Performance Evaluation of MANET Routing Protocols in Disaster Situations

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Abstract *- The presented paper analyzes the performances of a mobile ad hoc network which may form in a disaster area, being based on exchanging messages with useful information among rescue teams, volunteers, ambulances and hospitals. The simulated scenario does not assume any support from networks with fixed infrastructure and stresses the conditions in order to see which protocol can better scale and react in such an environment. Therefore, there are no limitations to pre-established architectures/topologies. The purpose is to identify the particularities of a MANET in a disaster situation and determine future developments and techniques for improving the traffic flow, the allocation of resources and coordination of rescue and relief missions. The routing protocols under investigation are the table driven Destination Sequenced Distance Vector (DSDV) protocol, the source-initiated Ad hoc On Demand Distance Vector (AODV) and Dynamic Source routing (DSR) protocols. Network Simulator NS-2 and Network AniMator NAM were used to simulate the scenario and the performances were highlighted using graphic representations. Packet delivery ratio, end-to-end delay, routing overhead and throughput were considered relevant aspects for a communications system in a real disaster environment.*

Keywords*: MANET, routing protocols, disaster environment, performance analysis*

1. INTRODUCTION

Mobile ad hoc networks (MANET) are communication networks composed of mobile devices without being tied in any fixed topological infrastructure. The devices are not only the source and destination of the exchanged information, but they also act as intermediate devices to relay information from one device to another that is not within the communication range. Mobile nodes can be very effective in disaster situations, being able to route information towards different destinations and reach the rescue teams. If there are sensors attached to the node, they can provide further information related to the persons or surrounding conditions of the affected area [13]. Analyzing the information about the signal strength in relation to the environment, the number of hops between the emitter and the receiver, one can approximately determine the location of the victim when a GPS system is absent or not working.

Medicine is one of the fields that will benefit from the advantages that wireless technologies are offering. As a medicine branch, telemedicine is defined as "remote medical expertise by means of telecommunications and information technologies". The distance could be as small as a few meters (rooms in a hospital or home) or as large as tens of kilometers (connecting rural areas to city hospitals in disaster situations etc). Taking into account the number of terminal equipments implied in telecommunication schemes the scenarios that may appear are "one-to-one", "one-to-many", "many-to-many" and "many-to-one".

Wireless ad hoc networks and wireless sensor networks in collaboration with healthcare information technology can be extremely useful in disaster situations.

Following a disaster, whether natural or provoked, it is important for the personnel present in the area to have efficient and reliable means of communication. In such cases, the infrastructure may have been totally or partially destroyed, thus unavailable. As a result, mobile ad hoc networks provide the solution. The entire network must function independent of the existent networking present at the site, if any. MANETs offer higher reliability because packets can be sent over different routes if some node fails and also by their nature - these networks do not need further networking hardware, for example access points.

Many people trapped in the disastrous area under collapsed buildings or landslides may have a great chance of survival if they are rescued in 72 hours, also known as "the golden 72 hour" [1]. Rescue teams consist of few trained professional squads, army, police, fire fighters and many disorganized volunteers. If a part of the infrastructure is still available, the chances are that the intense use of phones by the general population would cause sudden and severe congestions in the phone system and block communication. For example, the largest telecommunication operator in Taiwan, ChungHwa Telecom, required 15 days of 24/7 operation to restore its mobile communication systems after the Jiji earthquake.

If volunteers would have mobile devices (notebooks, PDAs etc.) a MANET can form, including them and the rescue team. This way, the trained personnel may coordinate the volunteers and act in an

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Manuscript received November 13, 2009.

organized manner. Rescue and relief resources may be misplaced if communication between mission teams cannot take place. The information may need to spread over a large area and in this situation an effective multi-hop routing is necessary. Mobile ad hoc networks must form between ambulances and hospitals as well. In the case of a disaster, some hospitals may become over-saturated with victims and if others are brought to the same facility, they might not have the chance to survive because the personnel cannot provide them with the medical care they need. If the ambulances and the hospitals communicate, such vital information will be transmitted and will determine the change of route for the vehicles transporting the victims. The vehicles exchange this information as well and may be aware of the entire situation. If the MANET can spread itself sufficiently to reach an area where the infrastructure is available, the process of assisting the treatment of a victim may be delivered by medical personnel that has more availability to offer such information, while the specialists that are on site are overwhelmed with treating the victims that are already there.

