Objects Communication Behavior on Multihomed Hybrid Ad Hoc Networks

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1 Introduction

According to the "The Internet of Thing" paradigm, physical objects connect to Internet for sharing information about themselves and their surroundings [1]. When the considered objects move around, it is necessary to use wireless means to connect them to Internet. But, when the paths followed by these objects are unpredictable and/or when the objects move away from networks structures, MANET (Mobile Ad Hoc Networks) may be the only way to maintain connection. MANET consists of a number of self-organized mobile nodes or objects with routing capabilities, which may be implemented isolated or connected to structured networks by means gateways [2,3]. The integration of MANETs with fixed infrastructures, as Internet, must be carefully studied to evaluate its capabilities. In such integrated scenarios, 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 with those on the fixed network forwarding packets through the gateways found on the edge which joins both types of network.

Much of the MANET research has primarily focused on its isolated performance without considering how it behaves when connected to a fixed network. Performance of hybrid ad hoc networks is strongly impacted by node mobility on the MANET. Two of the aspects that may affect this performance are MANET node address allocation and the dynamic gateway changes. When objects on MANETs move around, they may find themselves on a different MANET subnetwork from where they registered and got their address from, and for that reason, their IP address must be changed accordingly while maintaining ongoing connections and delivering the packets belonging to these connections continuously. After changing address, mobile nodes will be required to use a different gateway to continue forwarding and receiving packets that flow between the MANET and the fixed network. Address

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and gateways changes may cause packet delivery interruption, packet losses, and even connection losses that may probably affect communication between moving objects and fixed nodes.

In this chapter, a comparative evaluation is made between the performance of two scenarios of Hybrid ad Hoc Networks: one in which a proactive protocol is used in the MANET side of the network, like Optimized Link State Routing Protocol (OLSR), and one in which a reactive one is used, like Ad-hoc On-Demand Distance Vector (AODV). In both scenarios, we consider that the interconnection between the MANET and the fixed network will be by means of two or more gateways placed away from each other allowing the formation of different subnetworks; one for each gateway. A mobile object with MANET communication capabilities will be allowed to move from the vicinity of one gateway to the vicinity of the others while engaged in a communication with a host placed on the wired network. Then, estimations of packet losses, delay and jitter are evaluated.

The rest of this work is organized as follows: in Sect. 2, the scenarios to be evaluated are presented, describing how addresses are allocated on MANET objects, how gateways are chosen, and how MANET routing protocols work in this scenarios. In Sect. 3, a detailed description of the scenarios is presented and a conceptual analysis of the events that occur when an object engaged in a communication with a host in the fixed network moves and have to change gateway to continue forwarding packets vs. the fixed network. Finally, on Sect. 4, results and conclusions are presented.

2 The Multihomed Scenarios

Hybrid ad hoc networks, as it is shown on Fig. 1, are composed of three different parts: (1) the fixed network, where hosts remain always in the same subnetwork without changing their address prefixes, and a traditional Internal Gateway Protocol

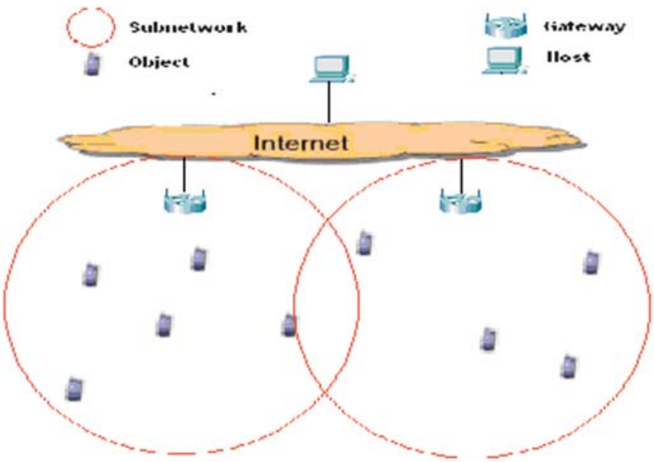

Fig. 1 Hybrid ad hoc network

(IGP) is used to find usable routes. (2) The MANET, where mobile objects may move and change their subnetwork associations and addresses, besides running a MANET routing protocol to find usable routes. (3) The gateways, which are special routers that interconnect 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. It means that gateways must have at least one interface belonging to the fixed network and one interface belonging to the MANET. When two or more gateways connect the MANET to the fixed network, it is referred as Multihomed Hybrid Ad Hoc Networks.

On "The Internet of Things," it is expected that mobile objects participate into information networks without position communication limitations, and if MANET networks are used as a part of its supporting structure, then we should consider the effects that over ongoing communications appears when these objects move from one subnetwork to another, especially those related to address reallocation, dynamic gateway changes, and routing protocol convergence.

