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Impact of MAC Layer on the Performance of Routing Protocols in Mobile Ad hoc Networks

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***Abstract*—**Mobile Ad hoc Networks is an autonomous system of mobile nodes connected by multi-hop wireless links without centralized infrastructure support. As mobile communication gains popularity, the need for suitable ad hoc routing protocols will continue to grow. Efficient dynamic routing is an important research challenge in such a network. Bandwidth constrained mobile devices use on-demand approach in their routing protocols because of its effectiveness and efficiency. Many researchers have conducted numerous simulations for comparing the performance of these protocols under varying conditions and constraints. Most of them are not aware of MAC Protocols, which will impact the relative performance of routing protocols considered in different network scenarios. In this paper we investigate the choice of MAC protocols affects the relative performance of ad hoc routing protocols under different scenarios. We have evaluated the performance of these protocols using NS2 simulations. Our results show that the performance of routing protocols of ad hoc networks will suffer when run over different MAC Layer protocols.

***Keywords*—**AODV, DSR, DSDV, MAC, MANETs, relative performance

I. INTRODUCTION

MOBILE Ad hoc Networks is a collection of mobile nodes that are dynamically communicating without centralized supervision. It is self-creating, self-organizing and self-administrating network. Absence of the base station from the network necessitates the functionality of the network nodes to include routing as well. This task becomes more complex as the network nodes change randomly their positions. An efficient routing protocol that minimizes the access delay and power consumption while maximizing utilization of resources remains a challenge for the ad-hoc network design. For these reasons we have considered efficient routing protocols and we have evaluated their performances on a different MAC layers.

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The most popular routing approach in ad hoc networks is on-demand routing. On-demand routing protocols build routes only when a node needs to send data packets to a destination. The most popular on demand routing algorithms are the Ad hoc On-Demand Distance Vector routing (AODV) [1] and Dynamic Source Routing (DSR) [2]. On the other end table driven protocols are also used in some scenarios. We have considered two table driven protocols such as Wireless Routing Protocol (WRP) [3] and Destination Sequenced Distance Vector (DSDV) [4] protocol. There is continuous effort to establish and maintain routing paths in these ad hoc mobile networks. This has lead to development and design of numerous unicast and multicast routing protocols.

To determine the advantage of these protocols, there have recently investigations comparing the performance of these protocols under various conditions and constraints [5], [6], [7], [8]. The Ad hoc Networks MAC protocols such as IEEE 802.11 DCF (Distribution Co-ordination Function) [9], Evolutionary TDMA [11] and CSMA/CA [10].

The rest of the paper is organized as follows. In section 2 related works on performance of routing protocols over MAC protocols are discussed. In section 3, we present brief Overview of routing protocols used. The MAC protocols are described in Section 4. The simulation environment and results are described in Section 5. Finally, Section 6 concludes this paper.

II. RELATED WORK

In the beginning protocol performance comparison was carried out by Broch, Maltz, Johnson, Hu and Jetcheva [22]. They conducted experiments with DSDV, TORA, DSR and AODV routing protocols. The simulations were quite different for they used a constant network size of 50 nodes, 10 to 30 traffic sources, seven different pause times and various movement patterns. The *ns-2* discrete event simulator [16] developed by the University of California at Berkeley and the VINT project [23] was extended to correctly model the MAC and physical-layer behavior of the IEEE 802.11 wireless LAN standard. DSR and DSDV were simulated and compared to a newly developed Cluster-based Routing Protocol (CBRP) by Mingliang, Tay and Long [24]. The simulations were performed with pause times from 0 to 600 seconds and with 25 to 150 mobile nodes. The focus of this presentation is set to CBRP, especially how it scales in larger networks and in situations with higher mobility. It can be seen that the packet delivery ratio of DSR falls to approximately 65% in a network of 150 nodes, which is good comparable to our results. CBRP performed much better with a delivery ratio always greater then 90 percent and a lower routing overhead than DSR in larger networks.

