors and could span many packets whereas in an incremental update only those entries from the routing table are sent that has a metric change since the last update and it must fit in a packet. If there is space in the incremental update packet then those entries may be included whose sequence number has changed. When the network is relatively stable, incremental updates are sent to avoid extra traffic and full dump are relatively infrequent. In a fast-changing network, incremental packets can grow big so full dumps will be more frequent

D. TORA

The Temporally-Ordered Routing Algorithm (TORA) is “an adaptive routing protocol for multi-hop networks”. TORA is a distributed algorithm so that routers only need to maintain knowledge about their neighbors. TORA also maintains states on a per destination basis like other distance-vector algorithms. It uses a mix of reactive and proactive routing. Sources initiate route requests in a reactive mode. At the same time, selected destinations may start proactive operations to build traditional routing tables. Usually, routes to these destinations may be consistently or frequently required, such as routes to gateways or servers. TORA supports multiple path

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routing. It is said that TORA minimizes the communication overhead associated with adapting to network topology changes. The reason is that TORA keeps multiple paths and it does not need to discover a new route when the network topology changes unless all routes in the local route cache fail. Hence, the trade off is that since multiple paths are used, routes may not always be the shortest ones.

TORA uses the concept of *height* associated with a certain destination to describe the routing metric used by routers. Like water flows in pipes, routers with higher heights may forward packet flows to neighbors with lower heights. Note that since heights for routers are associated with particular destinations, the paths to forward packets are also associated with the corresponding destinations. In networks using TORA, an independent copy of TORA runs for each possible destination. So for different destinations, routers may have different heights and links can have different directions.

III. Observed Problem in Constrained Situation

The experiments are conducted with six CBR traffic sources sessions between common destination using AODV, DSR, DSDV and TORA. We have considered three performance metrics such as Packet Delivery Ratio, Average End-to-End Delay and Routing Overhead. In normal case AODV outperforms better than other three routing protocols. The TORA performs better than DSDV. The Figure 1 shows the performance comparison for the simulation setup given in section- V.

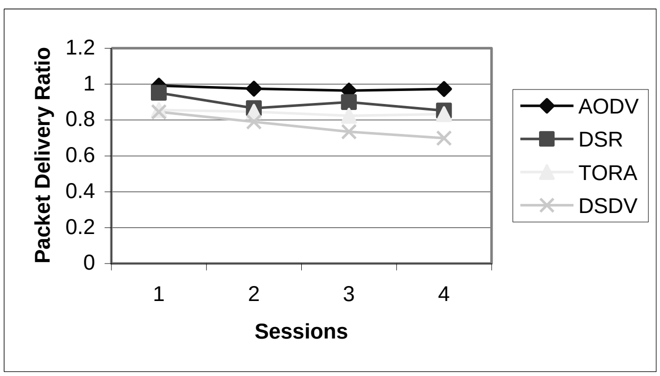

Figure 1. Performance of Routing Protocols in Normal Situation

But under constraint situation the same routing protocols behaves differently. With the six CBR traffic sources to a common destination, AODV suffers degradation up to 35% whereas DSR suffers only 10% compared to normal situation. TORA suffers degradation of 45% whereas DSDV suffers only 15%. On comparing their performances, it was observed that DSR performs better than other three routing protocols.
The main reason for performance degradation in packet delivery ratio is due to packet drops by the routing algorithm after being failed to transfer the data in the active routes. There are several reasons for packet drops such as network partitioning, link break, collision and congestion in the ad hoc networks. The main important property of routing algorithm is quick link recovery through efficient route maintenance. Therefore the DSR routing protocol has fast reaction for link recovery and finds alternative path (during congestion) in compared with AODV and other routing protocols in the given situation. This is shown in the Figure 2.