2.1 Address Allocation

Address allocation on MANET objects that communicate to the Internet is preferably done by using a stateless autoconfiguration mechanism based on network prefixes advertised by one or more gateways nodes. This solution is adopted because it deals better with network partitions on MANET [4]. With stateless autoconfiguration, mobile nodes set its IP address according to the network prefix announced by the closest gateway. In this way, it is possible the formation of subnets of nodes sharing a common network prefix, A host realizes that it is in a zone belonging to a different subnetwork when it recognizes that its distance to another gateway, measured in route hop counts, is less than that from which it got its current address from. Address reallocation is done dynamically according to object mobility, and thus, routing tables on MANET nodes and gateways will have to adjust their routes and summaries, which may probably cause, connection and packet losses and packet forwarding delay.

2.2 Gateways

The paths used to forward packets between mobile and fixed networks may also affect communication performance. Before setting its address, MANET nodes must select a gateway for traffic forwarding to and from the fixed network. Gateways discovery is associated to the MANET protocol used, thus, it may be done using one of two mechanisms: a reactive one and a proactive one [5,6]. In the reactive version, when an object 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 objects to create routes to the Internet in an unsolicited manner. If objects receive routes to more than one gateway, they choose the closest one, but only on the proactive approach objects may be sure that the selected gateway will remain the closest, since on the reactive approach, gateway updates only occur when its routes are lost. Changing forwarding gateways during ongoing connections will bring time gaps during which packets are not forwarded or are lost. Even more, the connection to the distant host may be lost.

2.3 MANET Protocols

The MANET routing protocol used on hybrid ad hoc network also affects its performance significantly when object move between different subnetworks. 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 reactive protocols. Proactive protocols maintain and regularly update full sets of routing information, trading off greater protocol overhead and higher convergence time in the interest of smaller packet delays. OLSR is an example of a proactive protocol. Paradoxically, reactive protocols tend to take less time than proactive protocols to recover from route losses, especially as a consequence of object mobility. This is because it uses a smaller time to declare a lost route and only cares about recovering specific routes. Each MANET protocol type will react differently when objects move between different MANET subnetworks and find routes to new gateways to keep their ongoing communications active. The important parameter to observe is the time taken for each protocol to reach convergence. To better understand their behavior, a brief description of one protocol of each type follows.

2.3.1 AODV

AODV [8] focuses only 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 an object 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 object 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 3,561, Hello messages are transmitted with a frequency of 1 s. If a Hello from an active object is not received

Table 1 Main parameters of the MANET protocols

MANET protocol	Route/neighbor discovery	Identification of route change
AODV	Route request Route reply Hello for active nodes (1 s)	No Hello within 2 s
OLSR	Hello (2 s) Topology control (5 s)	No Hello within 6 s

within 2 s, 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

OLSR [7] 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.

The time that each type of protocol takes to help objects discover new gateways, set its addresses, and find adequate routes to given destinations on the fixed network in the presence of object mobility heavily impact hybrid ad hoc networks performance. Table 1 shows main timing values for AODV and OLSR protocols. It can be seen that AODV only keeps routes to requested destinations, reducing thus congestion and routing table size, but most important, AODV takes less time than OLSR to react on the event of lost routes. Even more, AODV is only interested in recuperate that specific lost route and not every possible route.

3 Multihomed Hybrid Ad Hoc Networks Analysis

As shown in Fig. 1, the scenarios analyzed consider the interconnection of a MANET and a fixed network by means of two gateways placed away from each other, providing each one a different network prefix, allowing the formation of two different subnetworks. A mobile object will be allowed to move from one subnetwork to the other following a straight path, while keeping a communication connection with a host placed on the wired network. Packet losses, delay and jitter are evaluated during this transition. The MANET routes announced by the gateways to the fixed network, if necessary, may be summarized in order to reduce frequently update exposure coming from the MANET routing.

The mobile object will set its IP address in correspondence to the public prefix announced by the closest gateway. Alternatively, node addresses may be manually fixed or dynamically autoassigned using private address, which can later be translated to public address by means of NAT servers loaded on gateways. In either case, when an object moves closer to a different gateway from which it got its original address, it must set a new one corresponding to the new subnetwork prefix, and use it to forward packets toward the fixed network throughout the new gateway. On their way back, packets coming toward objects on MANET should enter using the same gateway used by the packets exiting 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 its loosing when return packets try to enter MANET using the wrong gateway, physical links between gateways should be implemented, which will permit packets to find its way vs. the originating object [9].