Evaluations of network performances are necessary for a better understanding of network connectivity and resource sharing. Simulation methods can be used in this purpose. In multi-hop mobile ad hoc networks, the focus is on different types of routing protocols and medium access techniques.

Many research studies present hybrid architectures for disaster situations and develop systems that relay on a base station or are divided in collaborative zones. Such scenarios are based on well-aware and organized teams, but do not focus on the number of volunteers that might hinder the missions or, on the contrary, support it efficiently [2][3][5][11]. For the simulation of these scenarios a wireless-cum-wired environment was used.

The main purpose of this paper is to analyze the performances of routing protocols in mobile ad hoc networks, formed in disaster circumstances. Some particular characteristics are introduced. The simulated scenario does not assume any support from infixed infrastructure networks and stresses the conditions in order to see which protocol can better scale and react in such an environment. Therefore, there are no limitations to pre-established architectures/topologies and the particularities of a MANET in affected areas are highlighted.

2. AD HOC ROUTING PROTOCOLS OVERVIEW

In disaster situations, where infrastructure-less mobile ad hoc networks are best suited, packet switching is used for communication. Every node computes its own routing table and there is no central entity for administration. So, routing can be a challenging task in mobile wireless networks.

The considered characteristics of the network are:

- a fast-changing network topology;
- a destination wireless node, that may be multiple hops away from the source node;
- nodes which may switch on/off and move in/out at any time;
- the presence of sleeping nodes that may receive traffic just for themselves and not forward traffic to others.

These conditions do not allow the traditional dynamic algorithms implemented on wired networks to be also implemented on mobile ad hoc networks.

Routing systems can be classified in two main groups: proactive and reactive. In proactive systems, periodically, the nodes broadcast information about their routing tables, every node storing the routes to reach each other node from the network. By contrast, in reactive systems, the nodes request their neighbors to find a route only when it has a package to send. The routing system is the most vulnerable point of mobile ad-hoc networks, as such a network has no infrastructure, no fixed routers, but all nodes are capable of moving and being connected in an arbitrary manner [6].

The protocols under investigation are the table driven Destination Sequenced Distance Vector (DSDV) protocol, the source-initiated Ad hoc On Demand Distance Vector (AODV) protocol and Dynamic Source routing protocol (DSR).

2.1. The Destination Sequenced Distance Vector (DSDV) Protocol

The Destination Sequenced Distance Vector (DSDV) is a proactive mobile ad hoc routing protocol based on the traditional Bellman-Ford algorithm. Every node maintains a routing table with one route entry for each destination in which the shortest path (based on number of hops) is recorded. A destination sequence number is used to keep track of the changes that occur in the node’s neighborhood. Nodes always select among alternative routes based on the greatest sequence number, thus selecting the most recent information. The sequence number is incremented only by the node it is associated with [6].

The route updates of DSDV can be either time-driven (periodically) or event-driven. If a significant change occurs since the last update, a node can transmit its new routing table in an event-triggered style. There are two ways of sending the information. One is “full dump”, meaning that the full routing table is included inside the update and might need to span many packets. An incremental update contains only those entries whose metric has changed since last update and thus fits in one packet [8].

2.2. The Dynamic Source Routing (DSR) protocol

The Dynamic Source Routing protocol is a reactive routing protocol that utilizes source routing algorithm. This means that the source includes the full route in the packets’ header. The intermediate nodes use it to forward packets toward the destination and maintain a route cache containing routes to other nodes.

The functionality of the protocol is divided in two phases, the route discovery and the route maintenance.

If there is a new destination to reach, the source node will initiate route discovery. The node broadcasts route discovery request (RREQ) to its neighbors which can either reply to the initiator or forward the RREQ to their neighbors after having added their address to the request message. The route reply message can be returned to the initiator either using a route already present in the routing table or by following the path recorded in the RREQ.

