Performance Analysis of Multi-Homed Hybrid Ad Hoc Network

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ABSTRACT
Mobile Ad Hoc Networks consist of a number of self organized mobile nodes with routing capabilities that are commonly known as hybrid ad hoc networks when connected to a fixed network. When more than one gateway join a MANET to a fixed network, packets belonging to the same ongoing connection may pass from one network to the other using different gateways. This is typically the case of mobile nodes when they lose their routes versus a given gateway and then find new ones that pass throughout a different gateway to reach their destinations. This phenomenon may cause performance problems whose extent depends on the type of connection, the mobile node address management and routing protocols used in both fixed and mobile networks. In this paper, we examine these problems for real time and non-real time services connections between MANET and fixed nodes. We focus on three different scenarios, where the AODV, the OLSR, or the OSPF with MANET extensions are used as the MANET routing protocol. In all three scenarios, OSPFv2 is used as the Internal Gateway Protocol on the fixed network. Our analysis shows that the AODV presents the best performance in terms of network delays.

Keywords
Manet; hybrid ad hoc network; multi-homed; Manet gateway

1. INTRODUCTION
Communications among mobile hosts that are away from networks structures presents a major challenge, and the use of MANET (Mobile Ad Hoc Networks), which consists of a number of self organized mobile nodes with routing capabilities, provides a possible solution [1][9]. Much of the MANET research has primarily focused on its performance without considering how they behave when connected to a fixed network.

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The integration of MANETs and fixed infrastructures, as Internet, must be carefully studied in order to evaluate its capabilities, specially for the adequate transportation of multimedia real time information. In such integrated scenario, commonly known as hybrid ad hoc networks, a MANET can be seen as an extension to the existing infrastructure, whose mobile nodes may seamlessly communicate to those on the fixed network by means of gateways found on the edge with join both type of networks.

Performance of hybrid ad hoc networks are strongly impacted by node mobility on the MANET. Two of the aspects that may affect this performance, specially for real time traffic, are MANET nodes address allocation and gateway changes when traffic is being forwarded between MANET nodes and fixed networks nodes. When users on MANETs move around, they may find themselves on a different MANET sub network from where they registered and got their address from, and for that reason their IP address must be changed accordingly, while ongoing connections must be maintained and the packets belonging to these connections must be delivered continuously [2][10]. After changing addresses, mobile nodes will require to use a different gateway to continue forwarding and receiving packets that flow between the MANET and the fixed network; the one associated to the new sub network. Address and gateways changes may cause packet delivery interruption, packet losses and even connection losses that securely may affect communication between moving objects and fixed nodes.

The performance of an hybrid ad hoc network must specially be considered when it is desired to have support for multimedia real time and streaming applications, for which QoS requirements in terms of packet losses, delay and jitter are more stringent than those characterizing data applications [3]. This is especially true when these applications must be established between nodes placed in both, the fixed network and the MANET, because as a consequence of node mobility, ongoing connections must change frequently the paths used to find their destinations, and some times, the gateways used to traverse from one network to the other.

In this work, a comparative evaluation is made between the QoS performance of three possible scenarios of an hybrid ad hoc network; one in which a MANET using a proactive protocol like Optimized Link State Routing Protocol (OLSR) connects to a wired network using a popular Internal Gateway Protocol (IGP) protocol like Open Shortest Path First (OSPF), one in which the MANET part uses a reactive protocol like Ad-hoc On-Demand Distance

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Vector (AODV), and one in which the MANET part uses OSPF with MANET extensions. In these scenarios, we consider that the interconnection between the MANET and the fixed network is made by means of two or more gateways placed away from each other allowing the formation of different sub networks; one associated to each gateway. Then, a mobile node will be allowed to move from the vicinity of one gateway to the vicinity of the others while maintaining voice and FTP connections with a host placed on the wired network. For this scenarios, evaluations are made of packet losses, delay and jitter when, while data packets are being transferred, different gateways have to be used as a consequence of loosing and gaining routes versus the destination.