The objective of this paper is to compare traffic performance for the two types of MANET routing protocols, when a moving MANET object maintains a communication connection whit a node placed on the fixed network, which is connected to the MANET by means of two or more gateways. The considered metrics to evaluate 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. When an object on MANET needs to forward packets vs. the Internet, but does not have a valid route to its destination, it broadcasts a request. This request is forwarded by neighbor objects until a route is found. For destinations outside MANET, gateways, if present, will respond with a route. Among those that respond to, the originating object chooses the closest gateway, from which it also gets its address prefix, which will use to forward its packets. The gateway will forward all packets received from the mobile object toward its destination on the fixed network. Return packets will use the same gateway in its way back to the originating object. When objects move and routes to the gateway get lost, they use new requests to find new ones. New routes may or may not use the same gateway for destinations outside the MANET. In any case, until new routes are found, there will be a time lapse when 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 objects, but will always be superior to 2 s, which is the time needed before declaring a lost route in AODV. If the new destination route goes throughout a different gateway, then the object will have to change its address before continuing to forward packets. It is also important to note that since AODV is a reactive protocol, as long as they have a route, mobile objects will not notice if they are closer to a different gateway from which they got their address prefix, thus, they will continue forwarding packets throughout the same gateway, even if they take a longer path, until gateways routes are lost. Being AODV a reactive protocol, it will not generate as much routing traffic as proactive ones, thus it won't be required to summarize MANET routes to reduce exposure over the IGP on the fixed network, hence helping it on finding better return routes.

3.2 Scenario 2

OLSR. Without needing to forward any packet, objects on MANET discover routes to any possible destination by establishing neighborhood relations to some nearby nodes. Besides its known routes, gateways on MANET announce routes to the fixed network as a default route. Mobile objects choose, between those routes going outside MANET, the one going throughout the closest gateway, from which it also gets its address prefix that uses to forward its packets. The gateway will forward all packets received from the mobile object toward its destination on the fixed network. Return packets will use the same gateway in its way back to the originating node. When any mobile object 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 objects, but will always be superior to 6 s, which is the time needed before declaring a lost route. Since OLSR is a proactive protocol, any route recalculation on the MANET will make all objects notice if they are closer to a different gateway from which they got its address prefix, so they will have to change it according to the new prefix before continuing to forward packets throughout the new gateway. Finally, OLSR generates so much routing traffic, that MANET route summarization will be required on the fixed network in order to reduce routing exposure over the fixed network IGP, thus decreasing granularity on MANET routes.

4 Results and Conclusions

After evaluation of the two types of MANET routing protocols and how they react when MANET objects move between different MANET subnetworks, the most important characteristics are presented on Table 2. It may be observed that AODV reacts better to object mobility. Although it would not have a route to a given destination right away, as it will have OLSR, when routes are lost, it will recuperate them faster. This is not only because it uses less time to declare lost routes but also

Table 2 Expected behavior for each routing protocol

MANET protocol	Protocol characteristic	Object mobility impact
AODV		Do not require route summarization
		Do not require gateway interlinks
	2 s to declare lost routes	PDR will be smaller
	Only rediscover lost routes	End-to-end delay is bigger
	Minor routing congestion	Jitter will be smaller
OLS		Require route summarization
	6 s to declare lost routes	Require gateway interlinks
	Rediscover every routes	PDR will be bigger
	Major routing congestion	End-to-end delay is slower
		Jitter will be bigger

it recovers only those routes that are needed. Additionally, AODV uses less routing packets to get and maintain its routes, thus creating less congestion.

As a consequence, PDR will be higher on AODV than on OLSR. Packets from an object to a node in the fixed network won't be delivered from the moment that a route to the current gateway is lost until it is rediscovered. In AODV, this time includes 2 s for declaring that route as lost, and some additional time required to find a new route. How many packets are lost also depends on its generation rate and on the object buffer size. On the other hand, OLSR uses 6 s to declare a route as lost, and will take a longer time to find new routes, because all objects must reach the convergence. Additionally, OLSR, besides generating bigger congestion, it will stop forwarding any packets when any route is lost, and not only those aimed to nodes outside the MANET.

End-to-End Delay will be usually longer on AODV because it will not be recognized unconditionally if there is a closer gateway, and may then use longer paths to forward its packets toward the fixed network. However, because AODV does not require the use of summarization, return packets may find shorter routes on the fixed network trajectory, and thus reducing the delay of returning packets, although this may not compensate the delay found on the MANET part path.

Since AODV reacts only when a required route is lost, there will not be as many routing table changes as when OLSR is used. In others words, routes on AODV will last longer, and thus there will be less delay variation. For this reason, Jitter will also be lower in AODV than in OLSR.

We may then finally conclude that it may result more convenient to use a reactive protocol than a proactive one on a MANET whose objects, being part of "The Internet of Thing," are engaged in communication connections and are moving. This is not the case when objects are static, for which proactive protocols where proposed to deliver a better performance. Future work on this area is aimed to evaluate the effects over the fixed network produced by object mobility on multihomed hybrid ad hoc network and to propose alternative solutions.

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