When a node detects that it cannot send packets to the next hop, it will create a route Error message (RERR) and send it to the source of the data packets. This is how route maintenance id initiated. The RERR contains the addresses of the node that sent the packet and of the next hop that is unreachable. Upon arrival of the RERR, the initiator will remove all routes from its route cache that have the address of the node in RERR. It then initiates route discovery for a new route if needed [8].

2.3. The Ad Hoc On-demand Distance Vector Routing (AODV) protocol

The reactive Ad Hoc On-demand Distance Vector Routing (AODV) protocol uses hop-by-hop routing and adopts the destination sequence number technique, used by DSDV, in an on-demand way. Hop-by-hop routing is realized by maintaining routing table entries at intermediate nodes [8].

The route discovery operation is done by broadcasting RREQs. These RREQs contain the source and destination addresses, the broadcast ID - an identifier, the last seen sequence number of the destination and the sequence number of the source node. The RREQ starts with a small TTL (Time-To-Live) value, but it is increased in the following RREQ if the destination is not found. AODV uses only symmetric links (bidirectional).

HELLO messages are used to notify the presence of a node to its neighbors. Therefore, an active route can be monitored. When a node discovers a link disconnection, it broadcasts a RERR packet to its neighbors, which in turn continues the propagation of the the RERR packet. Then, the affected source can re-initiate a route discovery operation if the route is still needed.

AODV is designed to support the shortest hop count metric. This metric favors long, low-bandwidth links over short, high-bandwidth links.

2.4. Performance issues

A theoretical comparison between the two main categories of routing protocols, highlights the following aspects: Delivery Ratio – proactive protocols perform better than reactive protocols; End-to-end delay – proactive protocols perform better than reactive protocols; Routing load – reactive protocols perform better than proactive protocols [6].

Control traffic overhead and loop-free properties are two important issues when applying proactive routing to mobile ad hoc networks.

DSR has increased traffic overhead by containing complete routing information into each data packet, which may degrade its routing performance.

AODV is a reactive improvement of DSDV protocol. In AODV the overhead might be less as it keeps small tables to maintain local connectivity and it can handle mobility at high speeds, while DSDV cannot due to lack of alternative routes as it maintains only the best path instead of multiple paths.

DSR has a potentially larger control overhead and memory requirements than AODV since each DSR packet must carry full routing path information. DSR can utilize both asymmetric and symmetric links during routing, while AODV only works with symmetric links (a constraint that may be difficult to satisfy in mobile wireless environment).

All these theoretical aspects were evaluated through simulation in relation to disaster situations.

3. SIMULATIONS AND PERFORMANCES EVALUATION

A random scenario was created to reflect an area affected by a disaster, where roads might be destroyed and the urban infrastructure is no longer in a predefined state. To analyze the packet delivery ratio, end-to-end delay, normalized routing overhead and throughput of the network, the number of possible connections among nodes, their speed and pause time were varied. The varying number of connections is motivated by the possibility of nodes denying connections, moving in and out of the network, refusing to forward information or by collisions and route failures. The speed was modified to reflect the movement of ambulances or rescue teams, and the pause time was used to suggest stops caused by traffic jam or destroyed terrain.

The paper does not model or simulate any obstacles. The obstacles affect the mobility of nodes by hindering straight line movement. However, obstacles only appear in the incident location. The other areas are chosen by humans and larger obstacles at the disaster location will be removed by specialized teams. The smaller ones can be ignored, because they have little impact on the movement and communication between nodes. Radio propagation is not totally suppressed by obstacles, thus a complex radio propagation model including obstacles may be added in the future.

The routing protocols described in section II were simulated with Network Simulator environment, version ns-2.33. To define the load that every node intends to offer, two parameters were fixed: packet generation rate and packet size. Four packets per second were considered to be a reasonable rate. The number of transmitted packets may increase due to retransmission. Each packet contains several parameters reflecting the state of the sender. Security issues were not a main purpose of this study, but they were implicitly taken into account as additional fields in the packet, increasing its length to 512 Kb. All simulations were based on the wireless LAN standard 802.11Ext, assuming that the radio coverage area and the interference range are regular. The radio range has been set to 250 m, using the TwoRayGround propagation model. As movement pattern the Random WayPoint was used.