Other authors have also studied similar scenarios. Ros *et al.* [2] presented results for Packet Delivery Radio, Gateway Discovery Overhead, Normalized Control Overhead, and Average End-To-End Delay when UDP connections for two MANET Protocols: AODV and OLSR. In this case, node mobility was set to follow random paths. Engelstad *et al* [1] proposed the use of modified Mobile IPv4 Foreign Agent (MIP-FA) or Network Address Translation (NAT) and links between gateways to maintain ongoing TCP connections. Spagnolo and Henderson [4] evaluated the advantages of using OSPF with MANET extensions as MANET routing protocol when OSPF is used on the wired network. They propose ways to avoid that frequent Link State Advertisements (LSA) coming from the MANET increase congestion and disturb the IGP on the fixed network.

The rest of this work is organized as follows: in Section 2, the scenarios to be evaluated are presented, describing how address are allocated on MANET nodes, how gateways are chosen, and a brief description of MANET routing protocols is presented. In Section 3, a more detailed description of the scenarios is presented and a conceptual analysis of the events that occur when a mobile node engaged in a voice and in a FTP connection with a node on the fixed network, have to change the gateway used to forward its packets. Finally, on Section 4, results and conclusions are presented.

2. THE MULTI-HOMED SCENARIOS

Hybrid ad hoc networks, as it is shown in Figure 1, are composed of three different parts: 1) The fixed network, where hosts remain always in the same sub network without changing their address prefixes, and a traditional IGP protocol, like OSPF, is used to find usable routes. 2) The MANET, where mobile hosts may move and change their sub network associations and their IP addresses, besides running a MANET routing protocol to find usable routes. 3) The gateways, which are special routers that connect the MANET to the fixed network, allowing not only that data packets traverse from one network to the other, but that the routing protocols from each of the networks may share their known routes. In order to do its work, gateways must have at least one interface belonging to the fixed network running the IGP routing protocol and one interface belonging to the MANET running the MANET routing protocol. When two or more gateways connect the MANET to the fixed network it is referred as Multi-Homed Hybrid Ad Hoc Networks, and mobile nodes must choose between them for setting their addresses and for forwarding packets versus the fixed network. The time a mobile node takes to find a new route to a gateway when the one is using becomes lost is different between the different MANET routing protocols, and thus the impact over ongoing connections will also be different.

Before better analyzing the scenarios, a description is made of how address are allocated on MANET nodes, how gateways are chosen, and a brief description of MANET routing protocols is presented.

2.1 Address Allocation

Address allocation on MANET nodes that connect to the Internet is preferably done by using a stateless auto-configuration mechanism based on network prefixes advertised by one or more gateways nodes[5]. This solution is adopted because it deals better with network partitions. Alternatively, it may be handled by means of a centralized entity, which is known as a stateful auto-configuration mechanism. With stateless auto-configuration, mobile nodes set its IP address according to the network prefix announced by the closest gateway, usually measured in hop counts. Since each gateway announces a different one, it is possible the formation of subnets of nodes sharing a common network prefix, that not only will help on reducing routing table sizes and on easing packet forwarding over MANETs, but also facilitates summarization of MANET routes propagated towards the fixed network on each gateway. As a consequence of node mobility, typical on MANETs, when a node enters a different subnet area from which it got its address from, it must selects a new gateway and changes its IP address in correspondence whit the new gateway prefix before continuing to forward packets versus the fixed network[1]. A node realizes that is in a zone belonging to a different sub network, when it recognizes that its distance to another gateway is less, than that from its current gateway. Address reallocation is done dynamically according to object mobility, thus, routing tables on MANET nodes and gateways will have to adjust their routes and summaries, which may cause, beside connection and packet losses, packet forwarding delay.