In Mar 2000 Das, Perkins and Royer [21] presented a performance comparison of the AODV and DSR protocol. The experiments were based on the NS2 simulator. The IEEE 802.11 MAC layer, a radio model similar to Lucent's WaveLAN radio interface and random waypoint mobility with pause times from 0 to 500 seconds are used. In two different scenarios, 50 and 100 nodes were utilized with an area size of 1500m x 300m respectively 2200m x 600m respectively. Although the results cannot directly be compared with this paper, it was also concluded that AODV outperforms DSR in more stressful situations (i.e. larger network, higher mobility).

In high mobility scenarios with low pause times, DSR performed badly due to the frequent use of stale routes and slow reaction to link changes. This will lead to poor delay and delivery ratio. DSR only showed advantage in the general lower routing overhead and in low mobility and small load scenarios. In [20] Royer, Lee and C.E. Perkins showed the effect of MAC protocols on ad hoc network communication. The simulations were carried out with three routing protocols over the MAC protocols. They did not concentrate on energy saving MAC mechanism. Loscri, Rango and Marano [19] done some performance evaluation of on-demand multipath distance vector routing protocol over only two MAC layers in Mobile Ad hoc Networks.

III. Overview of Routing Protocols

To analyze the effects of MAC protocols, four ad hoc routing protocols are selected for study. First, the Dynamic Source Routing (DSR) and Ad hoc On-Demand Distance Vector Routing protocol are included as examples of on-demand protocols. On-demand protocols only establish routes when they are needed by a source node, and only maintain these routes as long as the source node requires them. Next Destination-Sequenced Distance-Vector (DSDV) and Wireless Routing Protocol (WRP) that are distance vector table-driven protocols. Table-driven protocols periodically exchange routing table information in an attempt to maintain an up-to-date route from each node to every other node in the network at all times.

A. Dynamic Source Routing (DSR)

The key distinguishing feature of DSR is the use of *source routing*. That is, the sender knows the complete hop-by-hop route to the destination. These routes are stored in a *route cache*. The data packets carry the source route in the packet header. When a node in the ad hoc network attempts to send a data packet to a destination for which it does not already know the route, it uses a *route discovery* process to dynamically determine such a route. Route discovery works by flooding the network with *route request* (RREQ) packets. Each node receiving an RREQ rebroadcasts it, unless it is the destination or it has a route to the destination in its route cache. Such a node replies to the RREQ with a *route reply* (RREP) packet that is routed back to the original source. RREQ and RREP packets are also source routed. The RREQ builds up the path traversed across the network. The RREP routes itself back to the source by traversing this path backward. The route carried back by the RREP packet is cached at the source for future use. If any link on a source route is broken, the source node is notified using a *route error* (RERR) packet. The source removes any route using this link from its cache. A new route discovery process must be initiated by the source if this route is still needed. DSR makes very aggressive use of source routing and route caching. No special mechanism to detect routing loops is needed. Also, any forwarding node caches the source route in a packet it forwards for possible future use.

B. Ad Hoc On-Demand Distance Vector Routing (AODV)

AODV shares DSR's on-demand characteristics in that it also discovers routes on an *as needed* basis via a similar route discovery process. However, AODV adopts a very different mechanism to maintain routing information. It uses traditional routing tables, one entry per destination. This is in contrast to DSR, which can maintain multiple route cache entries for each destination. Without source routing, AODV relies on routing table entries to propagate an RREP back to the source and, subsequently, to route data packets to the destination. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops. All routing packets carry these sequence numbers. An important feature of AODV is the maintenance of timer-based states in each node, regarding utilization of individual routing table entries. A routing table entry is *expired* if not used recently. A set of predecessor nodes is maintained for each routing table entry, indicating the set of neighboring nodes which use that entry to route data packets. These nodes are notified with RERR packets when the next-hop link breaks. Each predecessor node, in turn, forwards the RERR to its own set of predecessors, thus effectively erasing all routes using the broken link. In contrast to DSR, RERR packets in AODV are intended to inform all sources using a link when a failure occurs. Route error propagation in AODV can be visualized conceptually as a tree whose root is the node at the point of failure and all sources using the failed link as the leaves.