The movement scenario was generated using the *setdest* utility in NS2, with the number of nodes, the grid area, the maximum speed and pause time as parameters.

The scenario was created with a number of 50 nodes that are CBR (Constant Bit Rate) sources, in a grid area of 1500×300 meters, considered as a moderate scale network. The values of the speed were 1, 5, 10, 20 and 50 m/s and the pause times were 0, 30, 60, 120, 300, 600 and 900 seconds. The number of considered connections was 5, 10 and 20. The duration of each simulation was established to 900 seconds and for each interval, the initial layout of the nodes on the topography was in a random fashion, thus having also a spatial diversity.

The simulation focuses on the packet delivery ratio, end-to-end delay, normalized routing overhead and throughput under the modification of the above parameters.

The pause time was considered as a special parameter in mobility scenarios which means that a node stops for a period of time after a movement.

The packet delivery ratio, defined as the ratio between the number of packets originated by the application layer CBR sources and the number of packets received by the CBR sink at the final destination, was also considered.

The measured delay was established as the average end-to-end delay per flow, due to transmission, processing, collision and queuing of packets traveling from the source to the destination node.

Normalized routing overhead is the total number of routing packets divided by the total number of delivered data packets. In other words, the routing load means the average number of routing messages generated to each data packet successfully delivered to the destination. This metric provides an indication of the extra bandwidth consumed by overhead to deliver data traffic. An efficient routing protocol has a small routing overhead.

The throughput is the total number of packets received during the simulation over the communication channels.

Fig. 3.1, Fig. 3.2, Fig. 3.3 present the Packet Delivery Ratio in different situations, varying the pause time, the number of connections and speed.

Small values of pause time suggest a greater mobility, thus the topology changes rapidly, the nodes are in the range of each other for shorter periods of time and the routing updates and answered requests may carry false information.

DSDV has the best performance in this case (Fig. 3.1). DSR and AODV have similar results, but all three protocols show an improvement as the pause time increases. For a pause time of 900 seconds, all protocols reach 100% Packet Delivery Ratio.

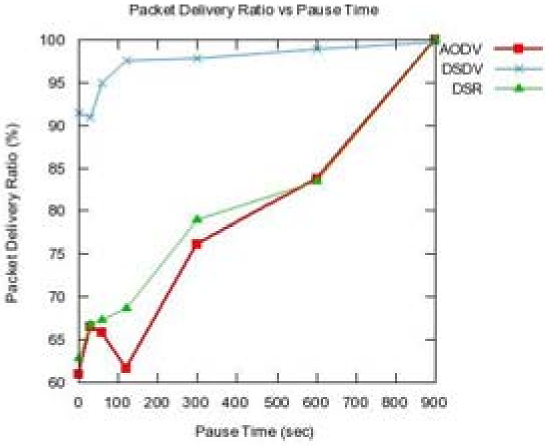

Fig. 3.1. Packet Delivery Ratio versus Pause Time: Speed = 20 m/s , No. of connections = 10.

With speed increasing, more broken links appear and for a greater number of connections established between the nodes, more collisions may appear. This depends on the unexpected changes in topology. Considering the wide area, establishing fewer connections may prove to be un advantage. As the number of connections grows, there are more alternative paths for sending the information, but it becomes harder to handle the routing information and the searching process in the routing table.

DSDV performs best, followed by DSR and AODV. None of the protocols reach a 100% Packet Delivery Ratio (Fig. 3.2).

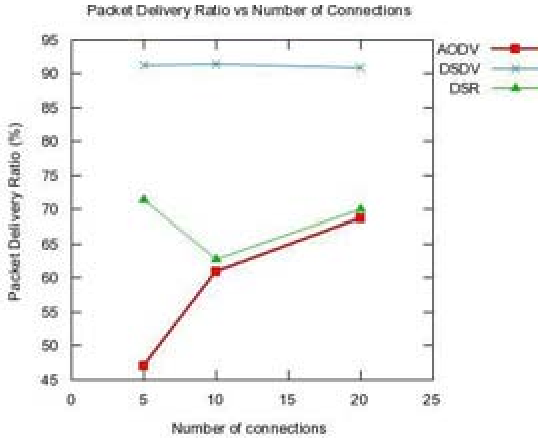

Fig. 3.2. Packet Delivery Ratio versus Number of connections: Pause Time = 0 sec , Speed = 20 m/s.