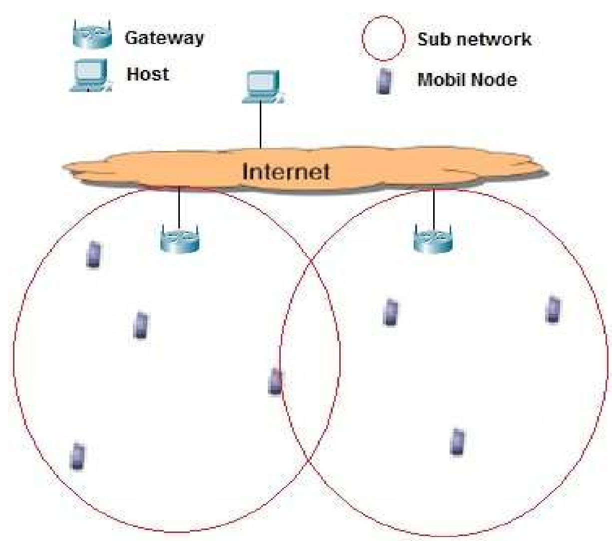

Figure 1. Hybrid Ad Hoc Network.

2.2 Gateways

The paths chosen to forward packets between mobile and fixed networks also affect the communication performance. Before setting its address, MANET nodes must select a gateway for

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traffic forwarding to the fixed network. Gateways discovery may be done using one of two mechanisms: a reactive one and a proactive one[6]. In the reactive version, when a node requires global connectivity, it issues a request message which is flooded throughout the MANET. When this request is received by a gateway, it sends a message which creates reverse routes to the gateway on its way back to the originator. The proactive approach is based on the periodic flooding of gateway advertisement messages, allowing mobile nodes to create routes to the Internet in an unsolicited manner. If nodes receive routes to more than one gateway, they choose the closest one measured in number of hops, but only on the proactive approach, nodes may be sure that the selected gateway will be always the closest one, since on the reactive approach gateway updates only occur when its routes are lost. Once a gateway is chosen, forwarding packets versus the fixed network may be done either using source routing, which permit forwarding packets trough a selected gateway, or by using default routes, which will forward packets trough the node's associated gateway. The first approach brings more overhead due to the additional header, but it is a flexible solution because nodes may choose a most convenient path to forward packets. On the other hand, on the second approach nodes expect that the remaining nodes correctly forward data packets to the associated gateway. If nodes move to a different sub network, they will have to use a different gateway for packet forwarding into the fixed network after having changed its address.

Forwarding packets to the MANET also has its issues. In order to reduce the effects that over the fixed network raise as a consequence of frequently link changes on the wireless network, solutions like summarization can be implemented to mitigate the Internal Gateway Protocol exposure, but at the expense of reducing granularity on the MANET routing paths, and thus, increasing delay and jitter. It may be even necessary to implement tunnel links between gateways to reroute packets in the case they try to enter the MANET using the wrong gateway. Summarization works better when mobile nodes set its address using gateways prefixes, because every node on a MANET sub network may be reached with an unique network route. Concluding, changing the gateway to use for incoming and outgoing packets transmission in an hybrid ad hoc network during ongoing connections may also have an impact on packet losses, delay and jitter.

2.3 MANET Protocols

The MANET routing protocol used on hybrid ad hoc network also affects their performance significantly when nodes moves between different MANET sub networks. Standard MANET protocols may be grouped in two types: Reactive MANET Protocols and Proactive MANET protocols[7]. Reactive protocols discover routing paths only when traffic demands it, and as a result, when there are route changes, trading off longer packet delays in the interest of lower protocol overhead. AODV is an example of a reactive routing protocol. Proactive protocols maintain and regularly update full sets of routing information, trading off greater protocol overhead and a higher convergence time in the interest of smaller packet delays. OLSR is an example of a proactive routing protocol. Paradoxically, reactive protocols tend to take less time than proactive protocols to recover from the effects of route losses as a consequence of node mobility, because they take less time to declare lost routes than does proactive protocols. One important aspect to consider about classical MANET routing protocols is that none of them was developed taking into account its integration with any commercial Interior Gateway Protocols, in such a way that routes exchange between them could be done in the most efficient manner. Open Shortest Path First with MANET extensions is a MANET proactive protocol proposed to deal with this integration issue when OSPF is used on the wired network.

