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QoS Metrics Evaluation in Two Network Layers in Wireless Ad Hoc Networks

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Abstract: Telecommunications services are evaluated by a set of parameters called QoS parameters such as throughput, delay, jitter and packet loss. QoS layered approach separates QoS aspects on each network layer in order to offer the possibility of selection a certain configuration according to network capabilities and correlated with user/application availability. This study analyzes QoS parameters from the network perspective looking on 2 different TCP/IP layers: Transport Layer (TCP and UDP) and Network Layer (DSR, AODV and DSDV). Also, an evaluation on the Impact of different node speeds on QoS Metrics in both Layers will be presented. According to the simulation results, AODV has the best performance even in networks with moving mobile nodes. The On-demand protocols, AODV and DSR perform better than the table-driven DSDV protocol. Although DSR and AODV share similar on-demand behavior, the differences in the protocol mechanics can lead to significant performance differentials. The performance differentials are analyzed using varying network load, mobility and network size. In transport Layer because of UDP's connection less nature, it doesn't need any confirmation for receiving data. So, this specification makes UDP protocol suitable in critical-time applications (real-time applications) in comparison with other transport layer protocols such as TCP.

Key words: Ad Hoc, AODV, DSR, DSDV, delay, throughput

INTRODUCTION

In order to provide a suitable level of QoS, an application needs to know which relevant network parameters have impact on the quality. In an Ad Hoc wireless networks a large group of these parameters, influencing the QoS of an application, are provided by different routing protocols and differences in Transport Layer Protocols (Basagani *et al*., 2004; Chakrabarti and Mishra, 2001). This study proposes a set of measurements and does a comprehensive analysis of QoS metrics in AODV and DSR (Elizabeth, 1999) two commonly used Ad Hoc routing protocols with a TCP and UDP algorithms for Transport Layer Protocols using ns2 simulator.

In this study, we have considered TCP as transport protocol and a Constant Bit Rate (CBR) traffic generator. The analysis is significant because we considered all the metrics as suggested by RFC 2501 and till to-date there are a few comparisons based on TCP (Puschita *et al*., 2004). All the simulations are done by NS-2 version 2.30

Network simulator (ISI, 2005) and the output results are analyzed with Trace graph 2.02 in Matlab 7.0. In the simulations 20 mobile nodes are located in an 800× 800 m area. We considered IEEE 802.11 as a MAC protocols for each Ad Hoc node and a drop tail model for the Queues with a maximum capacity of 50 packets in queue.

WIRELESS NETWORKS

Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Wireless networks can be classified in the following two types (Basagani *et al*., 2004):

- Infrastructured networks.
- Infrastructureless (Ad hoc) networks.

In ad hoc networks all nodes are mobile and can be connected dynamically in an arbitrary manner. All nodes of these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network.

Ad hoc networks are very useful in emergency search-and-rescue operations, meetings or conventions in which persons wish to quickly share information and data acquisition operations in inhospitable terrain. This

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ad-hoc routing protocols can be divided into 2 categories (Basagani *et al*., 2004; Elizabeth, 1999):

- Table-driven routing protocols.
- On-Demand routing protocols.

In table driven routing protocols, consistent and up-to-date routing information to all nodes is maintained at each node. In On-Demand routing protocols, the routes are created as and when required. When a source wants to send to a destination, it invokes the route discovery mechanisms to find the path to the destination. In recent years, a variety of new routing protocols targeted specifically at this environment have been developed. There are 4 multi-hop wireless ad hoc network routing protocols that cover a range of design choices:

- Destination-Sequenced Distance-Vector (DSDV).
- Temporally Ordered Routing Algorithm (TORA).
- Dynamic Source Routing (DSR).
- Ad hoc On-Demand Distance Vector (AODV).

While DSDV is a table-driven routing protocol, TORA, DSR and AODV fall under the On-demand routing protocols category (Elizabeth, 1999).

DESCRIPTION OF THE AD-HOC ROUTING PROTOCOLS

Dynamic Source Routing (DSR): The DSR protocol as shown in Fig. 1 is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad-hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of 3 main mechanisms: Routing, route discovery and route maintenance. The essential advantage of Source Routing (SR) is that intermediate hops do not need to maintain routing information in order to route the packets they receive (Basagani *et al*., 2004; Elizabeth, 1999).

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.