Speed is another mobility parameter. It refers to the movement of nodes between an initial point and destination point, where they stop and wait for a period of time equivalent to the value of pause time.

As speed increases, the performance decreases. AODV and DSR do not entirely follow this pattern, as for a speed of 20 m/s have a lower Packet Delivery Ratio than for a speed of 50 m/s. Although being at a greater speed, if the nodes are moving in the range of each other, the communication can take place. DSDV is the best protocol for this situation (Fig. 3.3).

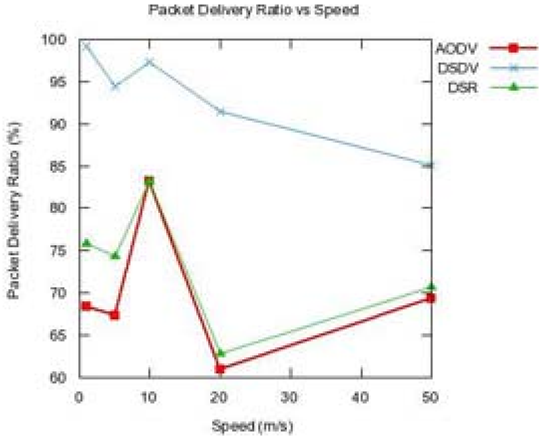

Fig. 3.3. Packet Delivery Ratio versus Speed: Pause Time = 0 sec , No. of connections = 10.

Fig. 3.4, Fig. 3.5 and Fig. 3.6 are the representations of the average end-to-end delay in the given scenario, for an area of 1500x300 meters with 50 nodes that have varying pause time, speed and number of connections.

The end-to-end delay presents some variations, but considering that these are measured in milliseconds [ms], they are not critically significant. One of the assumptions for the scenario of a disaster is that only basic tele-emergency services will be provided and not complete multimedia services. The basic services refer to still images, ECG, oxymeter information, patient database record access, location information and all of the communication situations presented in the Introduction section.

DSR performs best, but AODV follows closely and both are stable. The traffic is not evenly distributed and this causes DSDV to have good results even in the case of higher mobility, but overall, it is the last of the three protocols in the hierarchy of delivered performance (Fig. 3.4).

As the number of connections increases, the delay is significantly higher than in the previous evaluation. More connections may lead to more hops towards the destination, the destination may be further away and there are more alternative paths.

DSR has the best end-to-end delay, followed by DSDV with values ranging from 45 ms to nearly 100 ms. AODV reaches almost 800 ms of delay, but for 20 connections improves significantly (Fig. 3.5)

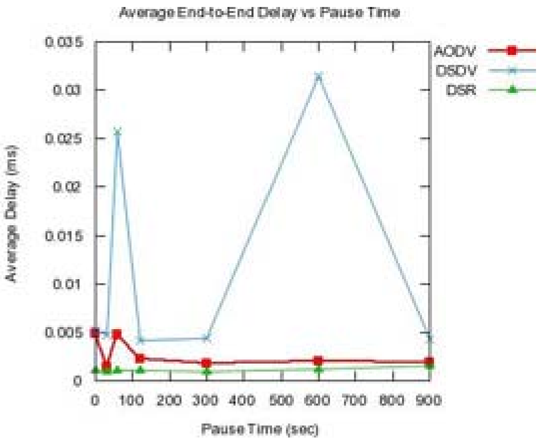

Fig. 3.4. Average end-to-end delay versus Pause Time: Speed = 20 m/s , No. of connections = 10.