Each MANET routing protocol reacts differently when mobile nodes move between different MANET sub networks and have to change their address and the associated forwarding gateway in order to keep their ongoing connection active. The important parameter to observe is the time taken for each protocol to reach convergence, because it may affect ongoing communications. To understand better their behavior, a brief description of each MANET routing protocol follows.

2.3.1 AODV[8]

AODV only focus on learning about those neighbors that are useful in order to transmit data to a particular destination. To learn about a new destination, a Route Request (RREQ) is broadcast within a specified area, initially set at 1 hop. With each failed Route Request, the broadcast area is increased. When the RREQ reaches a node that has information to the required destination, it responds with a Route Reply message. If an active route fails, a Route Error is sent from the node that has noted the failed link and a new RREQ is initiated. Active routes in AODV are maintained via periodic Hello messages. According to RFC 3561, Hello messages are transmitted with a frequency of 1 seconds, and if a Hello from an active node is not received within 2 seconds, the route is considered unreachable, a Route Error message is broadcast to all nodes, and another series of Route Requests are broadcast.

2.3.2 OLSR[7]

OLSR is a proactive protocol in which periodic HELLO messages are used to establish neighbor links and to distribute MultiPoint Relays (MPRs), determined by a particular algorithm. Hello messages track link connectivity. Topology Control (TC) messages, distributed by MPRs, propagate link state information throughout the network, and are broadcast periodically as well as when there is a change to the topology. Control traffic consists of periodic hellos and TC messages. Overhead is controlled by MPR broadcast and redistribution of TC messages throughout the network, rather than broadcasts of link state from each router.

2.3.3 OSPFv3 with MANET extensions[4]

OSPFv3 with MANET extensions Hello messages are used for neighbor discovery. MANET Designated Routers (MDRs) are chosen based on 2-hop neighbor information learned from Hellos and are distributed in subsequent Hello messages. As in OLSR, Hello messages track link connectivity. If a Hello has not been received within 6 seconds, the link is declared down and a new Link State Advertisement is distributed. Database Description and Link State Advertisements (LSAs) are distributed by MDRs to share the network's complete picture. OSPFv3-MANET uses MANET Designated Routers (MDRs) to control overhead, similar to OLSR's use of MPRs. A range of overhead control is available and LSA flooding can vary from minimal flooding by MDRs only, to full

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LSA flooding by all routers, similar to that of the OSPFv2 protocol.

The time each protocol takes to help nodes discover a new gateway, get its address and find adequate routes to a given destination in the presence of nodes mobility heavily impact hybrid ad hoc networks performance. Table 1 shows the main differences between control packet sizes and timing between these protocols. Similarities between OLSR and OSPFv3 MANET routing protocols are clear, since both are proactive protocols that try to maintain updates to every possible route on the MANET, but at the cost of increased congestion and larger routing tables. On the other side, although it will not have routes ready to begin forwarding packets immediately, AODV only keeps routes on its table for requested destinations, reducing thus congestion and routing table size. Additionally, and most important, AODV takes less time than OLSR and OSPF to react on the event of lost routes. Even more, AODV is only interested in recuperate those specific routes that are lost and not routes to every possible destination.

Table 1. Main Parameters of the MANET Protocols

	AODV	OLSR	OSPF
Route Discover	• Route Request • Route Reply • Hello (1 sec)	• Hello (2 sec) • TC (each 5 sec)	• Hello (2 sec) • LSA s (as needed)
Lost Route	No Hello within 2 seconds	No Hello within 6 seconds	No Hello within 6 seconds
Message	• Route Requests (24 bytes) • Route Replies (20 bytes) • Route Errors (20 bytes) • Hello messages (4-6 bytes)	• Hello (8 bytes + 4 bytes for each neighbor interface) • Topology Control (4 bytes + 4 bytes per advertised neighbor)	• Hello (36 bytes + 4 bytes per neighbor) • Router-LSAs (20 bytes + 40 bytes per neighbor)