C. Destination-Sequenced Distance-Vector (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. Wireless Routing Protocol (WRP)

The Wireless Routing Protocol (WRP) maintains routing information through the exchange of triggered and periodic updates. When a node notices a link break with one of its neighbors, it broadcasts an update message containing the distance and second-to-last hop information for each destination for which the routing information has changed. The second-to-last hop information is used to reduce routing loops. A neighboring node receiving an update message modifies its distance table entries and checks for new paths through other nodes. Any new paths are relayed back to the original node so that routing consistency is maintained throughout the network. Furthermore, a node successfully receiving an update message transmits an acknowledgment back to the sender, indicating the link is still viable. In the event that a node has not transmitted anything within a specified period of time, it must transmit a *Hello* message (instead of exchanging the entire route table) to ensure connectivity. Otherwise, the lack of messages from a node indicates the failure of that link. When a node receives a Hello message from a new node, it sends that neighbor a copy of its routing table information.

IV. Medium Access Control (MAC) Protocols

A. IEEE 802.11 DCF

The IEEE 802.11 specifies two modes of MAC protocol: Distributed Coordination Function (DCF) mode (for ad hoc networks) and Point Coordination Function (PCF) mode (for centrally coordinated infrastructure-based networks) [11-14]. The DCF in IEEE 802.11 is based on CSMA with Collision Avoidance (CSMA/CA), which can be seen as a combination of the CSMA and MACA schemes. The protocol uses the RTS–CTS–DATA–ACK sequence for data transmission.

Time slots are divided into multiple frames and there are several types of inter frame spacing (IFS) slots. The node waits for the medium to be free for a combination of these different times before it actually transmits. Different types of packets can require the medium to be free for a different number or type of IFS. For instance, in ad hoc mode, if the medium is free after a node has waited for DIFS, it can transmit a queued packet. Otherwise, if the medium is still busy, a backoff timer is initiated. The initial backoff value of the timer is chosen randomly from between 0 and CW-1 where CW is the width of the contention window, in terms of time-slots. After an unsuccessful transmission attempt, another backoff is performed with a doubled size of CW as decided by Binary Exponential Backoff (BEB) algorithm. Each time the medium is idle after DIFS, the timer is decremented.

When the timer expires, the packet is transmitted. After each successful transmission, another random backoff (known as post-backoff) is performed by the transmission completing node. A control packet such as RTS, CTS or ACK is transmitted after the medium has been free for SIFS. Fig.1 shows the channel access in IEEE 802.11.

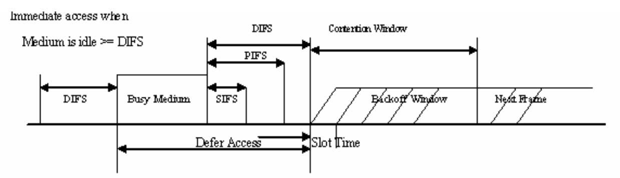

Fig. 1 IEEE 802.11 DCF

IEEE 802.11 DCF is a widely used protocol for wireless LANs. Many of the MAC schemes discussed in this paper are based on it. Some other features of this protocol will be discussed along with such schemes.

B. CSMA

The Carrier Sense Multiple Access (CSMA) protocol is the most primitive of the MAC protocols utilized in this study. The CSMA version used is non-persistent CSMA. In this protocol, a node senses the channel for ongoing transmissions before sending a packet.

If the channel is already in use, the node sets a random timer and then waits this period of time before re-attempting the transmission. On the other hand, if the channel is not currently in use, the node begins transmission. CSMA/CA was developed to overcome the hidden node problem. It incorporates a handshake protocol in the original CSMA protocol. In CSMA/CA, a sender must first transmit a request to send (RTS) frame. RTS contains the identification of the receiver so that only the intended receiver will answer this message with a clear to send (CTS) frame. Other mobile nodes intercepting either RTS or CTS defer their transmission for the period specified by the network allocation vector (NAV) in the handshaking frames RTS and CTS. Therefore, the number of hidden nodes is reduced by some degree.

C. E-TDMA

A major difficulty in a wireless environment is the “hidden terminal” problem. Due to the limited range of wireless transmissions, two nodes can be far enough apart that they cannot detect each other directly (they are “hidden” from each other), so their transmissions may collide with another node in the middle. Even the four-way handshaking scheme used in IEEE 802.11 cannot prevent collisions completely. In FPRP (Five Phase Reservation Protocol) [15], the collision from two hidden nodes is detected at the node where it occurs, and it is up to this node to explicitly inform both transmitters. This ensures that no collision, due two hidden nodes, can arise in the TDMA broadcast schedule.