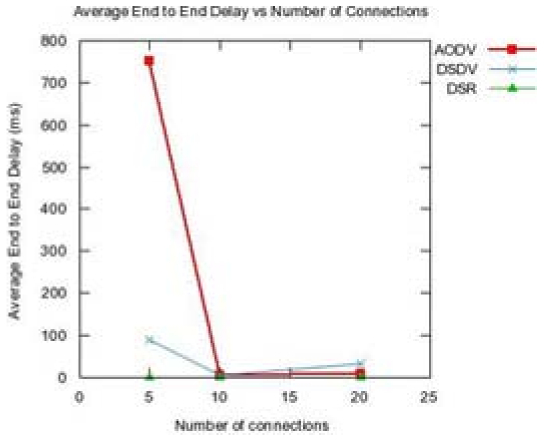

Fig. 3.5. Average end-to-end delay versus Number of connections: Pause Time = 0, Speed = 20 m/s.

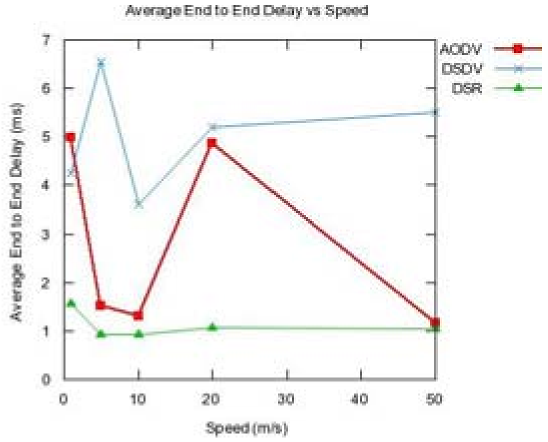

Fig. 3.6. Average end-to-end delay versus Speed: Pause Time = 0 sec , No. of connections = 10.

Increasing the speed of nodes (Fig. 3.6), the performance suffers degradation, mainly when using DSDV protocol. A value of 0 seconds for the pause time means high mobility. Taking into account also the speed, the end-to-end delay has better results than the case presented in Fig. 3.5. Numbers of connections and the changes in topology have been advantages for the scenario. DSR performs better than AODV which outperforms DSDV.

Fig. 3.7, Fig. 3.8 and Fig. 3.9 are the representations of the normalized routing overhead.

A relatively stable normalized routing overhead is a desirable property for the scalability of protocols. A major contribution to AODV routing overhead comes from route requests, while route replies constitute a large amount of DSR's routing overhead.

Whenever several nodes propagate a given routing message, the transmission on each hop is counted once in the total number of routing messages. These messages have been in a smaller number when DSDV protocol was used, followed in performance by DSR and finally by AODV (Fig. 3.7).

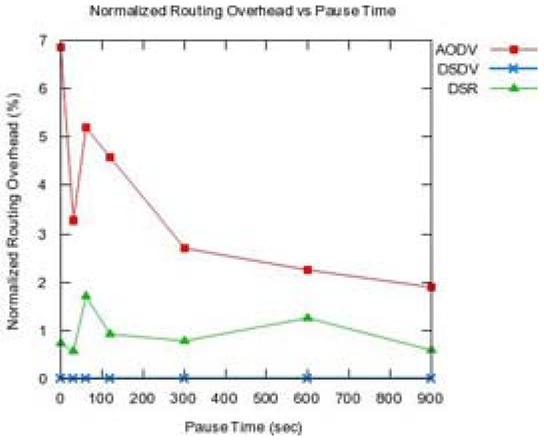

Fig. 3.7. Normalized Routing Overhead versus Pause Time: Speed = 20 m/s , No. of connections = 10.

As the pause time increases, which means the nodes remain in a position for a longer period of time, the performance improves for all three protocols.

The Normalized Routing Overhead has greater values as the number of connections increases (Fig. 3.8). The performance degrades due to limited resources, specific characteristic of the mobile nodes. The communication process is intense and it causes a cache overflow in busy nodes. While the protocol performs the route discovery, the application layer continues to generate packets. If the route is not discovered and the queue fills, the packets in the queue will be discarded.