3. PERFORMANCE ANALYSIS IN MULTI-HOMED SCENARIOS

As shown in Figure 1, the scenarios that we analyze in this paper consider the interconnection between the MANET and the fixed network by means of two gateways placed away one from the other. A mobile node will be allowed to move from the vicinity of one gateway to the vicinity of the other following a straight path. Then, measures of packet losses, delay and jitter are evaluated while this node maintains a voice and a FTP connections with a host on the wired network. In all the scenarios there will be one mobile node, several fixed nodes and two gateways on a MANET using 802.11b at 2 Mb/s with a radio range of about 250 meters each one, placed all in a rectangular area of approximately 1000 x 1000 m^2. The gateways will be placed on different corners of one side of the considered area and the fixed nodes will be placed randomly distributed at the vicinity of each one the gateways, allowing the formation of two distinct sub networks. The gateways connect the MANET to the fixed network which is running OSPFv2. The routes announced from the MANET to the fixed network, if necessary, may have a fixed cost, and may be summarized in order to reduce frequently routing update exposure coming from the MANET. It will be considered the cases in which on the MANET side it is used AODV, OLSR and OSPF with MANET extensions as the routing protocol.

Each gateway will provide a different prefix address to the MANET nodes. The mobile node will then set its IP address in correspondence to the public prefix announced by the closest gateway. Alternatively, node addresses may be manually fixed or dynamically auto-assigned using private address, which can later be translated to public address by means of NAT servers loaded on gateways. In either case, when a node moves closer to a different gateway from which it got its original address, it must set a new one that corresponds to the new sub network prefix, and use it to forward packets towards the fixed network through the new gateway, either using default route, or using source routing. On their way back, packets coming towards nodes on MANET should enter, passing throughout the same gateway used by the packets exiting the MANET. This is not always true, especially when, to reduce frequently routing update exposure coming from the MANET, route summarization is implemented on gateways, hence reducing granularity on MANET routes. In order to avoid packet loosing when return packets try to enter MANET using the wrong gateway, physical links between gateways should be implemented.

The main objective of this study is to compare real time traffic performance for the three MANET routing protocols, when a moving MANET node maintains a voice and a FTP connection whit a node on the fixed network, and the MANET is connected by means of two or more gateways to the fixed network running OSPFv2. The considered metrics to evaluate the MANET protocol performance are:

- Packet Delivery Ratio (PDR): The ratio of the number of data packets received to the number of data packets transmitted
- End-to-End Delay: The time needed to deliver a packet from the data source to the data destination
- Jitter: Variability of End-to-End Delay

3.1 Scenario 1

AODV-Voice/FTP. We first consider the case in which a voice connection is established between a mobile node in a MANET running AODV and a node in a fixed network running OSPF. When a node on MANET needs to forward packets, but does not have a valid route to its destination, it broadcast a request. This request is forwarded by neighbor nodes until a route is found. For destinations outside MANET, gateways, if present, will respond with a valid route. Among those that respond to, the originating node chooses the closest gateway, from which it also gets its address prefix, which will be used to forward its packets. The gateway will forward all packets received from the mobile node towards its destination on the fixed network. Return packets will use the same gateway in its way back to the originating node. When mobile nodes move and routes get lost, they use new requests to find new routes. If founded, this new routes may or may not use the same gateway for destinations outside MANET. In any case, until new routes are found, there will be a time where packets will not be forwarded or will be lost. This time is not always the same, and will depend on the links that are set or lost between mobile nodes, but will always be superior to 2 seconds, which is the time needed before declaring a route as lost. If as a consequence to node mobility, a node needs to use a different gateway, then it will

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also have to change its address, but this should not affect ongoing voice connections since it uses UDP as transport protocol. It is important to note that since AODV is a reactive protocol, as long as there is a valid route, it will not notice if the mobile node is closer to a different gateway from which it got its address prefix from, and then, it will continue to forward packets to its original gateway, even if they take a longer path, until the route is lost.