In the FPRP the five-phase scheme attempts to minimize the probability of collision in a efficient and robust. A packet has a very small size and it carries only a single logical bit in order to exploit a reservation cycle. The FPRP uses the fact that a collision always occurs one hop away from the sender. A collision is detected at the node where it occurs (unlike the CSMA/CA protocol, where the sender detects the collision at the receiver) and is signaled to the sender that functions as a local hub. It collects collision information and makes the final decision. Before a reservation is successfully, no information has to be collected from or dissipated to nodes more than one hop away. This greatly simplifies the reservation process.

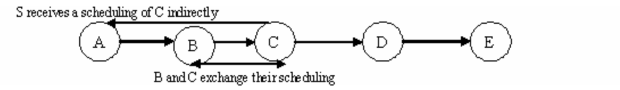

Fig. 2 Control Phase of E-TDMA Protocol with schedule updates between neighbor nodes

The first four phases of the FPRP bear a resemblance to the popular RTS-CTS exchange [Figure. 2]. A packet may collide with another packet, but the correct semantic is always inferred in the context of the protocol. In the Evolutionary-TDMA a transmission schedule is first generated and nodes transmit and receive according to this schedule. Generally the generation of the schedule requires substantial overhead and many scheduling problems are very difficult (NP-complete) even with accurate information of the entire network. As real-time multimedia traffic in these networks continues to increase, scheduling-based protocols will become more important. The studied TDMA scheduling protocols considers the mobility. At the center of their design is the speed with which the schedules are generated (or updated).

V. SIMULATIONS AND PERFORMANCE ANALYSIS

A. *Simulation Environment*

The simulations were performed using the Network Simulator 2 (NS-2) [16], which allows node mobility, thereby providing for simulation of mobile ad hoc networks. The NS-2 particularly popular in the ad hoc networking community, and protocols used in ad hoc networks have been supported. A mobile ad hoc network is generated as follows: there are 25 nodes in the network and they are confined to rectangular area 1000 m by 600 m. Node movement is modeled by the random waypoint mobility model [17]. In this mobility model when the node arrives at its randomly chosen destination, it rests for some pause time. It then chooses a new destination and begins moving once again. The pause times are varied between 0 and 600 seconds. The node transmission range is 250 m. Different network scenario for different number of nodes and pause times are generated.

Each simulation is run for 600 seconds and models a network of 25 nodes. The propagation model is the Two way ground model [18]. The bandwidth is 2 Mb/s, the data packet size is 512 bytes and packets are sent at a rate of four per second by each source. In case of E-TDMA an information epoch consists of four information frames. The FPRP cycle number for the contention phase is eight.

We have evaluated AODV, DSR, DSDV and WRP over IEEE 802.11, E-TDMA and CSMA. The MAC parameters impact differently on routing protocol performance.

B. *Performance Metrics*

We have primarily considered three performance metrics in our evaluation.

Packet Delivery Ratio (PDR): The Packet Delivery Ratio (PDR), which is defined as the ratio between payload packets, delivered to the destination in the Internet and those generated by the source nodes;

Average end-to-end delay: This includes all possible delays caused by buffering during route discovery, queuing delay at the interface, retransmission delays at MAC, propagation and transfer times;

Control Packet Overhead: This can be calculated by counting the number of hop-wise control packet transmission.

VI. RESULTS AND PERFORMANCE EVALUATION

In this section we determine whether the selection of MAC protocols affects the relative performance of the protocols. The MAC protocols IEEE 802.11, E-TDMA and CSMA are selected for simulation.

A. *IEEE 802.11*

Figure 4 shows the results of data packets delivered to destination with varying pause time.