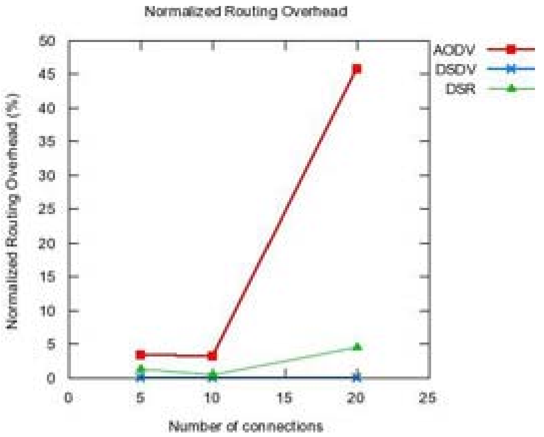

Fig. 3.8. Normalized Routing Overhead versus Number of connections: Pause Time = 0 sec , Speed = 20 m/s.

Given the moderate mobility, DSDV delivers better results than DSR and AODV. The latter nearly reaches 50% of Normalized Routing Overhead.

Fig. 3.9 shows that AODV has the greatest values for this metric and it affects the Packet Delivery Ratio as well (see Fig. 3.3).

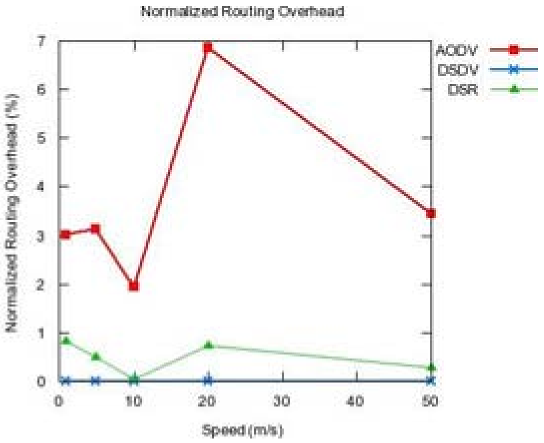

Fig. 3.9. Normalized Routing Overhead versus Speed: Pause Time = 0 sec , No. of connections = 10.

DSDV informs itself about the topology of the network in a proactive manner, so it keeps track of the changes and has the best results. DSR follows closely the performance of DSDV and is stable, contrary to AODV.

DSR has a lower routing overhead than AODV due to caching strategy used by DSR. DSR is most likely to find a route in the cache and therefore resorts to route discovery less frequently than AODV.

Fig. 3.10, Fig. 3.11 and Fig. 3.12 show the throughput of the MANET for the three routing protocols.

Varying the pause time, having a number of 10 connections and a speed of 20 m/s, DSDV has a greater value for throughput than AODV and DSR. The simulation runtime may affect the throughput decreasing because of queuing delays.

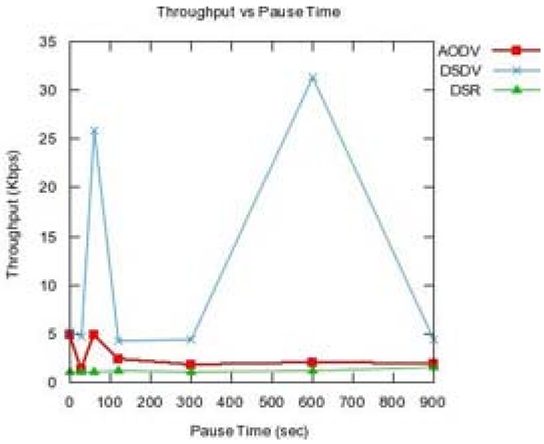

Fig. 3.10. Throughput versus Pause Time: Speed = 20 m/s , No. of connections = 10.

The number of connections positively influences the throughput, offering more paths in the network. Compared to the previous situation, all three protocols perform better, approaching 35 kbps in the case of DSDV and 27 kbps for AODV and DSR (Fig 3.11).

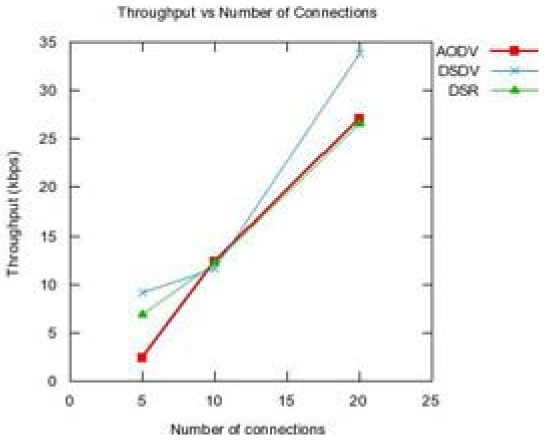

Fig. 3.11. Throughput versus Number of connections:
Pause Time = 0 sec , Speed = 20 m/s.