For FTP connections, which use TCP as transport protocol, route changes that go throughout the same gateway will cause the same type of problems found on voice connections; more than 2 seconds gaps for any route change. For route and gateway changes, FTP connections will be lost, unless a mechanism is used for identifying hosts with an unique public address, like Mobile IP, which is a mechanism that permit mobile hosts to be assigned an unique public address along with its sub network associated address. It is required that host must registering to servers that keep track of their actual network position[1]. In this case, an additional retard on return packets will appear caused for the longer path that packets will have to take. Additionally, permanent links have to be established between gateways to reroute packets that try to enter MANET using the wrong gateway. Being AODV a reactive protocol, it will not generate as much routing traffic as proactive ones, thus it will not be required to summarize MANET routes to reduce exposure over OSPF on the fixed network, hence there will be better chances that return packets find better routes.

3.2 Scenario 2

OLSR- Voice/FTP. In this scenario, a voice connection and a FTP connection is established between a node in the MANET running OLSR and a node in the fixed network running OSPF. Without needing to forward any packet, nodes on MANET discover routes to any possible destination by establishing neighborhood relations to some nearby nodes. Besides its known routes, gateways on MANET will announce routes to the fixed network as a default route. Mobile nodes choose, between those routes learned going outside MANET, the one with the closest gateway, from which it will also get its address prefix, which will use to forward its packets. The gateway will forward all packets received from the mobile node towards its destination on the fixed network. Return packets will use the same gateway in its way back to the originating node. When any mobile node moves, and link connections are added or lost, routes must be recalculated on the whole MANET. New routes going outside the MANET may or may not use the same gateway. In any case, there is a hold time before declaring a route to be lost, in which, packets forwarded using lost routes will also be lost. The time to discover new routes is not always the same, and will depend on the links that are set or lost between mobile nodes, but will always be superior to 6 seconds, which is the time needed before declaring a lost route. Since OLSR is a proactive protocol, any route recalculation on MANET will make nodes notice if they are closer to a different gateway from which they got their address prefix, so they will change address according to the new prefix before continuing to forward packets throughout the new gateway, but this should not affect either type of connections.

On the other hand, for FTP connections, route changes using the same gateway will cause the same type of problem found on voice connections: more than 6 seconds gaps for any route change. For route and gateway changes, FTP connections will be lost unless a mechanism is used for identifying hosts with an unique public address, like Mobile IP. In this case, an additional retard on return packets will appear caused for the longer path packets will have to take and permanent links have to be established between gateways to reroute packets that try to enter MANET using the wrong gateway. Being OLSR a proactive protocol, it will generate so much routing traffic that MANET route summaries will be required on the fixed network in order to reduce routing exposure over OSPF, but this will decrease granularity on MANET routes, reducing the chances of finding better routes.

3.3 Scenario 3

OSPF- Voice/FTP. In this scenario, a voice connection and a FTP connection is established between a node in the MANET running OSPF with MANET extensions and a node in the fixed network running OSPF. This scenario is similar to scenario 2 since in both cases it is used a MANET proactive protocol. Even the time for declaring a lost link/route is the same (6 seconds). Thus, the same behavior as in scenario 2 is found: The time to discover new routes will always be superior to 6 seconds. Nodes will notice if they are closer to a different gateway from which they got their address prefix, so it will have to change address, but this should not affect ongoing voice connections. For route and gateway changes, FTP connections will be lost unless a mechanism is used for identifying hosts with an unique public address, like Mobile IP, but additional retard on return packets will appear and permanent links have to be established between gateways to reroute packets. OSPF with MANET extensions will also generate so much routing traffic that MANET route summaries will be required in order to reduce exposure over OSPF on the fixed network, but thus will decrease granularity on MANET routes.