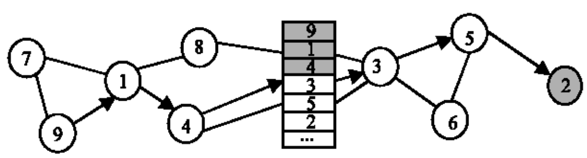

Fig. 1: DSR routing mechanism

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 a message 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 (Basagani *et al*., 2004; Elizabeth, 1999). 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.

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. It is important to note that simulation results for DSDV protocol was not covered in this study.

Temporally Ordered Routing Algorithm (TORA): TORA is a distributed routing protocol based on a link reversal algorithm. It is designed to discover routes on demand, provide multiple routes to a destination, establish routes quickly and minimize communication overhead by localizing algorithmic reaction to topological changes when possible. Route optimality (shortest-path routing) is considered of secondary importance and longer routes are often used to avoid the overhead of discovering newer routes.

The actions taken by TORA can be described in terms of water flowing downhill towards a destination node through a network of tubes that models the routing state of the real network. The tubes represent links between nodes in the network, the junctions of tubes represent the nodes and the water in the tubes represents the packets flowing towards the destination. Each node has a height with respect to the destination that is computed by the routing protocol. If a tube between nodes A and B becomes blocked such that water can no longer flow through it, the height of A is set to a height greater than that of any of its remaining neighbors, such that water will now flow back out of A (and towards the other nodes that had been routing packets to the destination via A). When a node discovers that a route to a destination is no longer valid, it adjusts its height so that it is a local maximum with respect to its neighbors and transmits an UPDATE packet. If the node has no neighbors of finite height with respect to this destination, then the node instead attempts to discover a new route as described above. When a node detects a network partition, it generates a CLEAR packet that resets routing state and removes invalid routes from the network.

QUALITY OF SERVICE IN AD HOC NETWORKS

In this study, general concepts of QoS are introduced first. It includes the QoS definition and QoS parameters.

Quality of services problem has two major perspectives: Network perspective and application/user perspective (Feakas *et al*., 2006). From the network perspective, QoS refers to the service quality or service level that the network offers to applications or users in terms of network QoS parameters, including: Latency or delay of packets raveling across the network, reliability of packet transmission and throughput. From the application/user perspective QoS generally refers to the application quality as perceived by the user. That is, the presentation quality of the video, the responsiveness of interactive voice and the sound quality of streaming audio. The layered QoS approaches separate QoS aspects on each layer and in this study we tried to evaluate QoS metrics in Transport Layer and Network Layer (Table 1). Quality of Service is the performance level of a service offered by the network to the user. In the originally used network model, traffic is transmitted only with best-effort. It means that there is no quality guarantee for each transmission. When with the real-time traffic is transmitted in the network, QoS becomes demanding. In addition, because of the limitation of network resources especially in wireless networks, real time traffic need to be given higher priority to ensure that the real time traffic arrive the destination on time.

Table 1: Network Layers and Protocols

Transport Layer	Transport Layer protocols (TCP,UDP)
Network Layer	Routing Protocols (AODV,DSR,DSDV)
Data Link Layer	Medium Access Techniques (DCF,EDCF)

QoS parameters: QoS parameters differ from application to application. For example, for multimedia applications, the data rate and delay are the key factors, whereas, in military use, security and reliability become more important. The generally used metrics for real time applications are delay, delay variance (jitter) and packet loss and data rate (Feakas *et al*., 2006). In order to evaluate the performance of ad hoc routing protocols we used the following metrics.

Average end to end delay: The average time in ms it takes to transmit a packet from the source to the destination.

Jitter: It describes how much the packets vary in latency. It is determined by calculating the standard deviation of the latency.

Packet loss ratio (percent): The loss rate determines the amount of sent packets in relation to the amount of packets that have not been received successfully at the destination.

Packet delivery ratio (percent): The Delivery Ratio determines the amount of received packets at destination in relation to the amount of packets that have been generated in source.

Normalized routing load: The number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.The first four metrics are the most important for best-effort traffic. The routing load metric evaluates the efficiency of the routing protocol. Note, however, that these metrics are not completely independent. For example, lower packet delivery fraction means that the delay metric is evaluated with fewer samples. In the conventional wisdom, the longer the path lengths, the higher the probability of a packet drops.