The speed produces rapid changes in topology and nodes leave the range of one another unpredictably. This also has an impact on contention at the MAC layer and affects overall throughput. As seen in Fig. 3.12 the values of the performance parameter are smaller than in the cases of modified pause time and number of connections, only approaching 17 kbps. Having the pause time of 0 seconds, the mobility is increased and with only 10 connections, the alternative paths in the networks are not so many and not so hard to maintain. DSDV's performance drops dramatically, but maintains itself above 9 kbps. AODV reaches its peak of 17 kbps for this scenario, closely followed by DSR.

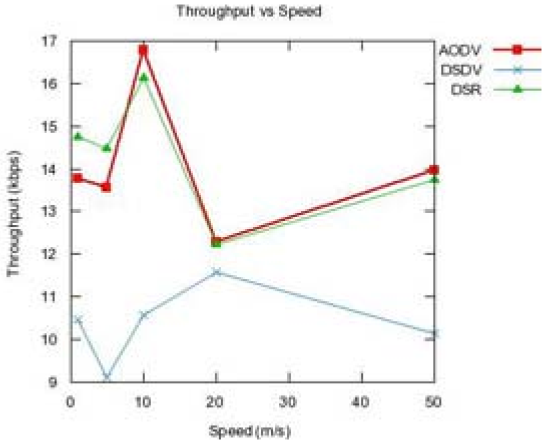

Fig. 3.12. Throughput versus Speed:
Pause Time = 0 sec , No. of connections = 10.

On-demand routing protocols, AODV and DSR, broadcast route requests (RREQ) for route discovery. In disaster circumstances, this may be a concern because RREQ packets generated from massive nodes may cause traffic congestion and communication failure. High mobility requires frequent route discoveries. In the case of DSDV, the network evolves into intense traffic conditions since the changes in topology happen suddenly and simultaneously.

4. CONCLUSIONS

This study evaluated the performances of different routing protocols in order to choose the best one for communications in disaster situations without limitations to pre-established topologies/architectures and using a pure MANET. The protocols are compared in terms of packet delivery ratio, average end-to-end delay, routing overhead and throughput using the ns-2.

The simulated scenario is dynamic, stressing the conditions, although in a disaster situation speed might not always be a main matter of choice. The illustrated results show that all metrics improve when mobility is reduced, thus approaching the situation in which a disaster area may hinder the movement of vehicles and humans as well.

Because both periodic and triggered updates are used, the performance of DSDV is tightly related to node movement. It has the best performance for the metrics of Packet Delivery Ratio and Normalized Routing Overhead.

AODV doesn't advertise routing updates, hence the packet delivery ratio is stable. In DSDV it decreases as it needs to advertise periodic updates and event-driven updates.

DSR does not perform so well in case of high mobility, but is satisfactory for the greater number of simulated connections. It proves to be the best of the on-demand routing protocols.

In general, both AODV and DSR work well in medium size networks with moderate mobility.

DSDV performed better than AODV and DSR in relation to Packet Delivery Ratio, Normalized Routing Overhead and Throughput. Throughput is affected by high mobility over a large area, suggesting that DSDV will provide better performance on smaller areas. DSDV, being proactive, causes greater energy consumption and adapts harder to large areas and intense mobility. Because the performance analysis was made in relation to a disaster situation, without fixed infrastructure and other assumed resources, the protocol must be able to scale and react promptly. These conditions and DSDV's area restrictions, make DSR the best choice in case of a disaster.

A significant aspect in ad hoc networks is the consumption of energy [9]. This issue is significant in relation to the environment, such as a disaster, in which recharging of devices might not be possible. Still, the network must keep on transmitting the emergency signals. Therefore, for future development, the chosen routing protocol, DSR, must be modified in order to reduce extra transmission, this implying also reduced energy consumption.

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