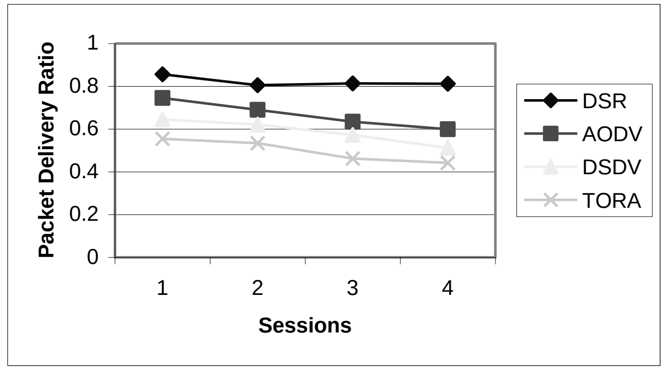

Figure 2. Performance of Routing Protocols in Constraint Situation

AODV keeps only the active and removes the stale ones. Therefore, unavailability of the alternate routes leads to route discovery by the source node. The congestion will be high when multiple CBR sources send data to a single destination. In AODV, the intermediate nodes are unable to send the data packets, link break situation perceived by AODV sends route error of finding new route through source will result in packet drops resulting in degradation of packet delivery ratio, increase in Average End-to-End delay and increase in Routing Overhead. In DSR, the routes caches have more alternative routes and in the constrained environment when most of the routes are fresh, therefore the route repair is localized. DSR also has more provision of more than one mechanism for local route repairs such as replying to Route Requests using Cached Routes, Packet Salvaging, Queued Packets Destined over Broken Link besides route maintenance. DSDV is proactive routing protocol and has more alternate paths than TORA. Thus, performance of DSDV is better than TORA in a Constraint environment. The delay for establishing route is less when compared to TORA. Routing Overhead is very high in reactive protocols AODV and DSR when compared to DSDV and TORA.

IV. Cross Layer Approach for Congestion Control

In cross layer approach, the advantage of exchanging information among interlayer is considered. The rate control may be used as congestion metric by the node in the MAC layer make uses queue length from the network layer. Queue length is used as metrics for making transmission decision. The congestion control only at sender is not sufficient. This is because whenever congestion occurs based the level of queue length threshold, the sender will try to send out all the packets and chooses high data rate. When we consider on the receiver side, it is vulnerable to reduce the data rate to avoid and limit more incoming packets waiting in its already congested queue. It is very much required to balance the data rate between sender and receiver to avoid congestion occurring at any end.

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This is because that the overall network performance will not come down. The data rate is selected based on the queue length of the sender and receiver.

In ad hoc networks the data forwarding load Is more or higher in some areas when compare to other areas. The nodes in the middle of the network carry high loads when routing protocol make use of shortest path strategy. The performance can be improved using the congestion information from MAC , Network and Transport layer. The routing protocol uses congestion information for the purpose of selecting route through the congestion area. The congestion level measure may be applicable for several modifications of TCP based on the ECN (Explicit Congestion Notification) bit in a packet IP header. Thus motivated by the idea of cross layer approach for congestion aware and adaptive idea which make of rate adaption to improve the overall performance of the network, efficient Cross layer congestion control adaptive(e-carp) protocol was developed.

V. Proposed e-CARA Protocol

The e-CARA designed to ensure the high availability of alternative routes and reduce the rate of stale route. This can be achieved by increasing the parameters of routing protocols (especially in AODV) that normally take more time for link recovery. The parameters such as active_route_time-out, route_reply_wait_time, reverse_route_life, TTL_start, TTL_increment, TTL_threshold and delete_period. The overall performance of routing protocols is increased to 8 to 15% in constrained situation. In the Figure 3 it is observed that AODV and DSDV out performs other routing protocols in constrained situation.