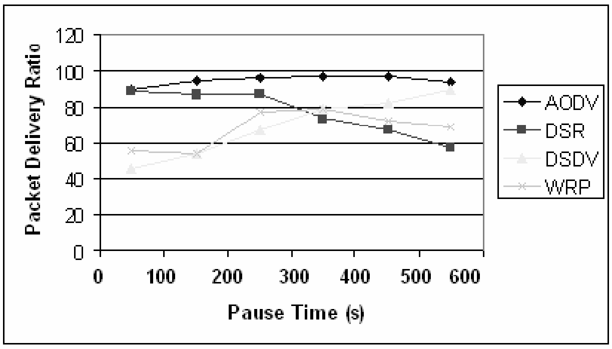

Fig. 4 Packet Delivery Ratio over IEEE 802.11 MAC

The relative performance of AODV and DSR remains fairly constant in the beginning while that DSR tends to vary by the MAC protocol used. When run over IEEE 802.11 AODV performs best for the higher mobility scenarios and outperforms the other protocols. Another important performance metric end-to-end delay is evaluated. Figure 5 shows the end-to-end delay measured against with the different pause time.

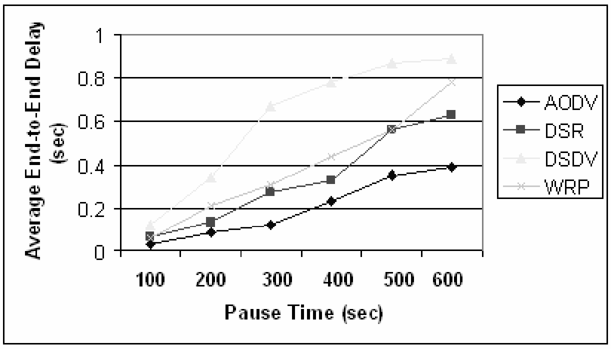

Fig. 5 End-to-End Delay over IEEE 802.11 MAC

AODV has less end-to-end delay when compared to other routing protocol. This is due to maintenance only route when are very active. Even DSR shows good performance in the establishing the route between source and destination. DSR performs better than DSDV and WRP protocols.

The number of hop-wise control packet transmissions during each simulation is shown in figure 6. Because WRP has both triggered and periodic updates, and hence the amount of control overhead increases as mobility increases (i.e. pause time becomes shorter).

AODV performs better when run over IEEE 802.11 DCF. The amount of control overhead generated by AODV is directly related to the number of routes it is maintaining. AODV does not maintain as many routes. DSDV performs better than other routing protocols with less control overhead. DSR performs better than WRP and fails to outperform DSDV and AODV.

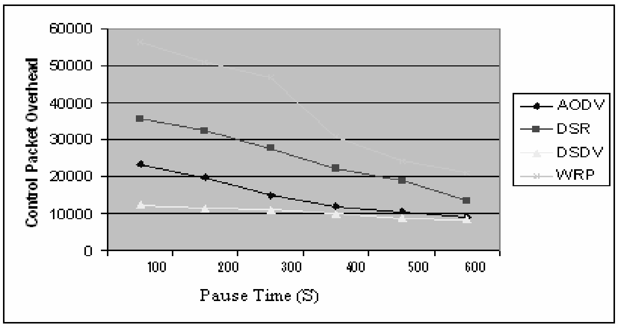

Fig. 6 Control Packet Overhead over IEEE 802.11 MAC

B. E-TDMA

The paper focus on the performance evaluation of the routing protocols over the novel distributed TDMA MAC protocol E-TDMA

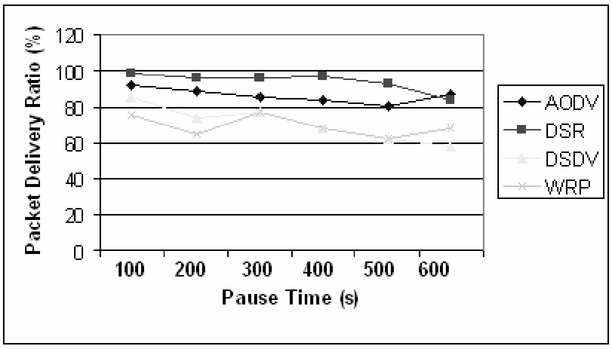

Fig. 7 Packet Delivery Ratio over E-TDMA MAC

As in case of IEEE 802.11 the AODV over TDMA MAC protocol does not generate messages for knowing the neighbors. This is because E-TDMA MAC uses intrinsic neighbors discovering mechanism. We have considered the variation of the pause time and number of nodes, which is shown in figure 7. It is very interesting to note that the varying the pause time there is difference in the performance. As the mobility increases, we can see the decrease in the throughput of the routing protocol. DSR outperforms all the other protocols and WRP faces heavy loss in the delivery of packets. DSR run over E-TDMA has less end-to-end delay when compared to other routing protocol. This is due to intrinsic mechanism used by the E-TDMA for identifying the neighbors. Even DSR shows good performance in the establishing the route between source and destination. DSR and AODV outperforms better than DSDV and WRP protocols.