Thus, with a lower delivery fraction, samples are usually biased in favor of smaller path lengths and thus have less delay.

SIMULATION ENVIRONMENT

We have used, in our simulations, the discrete event network simulator NS-2 (ISI, 2005) including the wireless extensions from the Monarch group (Feakas *et al*., 2006) to model the IEEE 802.11 MAC layer, node mobility, radio network interfaces and physical layer. Throughout the simulations, each mobile node shares a 2 Mbit/s radio channel with its neighboring nodes, using the IEEE 802.11 MAC protocol and two ray ground reflection model. The transmission range of each node is 250 m, which is a typical value for WLAN in a free area without any obstacles. The protocols maintain a send buffer of 50 packets. It contains all data packets waiting for a route, such as packets for which route discovery has started, but no reply has arrived yet. To prevent buffering of packets indefinitely, packets are dropped if they wait in the send buffer for more than 30 s. All packets (both data and routing) sent by the routing layer are queued at the *interface queue* until the MAC layer can transmit them. The interface queue has a maximum size of 50 packets and is maintained as a priority queue with 2 priori-ties each served in FIFO order. Routing packets get higher priority than data packets.

The traffic and mobility models: Continuous Bit Rate (CBR) traffic sources are used. The source-destination pairs are spread randomly over the network. Only 512 byte data packets are used. The number of source-destination pairs and the packet sending rate in each pair is varied to change the offered load in the network. The mobility model uses the *random waypoint* model in a rectangular field. The field configurations used is: 800×800 m field with 20 nodes. Here, each packet starts its journey from a source node to a destination with a specific speed (0, 20 or 40 ms^{-1}). Simulations are run for 50 simulated seconds. Identical mobility and traffic scenarios are used across protocols to gather fair results.

EVALUATING QOS PARAMETERS ON NETWORK AND TRANSPORT LAYERS

The first scenario of this study contains a wireless network with 20 mobile nodes. Wireless Mobile nodes are fixed. They keep the initial position during simulation. At this time we study the influence of mobile node's speed on the parameters. Some random number of the nodes

Table 2: QoS Metrics for TCP Protocol

	Protocol-TCP					
	AODV			DSR		
QoS Parameteres	Fix	20 ($msec^{-1}$)	40 ($msec^{-1}$)	Fix	20 ($msec^{-1}$)	40 ($msec^{-1}$)
Average E2E Delay($msec^{-1}$)	211	223	169	269	364	395
Packet Loss Ratio(%)	0.817	3.16	3.09	19.9	20.1	48
Packet Delivery Ratio (%)	96.5	98.2	89.4	90.3	94.2	80.1

Table 3: QoS Metrics for UDP Protocol

	Protocol-UDP					
	AODV	DSR				
QoS Parameteres	Fix	20 ($msec^{-1}$)	40 ($msec^{-1}$)	Fix	20 ($msec^{-1}$)	40 ($msec^{-1}$)
Average E2E Delay ($msec^{-1}$)	9.90	17.0	29.5	11.0	33.0	39.0
Packet Loss Ratio(%)	0.48	0.589	0.489	0.048	1.44	2.45
Packet Delivery Ratio (%)	99.9	98.9	99.3	99.9	98.7	97.7