4. RESULTS AND CONCLUSIONS

A resume of the characteristics of each scenario is presented in Table 2, together with the impact that will suffer ongoing connections when a MANET node moves between different sub networks, and thus having to use different gateways to forward packets versus the fixed network.

Table 2. Expected behavior for each routing protocol

	AODV	OLSR and OSPF
Behavior	• 2 seconds to declare lost routes • Only rediscover lost routes • Minor routing congestion	• 6 seconds to declare lost routes • Rediscover every routes • Major routing congestion
Mobility Impact	• Do not require route summarization • Do not require gateway interlinks • PDR will be smaller • End-to-End Delay will be bigger • Jitter will be smaller	• Require route summarization • Require gateway interlinks • PDR will be bigger • End-to-End Delay will be slower • Jitter will be bigger

It may be seen that there should not be mayor differences between OLSR and OSPF performance since they have similar characteristics: both are proactive protocols with similar timing design, and

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both react to route losses trying to rediscover every possible route, and thus both generate significant congestion.

On the other hand, even though AODV takes a longer time before a node may begin transferring packets, it will react faster to gateway route losses than OLSR and OSPF, not only because OLSR and OSPF will take 4 more seconds than AODV to declare a valid route as lost, but because AODV only recover a route when that one needed is lost. OLSR and OSPF recover every route when any route is lost.

From these characteristics presented, it may be inferred that the PDR will be higher on AODV than in OLSR and OSPF. In other words, packets in AODV won't be delivered from the moment that a route to a gateway is lost until it is rediscovered. This time includes 2 seconds to declare a route as lost, and an additional time until that particular route is found. How many packets are lost will also depend on its generation rate and on node buffer size. OLSR and OSPF use 6 seconds to declare a route as lost, and will take a longer time to find again every possible route. Additionally, besides generating more congestion, OLSR and OSPF will stop from forwarding any packet when any route is lost, and not only when are those aimed to nodes outside the MANET. In Figure 2, a comparison is made on the quantity of packets received when a mobile node changes gateways while engaged in a voice communication. When the node moves, there will be some lost packets for both types of protocols occasioned to link failures, but the important detail to notice is that when a new route is used, which occurs about in the minute 8, there are more lost packets when OLSR is used, than when it is used AODV. Again, this is because there will be about 6 seconds in OLSR and 2 seconds in AODV in which packets won't be transmitted.

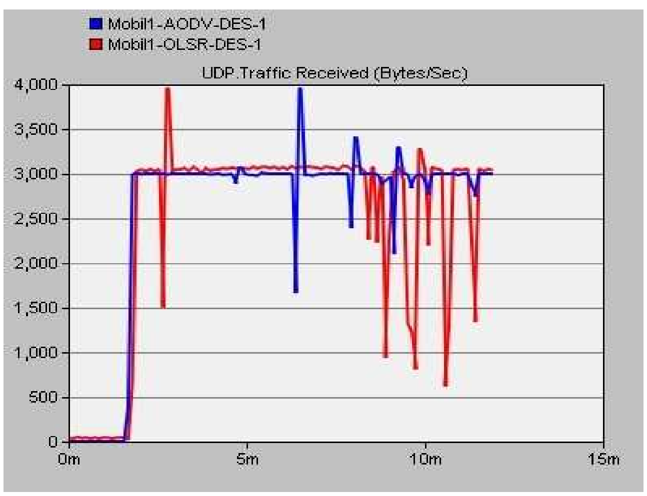

Figure 2. Packets Received

End-to-End Delay will be usually longer on AODV than on OLSR and OSPF, because, unless a route to its current gateway is lost, nodes will not recognized if there are closer gateways that may be used. For this reason, nodes may then use longer paths to forward its packets to their destination. However, because AODV does not require the use of summarization, return packets may find shorter routes versus the MANET, and thus, it may reduce packet delay, but this won't compensate the bigger delay found on the longer MANET trajectories. In the Figure 3 it may be seen a simulation result for AODV and OLSR when a Voice Connection is established between a mobile node on MANET and a node on the fixed network. OLSR reacts first, but introduces a 6 second delay. AODV reacts later, but has a 2 second delay, as expected.