In case DSR there may be chances of holding stale route for long time and this may lead to increase in establishing connection. This is depicted in the figure 8. DSDV and WRP show increase in end-to-end delay. This is because DSDV has to maintain all the possible routes in a static table. The number of hop-wise control packet transmissions during each simulation run over E-TDMA is shown in figure 9.

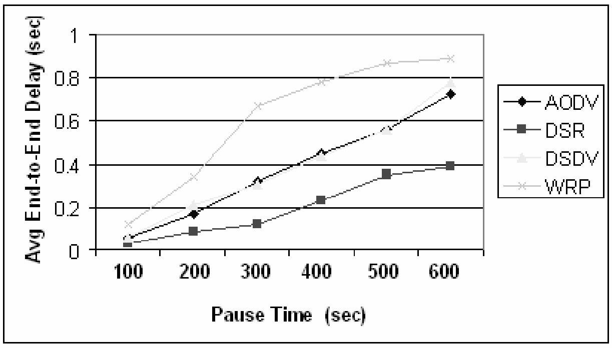

Fig. 8 End-to-End Delay over TDMA MAC protocol

WRP has both triggered and periodic updates, and hence the amount of control overhead increases as mobility increases (i.e. pause time becomes shorter). DSR performs better when run over E-TDMA MAC.

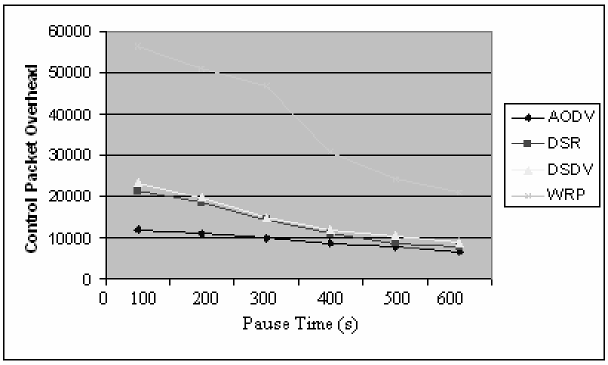

Fig. 9 Control Packet Overhead over E-TDMA MAC

This is because of E-TDMA MAC protocol support less message overhead to maintain the routes. The amount of control overhead generated by AODV is directly related to the number of routes it is maintaining. AODV does not maintain as many routes. DSDV performs better than other routing protocols with less control overhead. WRP has worst overhead of generating the control packets.

C. CSMA

In this section, paper focus on the performance evaluation of the routing protocols over the CSMA MAC protocol.

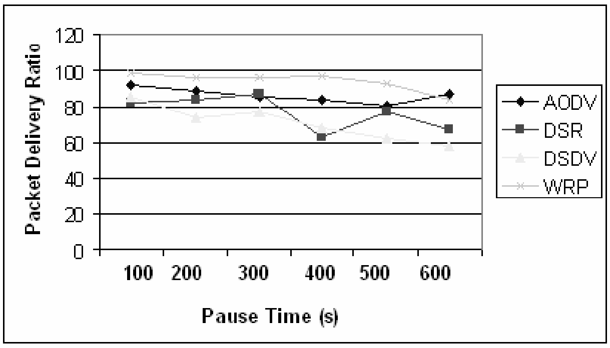

Fig. 10 Packet Delivery Ratio over CSMA MAC

The relative performance of data packets delivered to destinations in each of the networks is illustrated in figure 10. WRP remains fairly constant where as AODV and DSR tends to vary by the MAC protocol used. WRP performs best for the higher mobility scenarios. The most of MAC protocol tries to send RTS packet without sensing the channel.