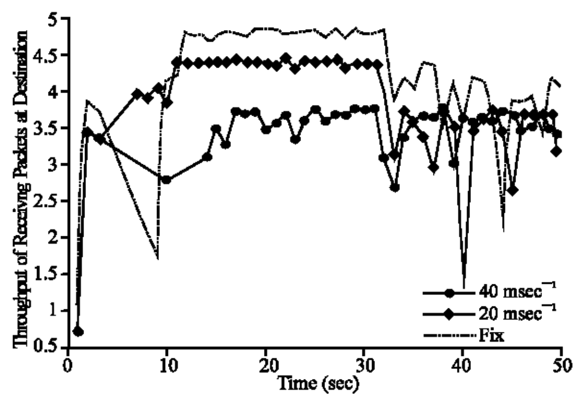

Fig. 2: Throughput of receiving packets for AODV protocol with different speeds

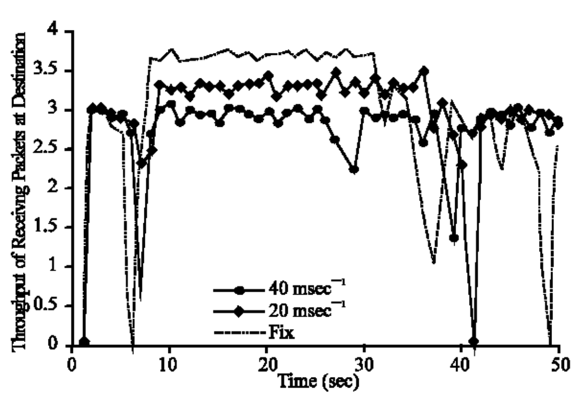

Fig. 3: Throughput of receiving packets for DSR protocol with different speeds

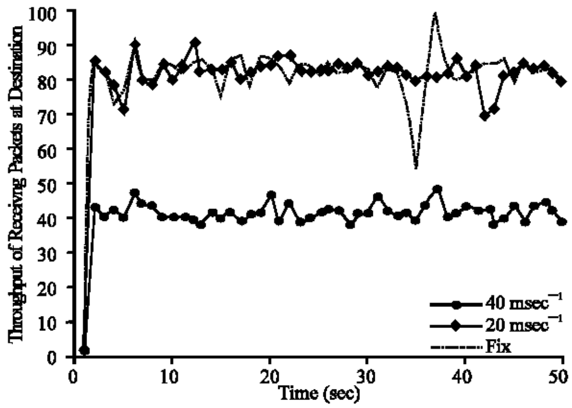

Fig. 4: Throughput of receiving packets for AODV protocol with different speeds

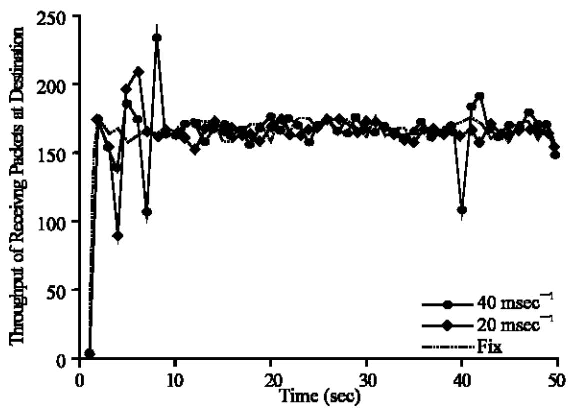

Fig. 5: Throughput of receiving packets for DSR protocol with different speeds

have been choose and given a random mobility pattern. At first the speed of moving nodes are set to 20 msec^{-1} and then it was set to 40 msec^{-1}. considered scenarios were analyzed looking on the following parameters: Throughput, routing overhead, packet loss ratio, average end-to end delay. The corresponding results and the varying QoS parameters in each case have been shown in Table 2. In Fig. 2 Throughput of receiving packets for AODV protocol with fixed nodes and different speeds is shown. In Fig. 3 the same situation was repeated with DSR routing protocol in network layer. As it's shown, in both cases, the best throughput is for the scenario with fixed nodes and as the speed of the nodes increases the overall throughput of the receiving packets decreases.

For evaluating QoS parameters on Network Layer this time a CBR application between two nodes (node 0 and node18) over a UDP transport protocol was set up. Simulation time is 50 sec. Again like before we switch the two routing protocols (DSR and AODV). In the second scenario we keep the initial network configuration with 20 mobile nodes and we try to evaluate the efficiency of the transport Layer. So, for UDP we switch between AODV and DSR routing protocols (Table 3). As it's shown in Fig. 4 and 5 again the best throughput is for the scenario with fixed nodes and as the speed of the nodes increases the overall throughput of the receiving packets decreases. With UDP as transport protocol in network layer the throughput of receiving packets.

PERFORMANCE COMPARISON OF THE PROTOCOLS

In this study an attempt was made to compare the 2 routing protocols under the same simulation environment. For all the simulations, the same movement models were used, the number of traffic sources was fixed at 20, the maximum speed of the nodes was set to 20 ms^{-1} and the pause time was varied as 0, 10, 20, 40 and 50 sec. Figure 6 and 7 highlight the relative performance of the two routing protocols. Both of the protocols deliver a greater percentage of the originated data packets when there is little node mobility.

Packet delivery comparison: The On-demand protocols, DSR and AODV performed particularly well, delivering over 85% of the data packets regardless of mobility rate (Fig. 6).