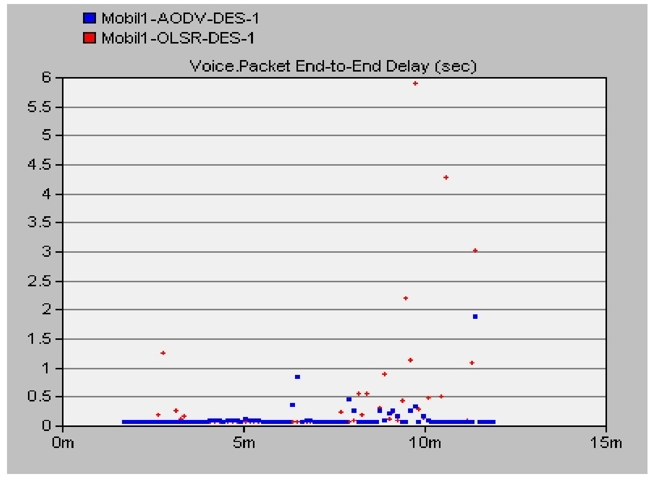

Figure 3. End-To-End Delay

Since AODV only reacts when the required route is lost, there will be not as many routing table updates as there will be when OLSR or OSPF are used. In other words, routes on AODV will last longer, and thus, there will be less delay variations. For this reason, Jitter will be lower in AODV. In Figure 4, Jitter for both types of protocols are showed for a voice communication established between a mobile node on the MANET and a node placed in the fixed network. It may be seen that there are bigger variations in the case of OLSR than in the case of AODV.

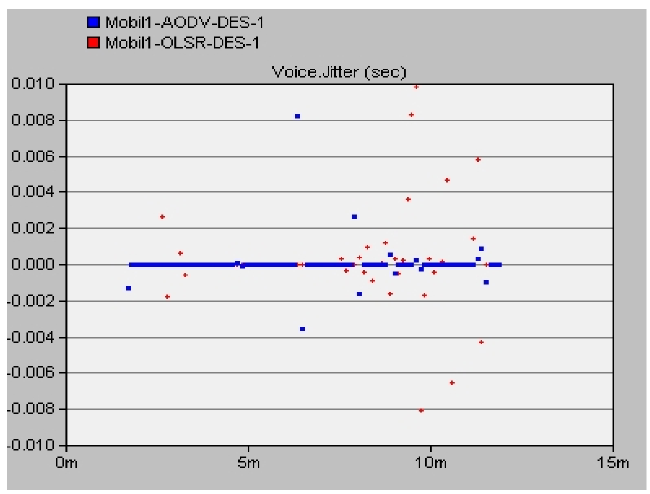

Figure 4. End-To-End Delay

With these results, we have verified the effects that over an ongoing connection between a mobile node in the MANET and a node in the fixed network of an Hybrid Ad Hoc Network occur, when MANET nodes move and have to change the gateway they use to forward packets between both type of networks. In the simulation, a voice connection was considered, but the results are expected to be similar in the case of a TCP connections, except for the fact that links must be implemented between gateways, in order to

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maintain connection. Since OSPF with MANET extensions have similar characteristics than OLSR, it is expected that its performance will be the same. It means that there will not be any significant advantage on using this MANET protocol to increase compatibility with the IGP protocol on the fixed network when MANET node move and have to use different gateways. The case will be different if MANET nodes do not move as much, and it is desired to have precise information on how to find them anywhere on the MANET.

With respect to the MANET routing updates versus the fixed network, since there are less MANET updates when AODV is used, we may infer that when summarization is not implemented, there won't be as many routing updates versus the IGP when AODV is implemented than when OLSR and OSPF are used. In conclusion, AODV presents more advantage on Hybrid Ad Hoc Networks when there is node mobility and when more than one gateway joint the MANET to the fixed network.

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