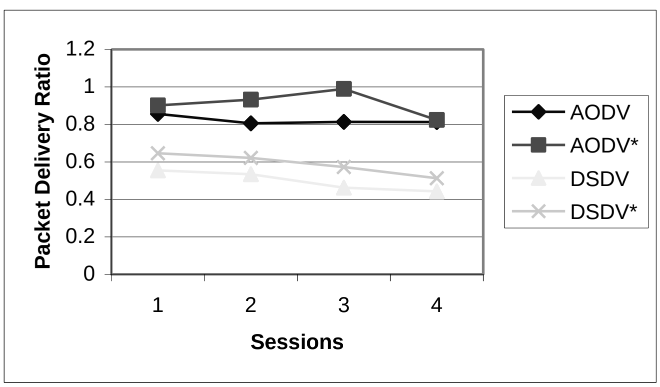

Figure 3. Performance of AODV/DSDV with improved routing parameters*

A. *PROTOCOL DESIGN*

Every node appearing on a route warns its previous node when there is congestion. The previous node uses "non congested" route to the node on the main route as shown in Figure 4. The thick line represents congestion and dashed line represents non congested route.

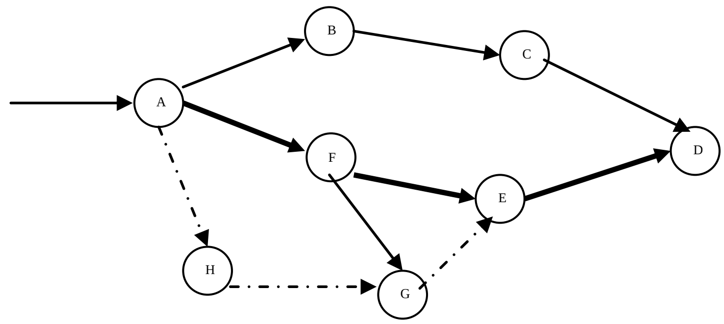

Figure 4. Ad hoc Network with congested/non-congested route

The congestion may result in any of the following reasons:

- Lack of buffer space
- Link load exceeds the carrying capacity
- Redundant broadcasting packets
- Number of packets timeout and retransmitted
- Average Packet Delay/ Standard Deviation of Packet delay
- Number of nodes increases

B. *Congestion Status Indicator:*

By checking the occupancy of link layer buffer of node periodically the congestion status C_s can be estimated.
C_s = Number of packet buffered in Buffer / Buffer Size.
Congestion can be indicated by three statuses "Go", "Careful" and "Stop"
"Go" indicates there is no congestion with $C_s \leq ½$
"Careful" indicates the status likely to be congested with $½ \leq C_s \leq ¾$ and
"Stop" indicates the status already congested, $¾ \leq C_s \leq 1$.

C. *Main Route Discovery Phase*

Broadcast RREQ packet toward the receiver and receiver responds to the RREQ by sending back a RREP packet. Each node has two routing tables: Main Table denoted by *MnTab* and non congestion Table denoted by *NcTab*. *MnTab* is used to direct packets on main route and *NcTab* is used to direct packets on non congested routes. If the *NcTab* = 0 indicates that no non congested route available for any connection at that moment. The table format for *MnTab* and *NcTab* are shown in Table I and II respectively.

Table I. MAIN ROUTING TABLE (*MnTab*)

Attribute	Description
Nc_dest	Destination of the non congested route
Nc_status	Congestion status of the non congested route
Nc_hop	Next node on the non congested
Prob	Probability to forward a packet to the main link

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Go_hop	Next "Go" node on the main route
Go_metric	Distance to Go_hop in hops
Hop	Next mode on the main route
Dest	Destination

Table II. NON CONGESTED ROUTING TABLE (*NcTab*)

Attribute	Description
Nc_src	Start node of non congested route
hop	Next node on non congested route
status	Congestion status of non congested route
Dest	Destination

Every entry in the table is unique to a destination. *MnTab* [N, D] specify the entry for destination D in the routing table of node N and *MnTab* [N, D].attr specify the value for the attribute attr. The traffic can be reduce by dropping RREQ packets when congestion status is "stop" and also stop broadcasting RREQ packets.