Average end to end delay: The average end-to-end delay of packet delivery was higher in DSDV as compared to both DSR and AODV (Fig. 7).

In summary, both the On-demand routing protocols, AODV and DSR performs well. Since both AODV and DSR did well, an attempt was made to evaluate the performance difference between the 2 by varying the Mobility pattern and Number of traffic sources.

Varying mobility and number of sources to see the performance difference between DSR and AODV: Now, again simulations were carried out with the number of traffic sources as 10, 20 and 40. The pause time is 0, 10, 20, 30, 40 and 50 sec and the packets were sent at a rate of 4 packets sec^{-1}.

Packet delivery comparison: The packet delivery fractions for DSR and AODV with 20 and 40 sources, AODV outperforms DSR by about 15 % (Fig. 8-10) at lower pause times (higher mobility).

Normalized routing load comparison: In all cases, DSR demonstrates significantly lower routing load than AODV (Fig. 11-13), with the factor increasing with a growing

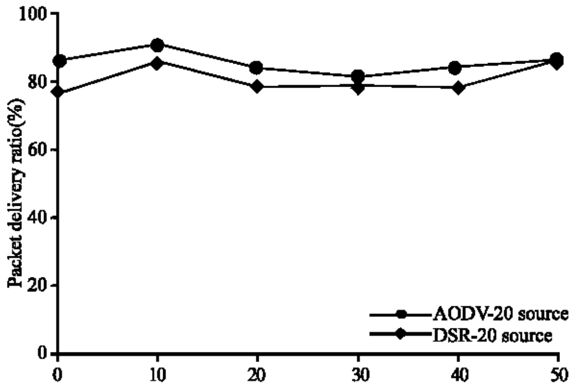

Fig. 6: Packet delivery ratio of AODV and DRS

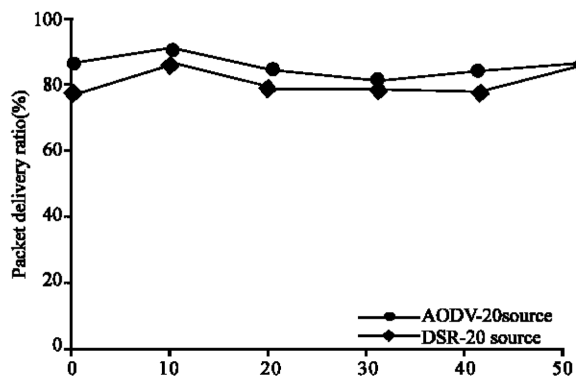

Fig. 7: Average end to end delay of AODV and DSR

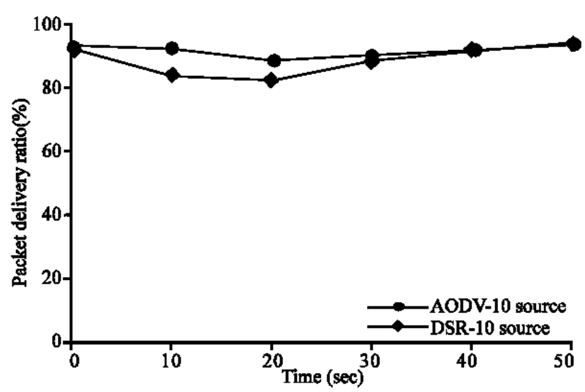

Fig. 8: Packet Delivery Ratio for 10 Sources

sources is low, the performance of DSR and AODV is similar regardless of mobility. With large numbers of sources, AODV starts outperforming DSR for high-mobility scenarios. As the data from the varying sources demonstrate, AODV starts outperforming DSR at a lower load with a larger number of nodes. DSR always demonstrates a lower routing load than AODV. The major contribution to AODV's routing over-head is from route number of sources. In summary, when the number of