This results in packet collisions and hence decreased throughput. IEEE 802.11 incorporates collision avoidance mechanism in it for the transmission of RTS packets aids in the reduction of the number of collisions. WRP run over CSMA has less end-to-end delay when compared to other routing protocol. This is due to HELLO messages used by the WRP and AODV to identify the neighbors. Even AODV shows good performance in the establishing the route between source and destination. WRP and AODV outperforms better than DSDV and DSR protocols.

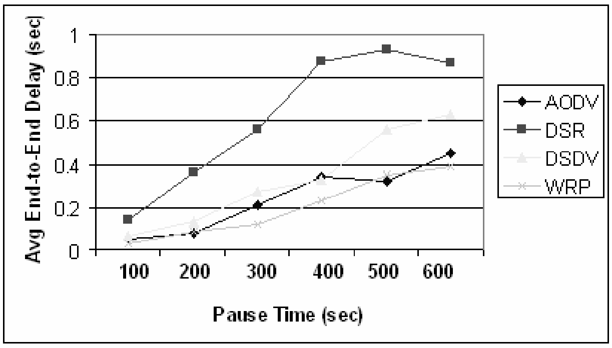

Fig. 11 End-to-End Delay over CSMA MAC protocol

In case DSR there may be chances of holding stale route for long time and this may lead to increase in establishing connection. This is depicted in the figure 11. DSDV show increase in end-to-end delay. This is because DSDV has to maintain all the possible routes in a static table.

The number of hop-wise control packet transmissions during each simulation run over CSMA is shown in figure 12. Because DSR has periodic updates and hence the amount of control overhead increases as mobility increases (i.e. pause time becomes shorter). DSDV and WRP perform better when run over CSMA MAC protocol. This is because of CSMA MAC protocol support less message overhead to maintain the routes.

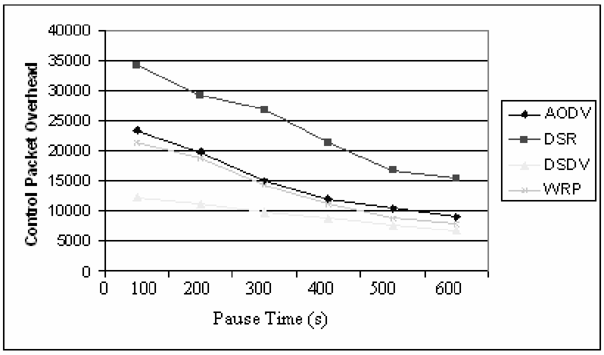

Fig. 12 Control Packet Overhead over CSMA MAC Protocol

The amount of control overhead generated by AODV is directly related to the number of routes it is maintaining. AODV does not maintain as many routes. DSDV performs better than other routing protocols with less control overhead. DSR has worst overhead of generating the control packets.

VII. Conclusion

This paper presents the performance evaluation of routing protocol over three kinds of MAC protocol for ad hoc networks: IEEE 802.11, E-TDMA and CSMA. The performance of AODV and WRP does not show the notable variation when run over the different MAC protocols. Neither routing protocol requires operational changes dependent upon the underlying MAC protocol, nor the results show that their relative performance remains approximately constant. This leads to the conclusion that table-driven protocols act similarly with different MAC protocols, although further study of additional table-driven protocols is needed to validate this conclusion. Because AODV requires periodic Hello messaging when run over link layer protocols that do not provide feedback when the next hop is unreachable, the amount of control traffic generated with these MAC protocols is considerably greater than when it is run over IEEE 802.11 DCF. AODV and DSR prove to be sensitive to the functionality of the MAC protocol, and hence its relative performance varies depending upon which MAC layer is used. Table-driven and on-demand protocols may react differently depending upon the MAC protocol used;

Over E-TDMA DSR outperforms all other routing protocols. But DSR suffers with more control overhead packets when compared to AODV. WRP shows good performance with the throughput and generate more control packets. When the performance is measured over CSMA the routing protocol WRP outperforms all other protocols with respect to throughput. The end-to-end delay is very less in case of AODV and generates less control packet overhead. The results show that the MAC protocol selected for simulation study is a key component of the performance of a routing protocol, and this aspect must be taken into consideration when doing comparative studies of the performances of routing protocols.

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