D. Non Congested Route Discovery Algorithm

Step 1: [Set the Main Routing table metric attribute.]
MnTab [N, D].nc_metric = 1.
Step 2: [Set the Destination node and Its congestion status as "Go"]
MnTab [N, D].nc_hop = D and MnTab [N, D].hop_status = "Go"
Step 3: [for every other node, Set Main Table has no congested node]
MnTab [N, D].nc_hop = -1
Step 4: [Node N receives a Update packet from its next main node N_{next}]
If MnTab [N_{next}, D].nc_status = "stop" and MnTab [N_{next}, D].nc_status = "careful" then node N initiate non congested route discovery process toward node of N obtained from the update packet.
Step 5: [Non congested route search]
(i) Non congested request packets set TTL to 2 x k. where k is distance between Node N and non-congested Node P on the main route.
(ii) Drop non congested request if arriving at a node already present on the Main route.
Step 6: Remove the entries in the *NcTab* if timeout occurs after certain period.
Step 7: [Traffic splitting effectively reduces the congestion status at the next main node.]
(i) If next Main node MnTab [N, D].hop = "stop" the incoming packets will follow Main Link N → MnTab [N, D].hop and with probability p = MnTab [N, D].prob = 0.5
(ii) Non congested link N → MnTab [N, D].nc_hop will have equal chance (1-p = 0.5)

VI. Performance Study and Result Analysis

We have implemented e-CARA protocol using Network Simulator NS-2 [18] version 2.28. We compared e-CARA to DSR, AODV, DSDV and TORA the most popular MANET routing protocols. In following sections observations are discussed.

A. Simulation Parameters

The network consists of 25 nodes in a 1500m x 800m rectangular and 1000m x 1000m square field. The MAC layer was based on IEEE 802.11 CSMA and interface queue at MAC layer could hold 50 packets. The nominal bit rate is 2 Mbps and transmission range is 250m. The routing buffer at the network layer could store up to 128 data packets. The random waypoint model [23] was used with maximum node speed of 4m/s as suggested in [24]. The traffic loads can be illustrated either varying the number of connections with fixed packet rate or varying the packet rate with fixed number of connections. The simulations were run for 900 seconds with 25 connections generated. For each connection, the source generated 512-byte data packets at a constant bit rate (CBR). This rate was varied among 1,5,10,15,20,30,40,50 packets/sec. With fixed packet rate of 20 packets/sec the number of connections varied among 1,5,10,15,20,25 connections.

B. Performance Metrics

We have considered three important metrics for the analysis of the results obtained. 1) The *packet delivery ratio* (PDR) which is defined as the ratio between payload packets delivered to the destination and those generated by the source nodes; 2) The average packet delay which can be defined as the delay for sending packets from source node to the destination node. This metrics includes all the possible delays caused by buffering during the route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, and propagation and transfer times; 3) The *routing overhead* defined as the number of packets carrying control messages for route discovery and routing to the number of packets carrying payload.

C. Simulation Result Analysis

The results were collected as average values over 15 runs of each simulation setting. We kept the fixed of connections to 20 and varied the packet rate. The improvement of e-CARA with Packet Delivery Ratio over other routing protocols is shown in Figure 5.