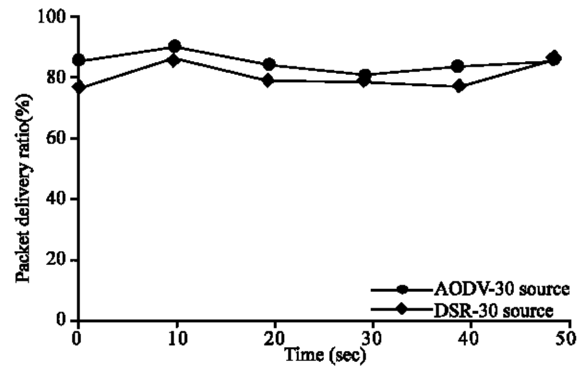

Fig. 9: Packet Delivery Ratio for 20 Sources

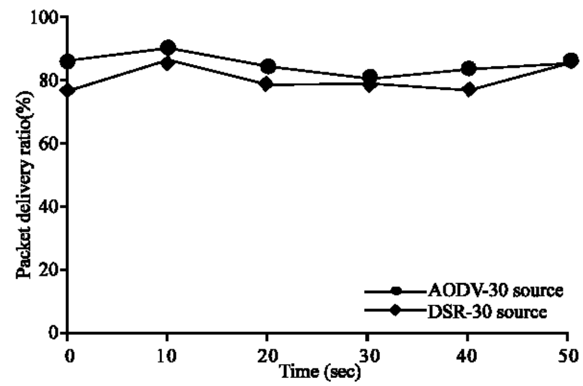

Fig. 10: Packet Delivery Ratio for 30 Sources

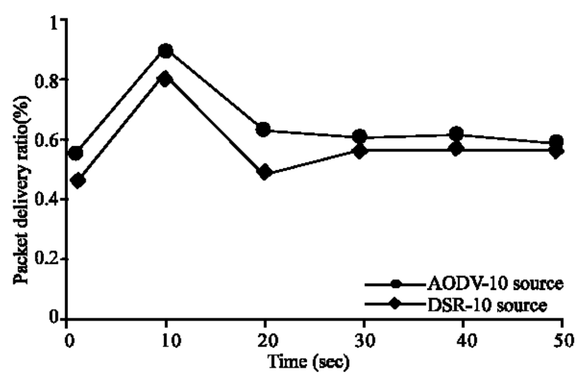

Fig. 11: Normalized Routing Load for 10 Sources

requests, while route replies constitute a large fraction of DSR's routing overhead. Furthermore, AODV has more route requests than DSR and the converse is true for route replies.

RESULTS

The simulation results bring out some important characteristic differences between the routing protocols. The presence of high mobility implies frequent link failures and each routing protocol reacts differently during link failures. The different basic working mechanisms of these protocols lead to the differences in the performance DSDV fails to converge below lower pause times. At higher rates of mobility (lower pause times), DSDV does poorly, dropping to a 70% packet delivery ratio. Nearly all of the dropped packets are lost because a stale routing table entry directed them to be forwarded over a broken link (Simulation results for DSDV protocol was not covered in this study). As described in the earlier section, DSDV maintains only one route per destination and consequently, each packet that the MAC layer is unable to deliver is dropped since there are no alternate routes. For DSR and AODV, packet delivery ratio is independent of offered traffic load, with both protocols delivering between 85% and 100% of the packets in all cases. Since DSDV uses the table-driven approach of maintaining routing information, it is not as adaptive to the route changes that occur during high mobility. In contrast, the lazy approach used by the on-demand protocols, AODV and DSR to build the routing information as and when they are created make them more adaptive and result in better performance (high packet delivery fraction and lower average end-to-end packet delays). Next the simulation results of Fig. 8-13, which compare the performances of AODV and DSR lead us to the following conclusions.

Effect of mobility: In the presence of high mobility, link failures can happen very frequently. Link failures trigger new route discoveries in AODV since it has at most one route per destination in its routing table. Thus, the frequency of route discoveries in AODV is directly proportional to the number of route breaks. The reaction of DSR to link failures in comparison is mild and causes route discovery less often. The reason is the abundance of cached routes at each node. Thus, the route discovery is delayed in DSR until all cached routes fail. But with high mobility, the chance of the caches being stale is quite high in DSR. Eventually when a route discovery is initiated, the large number of replies received in response is associated with high MAC overhead and cause increased interference to data traffic. Hence, the cache staleness and high MAC overhead together result in significant degradation in performance for DSR in high mobility scenarios. In lower mobility scenarios, DSR often performs better than AODV, because the chances of find the route in one of the caches is much higher. However, due to the constrained simulation environment (lesser simulation time and lesser mobility models), the better performance of DSR over AODV couldn't be observed.