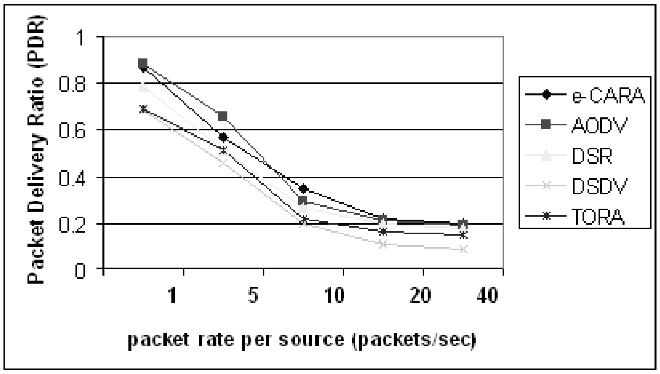

Figure 5. Packet Delivery Ratio Vs Packet Rate

In regard of Packet Delivery Ratio, both AODV and e-CARA outperforms DSR, DSDV and TORA. This is because packets are lost due to congestion in DSR were more than in the other routing protocols. When packets rate was small, AODV delivered more packets than e-CARA. This is due to less network load. With increase in the traffic of packet rate 20 packets/s, 30 packets/s and 40 packets/s, e-CARA successfully delivered packets more than AODV and other routing protocols. Similarly, for end-to-end delay we have computed worse case, which is shown in Figure 6. The e-CARA improved over AODV by 63.76%, DSR even better by 77.42%, DSDV by 79.12% and TORA by 80.67% in worst case. The delay variation less than that of AODV and DSR makes e-CARA more suitable for multimedia kind of applications as shown in Figure 6.

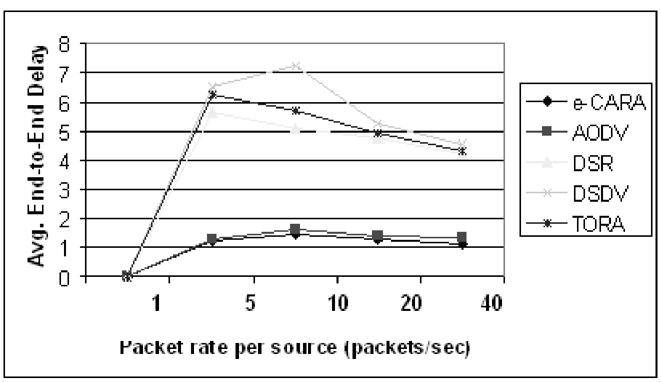

Figure 6. Average End-to-End Delay Vs Packet Rate.

The routing overhead incurred by e-CARA is very less when compared to other routing protocol. This is shown in Figure 7.

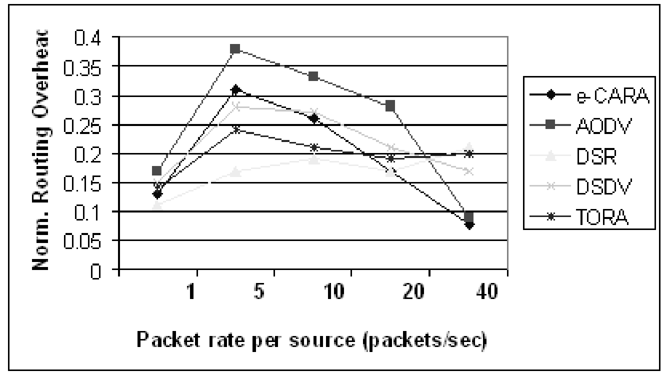

Figure 7. Normalized Routing Overhead Vs Packet Rate.

When packet rate was 50 packets/s the e-CARA incurred less routing head and delivered 21.34% more data than AODV. This because, upon link breakage, AODV tried to establish a new route to the destination by broadcasting RREQ and RREP packets, e-CARA tried to make use of non congested available route and uses route request packets very often. The overhead to maintain non congested paths in e-CARA is kept small by minimizing the use of multiple paths.

In the next scenario, we fixed the packet rate to 20 packets per seconds and varied the number of connections. Even in this scenario there was an improvement of e-CARA over other routing protocols. The improvement of e-CARA with Packet Delivery Ratio is shown in Figure 8.