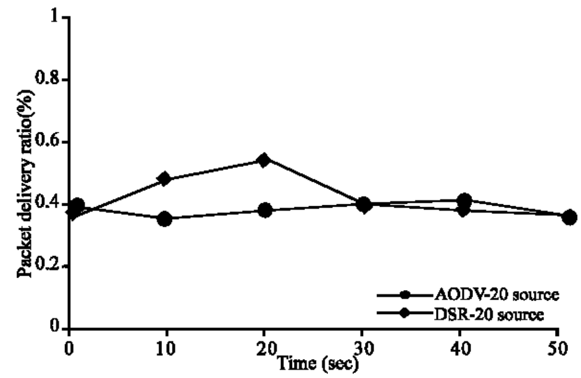

Fig. 12: Normalized Routing Load for 20 Sources

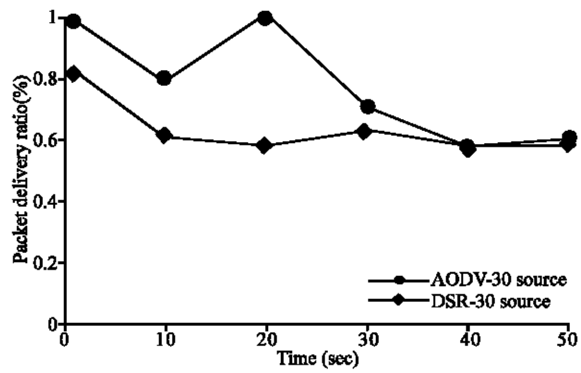

Fig. 13: Normalized Routing Load for 30 Sources

Routing load effect: DSR almost always has a lower routing load than AODV. This can be attributed to the caching strategy used by DSR. By virtue of aggressive caching, DSR is more likely to find a route in the cache and hence resorts to route discovery less frequently than AODV.

CONCLUSION AND FUTURE WORKS

Different people and communities perceive and interpret Quality of Services (QoS) in different ways. We consider that QoS problem has two major perspectives: Network perspective and application/user perspective. Networks receive from the applications implicitly or explicitly their QoS parameters and need to respond to these requests by supplying QoS services.

We propose and promote layered QoS approaches that separate QoS aspects on each layer. The study presents in an original fashion an evaluation of QoS parameters on different TCP/IP layers for wireless scenarios: Transport Layer (TCP and UDP) and Network Layer (DSR and AODV). We use ns-2.30 in our simulations. Each scenario is accompanied by simulations results and graphical representation. Synthesizing results we demonstrate that:

- AODV has the best performance even in a network with moving mobile nodes
- The higher the speed of mobile nodes the lower the throughput in the network
- The lowest throughput in the network is not influenced by the number of packets lost; it is about the routing overhead

On the transport layer, as we know, UDP Protocol is a Connection Less (CL) transport protocol. There is no confirmation of receiving data. It is more suitable in critical-time applications (real-time applications) than in no transmission error applications. This is obvious from our simulation. All these conclusions allow as stating the selection possibility of a certain configuration according to Network capabilities correlated with user/application availability. DSDV uses the proactive table-driven routing strategy while both AODV and DSR use the reactive On-demand routing strategy. Both AODV and DSR perform better under high mobility simulations than DSDV. High mobility results in frequent link failures and the overhead involved in updating all the nodes with the new routing information as in DSDV is much more than that involved AODV and DSR, where the routes are created as and when required.DSR and AODV both use on-demand route discovery, but with different routing mechanics. In particular, DSR uses source routing and route caches and does not depend on any periodic or timer-based activities. DSR exploits caching aggressively and maintains multiple routes per destination. AODV, on the other hand, uses routing tables, one route per destination and destination sequence numbers, a mechanism to prevent loops and to determine freshness of routes. The general observation from the simulation is that for application-oriented metrics such as packet delivery fraction and delay AODV, outperforms DSR in more "stressful" situations (i.e., smaller number of nodes and lower load and/or mobility), with widening performance gaps with increasing stress (e.g., more load, higher mobility). DSR, however, consistently generates less routing load than AODV. The poor performances of DSR are mainly attributed to aggressive use of caching and lack of any mechanism to expire stale routes or determine the freshness of routes when multiple choices are available. Aggressive caching, however, seems to help DSR at low loads and also keeps its routing load down. In the future, extensive complex simulations could be carried out using our simulation results, in order to gain a more in-depth performance analysis of the ad hoc routing protocols. TORA protocol performance could be studied too.

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