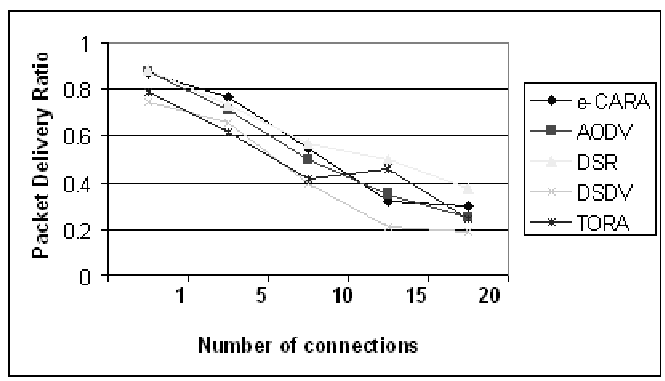

Figure 8. Packet Delivery Ratio Vs Number of Connections

In regard of Packet Delivery Ratio measured against varying the number of connections, both AODV and e-CARA outperforms DSR, DSDV and TORA. This is because packets are lost due to congestion in DSR were more than in the other routing protocols. When packets rate was small, AODV delivered more packets than e-CARA. This is due to less network load. With increase in the traffic of packet rate 20 packets/s, 30 packets/s and 40 packets/s, e-CARA successfully delivered packets more than AODV and other routing protocols.

For end-to-end delay, we have computed against varying the number of connections shown in Figure 9. The e-CARA improved over AODV by 65.36%, DSR even better by 79.25%, DSDV by 80.15% and TORA by 80.78% in worst case. The delay variation less than that of AODV and DSR makes e-CARA more suitable for multimedia kind of applications.

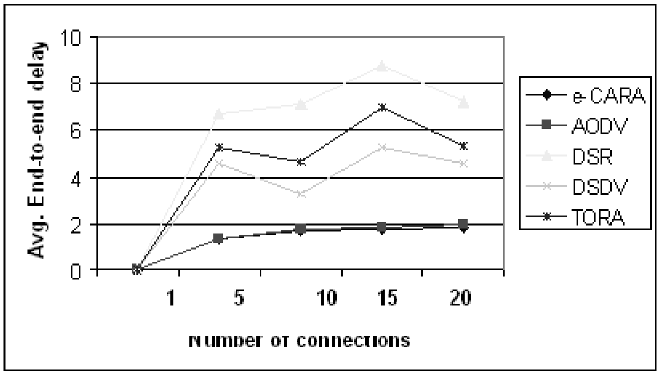

Figure 9. Average End-to-End Delay Vs Number of Connections

The routing overhead incurred by e-CARA is very less when compared to other routing protocol. This is shown in Figure 10. When number of connections was 20 the e-CARA incurred less routing head and delivered 18.45% more data than AODV. This because, upon link breakage, AODV tried to establish a new route to the destination by broadcasting RREQ and RREP packets, e-CARA tried to make use of non congested available route and uses route request packets very often. The overhead to maintain non congested paths in e-CARA is kept small by minimizing the use of multiple paths.

In all these measures e-CARA outperformed AODV, DSR, DSDV and TORA, especially when the network is heavily loaded. In case of DSR, every data packet carry the entire route information, thus making network severely congested. The DSDV contains all the routes for possible destinations and suffers buffer overflow as the packet rate increases due to congestion. AODV would result in a less congested network because neither data nor control packets are needed to include route information. As soon as the traffic load is increased, AODV fails in handling the congestion. In contrast, e-CARA efficiently distributes traffic over the main routes and non congested routes. It resolves the congestion in a better way and offers high PDR, shortest end-to-end delay and less routing overhead.

VII. Conclusion

The proposed e-CARA congestion control protocol enjoys fewer packet losses than routing protocols in a constraint situation. Most of the MANET protocols are not adaptive to congestion and cannot handle the heavy traffic load while offering services to multimedia applications. The non congested route concept in e-CARA help next node that may go congested. If a node is aware of congestion ahead, it finds a non congested route that will be used in case congestion is about to occur. The part of incoming traffic is split and sent on the non congested route, making the traffic coming to the congested node less. Thus congestion can be avoided. E-CARA does not incur heavy overhead due to maintaining of non congested paths. It also offers high Packet Delivery Ratio when the traffic in heavy. The maintenance cost is reduced because non congested is short and main node can only create at most one non congested route. The end-to-end delay and queuing delay is less because e-CARA makes network less congested. The delay incurred while establishing is low because of using existing non congested paths. Thus the proposed e-CARA is congestion aware and congestion adaptive efficient routing protocol for mobile ad hoc networks especially designed for multimedia applications.

The future work can be focused on designing and developing congestion adaptive routing protocol for multicast scenario.

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