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# Review Strategies and Analysis of Mobile Ad Hoc Network-Internet Integration Solutions

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**Abstract**

The desire to be connected anytime and anywhere has led to the development of wireless networks, opening new vista of research in pervasive and ubiquitous computing. Mobile Ad Hoc Networks (MANETs) use portable devices such as mobile phones, laptops or personal digital assistants (PDAs) for spontaneous establishment of communication. Most existing research in the area of mobile Ad Hoc Networks is limited to stand-alone isolated networks. But connectivity of a mobile Ad Hoc network to the Internet is also desirable as more and more applications and services in our society now depend on fixed infrastructure networks. It is therefore important that dynamically deployed wireless Ad Hoc networks should also gain access to these fixed networks and their services. The integration of MANETs into Internet increases the networking flexibility and coverage of existing infrastructure networks. Although researchers have proposed many solutions, but it is still unclear which one offer the best performance compared to the others. When an Ad Hoc network is connected to Internet, it is important for the mobile nodes to detect efficiently available Internet gateways providing access to the Internet. Internet gateway discovery time and handover delay have strong influence on packet delay and throughput. The key challenge in providing connectivity is to minimize the overhead of mobile IP and Ad Hoc routing protocol between Internet and Ad Hoc networks. There, this paper focuses on proposed technical solutions on Internet gateway discovery and also we briefly describe different ways to provide global Internet access for MANETs. Finally, some challenges are also mentioned which need in depth investigation.

***Keywords:*** *MANET, Internet Gateway Discovery, Mobile IP, Address Autoconfiguration, DAD, Internet, AODV*

## 1. Introduction

A Mobile Ad Hoc Network [1] is an autonomous network that can be formed without the need of any established infrastructure or centralized administration. Various routing protocols have been proposed for MANETs [39]. But one drawback of MANETs is that communication is limited to the Ad Hoc domain only. Many applications however need a connection to an external network, like the Internet. As illustrated in Fig. 1, in order to provide Internet connectivity to the nodes in an Ad Hoc network, routers or one or more nodes in the Ad Hoc network can serve as Internet gateways to an external network, where the external network can be an infrastructured network such as LAN, Internet or a cellular network, or even an infrastructure-less network such as another Ad Hoc network. When connecting MANETs with the Internet, the routing interoperability becomes a crucial challenge. Ad Hoc nodes can not obtain routing information beyond the scope of the MANET. Therefore, the interoperability between IP routing and Ad Hoc routing needs to be given attention. When an Ad Hoc network is connected to the Internet, it is important for the mobile nodes to detect efficiently available Internet Gateways providing access to the Internet. Internet gateway discovery time and handover delay have strong influence on packet delay and throughput. The key challenge in providing connectivity is to minimize the overhead of mobile IP [14,37] and Ad Hoc routing protocol between infrastructure and Ad Hoc networks.

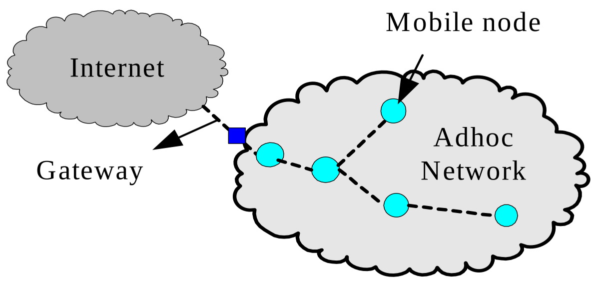


Fig. 1 Mobile Ad Hoc network connected with Internet

The challenge in integration of MANET-Internet is to inform mobile nodes about available Internet gateways while making a minimal consumption of the scarce network resources. So, an efficient gateway discovery for Ad Hoc networks becomes one of the key elements to enable the use of hybrid Ad Hoc networks in future mobile and wireless networks. In order to be able to communicate with the Internet, each mobile node within the MANET must configure globally routable IP address [2]. This includes acquiring a temporary address once it enters the MANET, which allows only local communication, within the Ad Hoc network. Next it needs to discover and select one Internet gateway to use its prefix and form a globally routable address. This paper also tackles this fundamental problem and addresses the interworking between Ad Hoc networks and the Internet. Let us take a closer look at the interconnection of MANET and fixed network. Unlike the fully hierarchical addressing scheme used in the Internet, MANETs have a completely flat addressing model. In fact, Ad Hoc routing protocol such as AODV does not employ the concept of IP subnet. They assume that a node in a MANET may use any IP address provided that it is not duplicated. In fact, Ad Hoc routing protocols use host-based routes rather than network prefixes. Unlike in traditional IP networks, two neighboring nodes are not required to have addresses belonging to the same IP subnet to be able to directly communicate with each other. These differences with traditional IP networks create some interworking issues as indicated below [3].

- Discovering Internet Gateways
- Address Auto-Configuration
- Reaching a Destination
- Duplicate Address Detection (DAD)

This paper presents a survey of recent advances in technical issues in connecting MANETs to the Internet. We analyze solutions proposed by other researchers and describe our up-to-date contributions. The remainder of the paper is organized as follows: In section 2, we briefly describe Internet routing protocols. The MANET-Internet connectivity, including the basic protocol stack is described in section 3. Address autoconfiguration and Internet gateway discovery approaches are briefly described in section 4 and 5 respectively. In section 6, we present analysis of different Internet connectivity proposals with mobile Ad Hoc networks. Section 7 summarizes and compares different technical solutions proposed for MANET-Internet interconnectivity and has been given in tabular form (Table 1). Finally, section 8 concludes the paper and defines topics for future research.

## 2 Internet Routing Protocols

Routing in Internet is IP address based. Each IP address consists of network id and host id portion. Routing decisions are taken by routers for packets based on the network id portions of the destination IP addresses [10]. The IP addresses of nodes within the same network thus share the common network id whereas the node address portion of the IP address identifies a specific node in the network. The highest level of the Internet hierarchy consists of a number of Autonomous Systems. Each Autonomous System is a distinct routing domain. Routers communicate with each other within an Autonomous System using intra-domain routing protocols, which are also known as Interior Gateway Protocols. Gateway routers are used to interconnect different Autonomous Systems. Exterior Gateway Protocols are used to exchange routing information between Autonomous Systems. Routing information Protocol (RIP) [12] and Open Shortest Path First (OSPF) [13] may be used as Interior gateway protocols. OSPF is a member of the “link state” family and commonly used nowadays. It uses multi-metrics of a link that may consider bandwidth, hop count, and reliability. A router in OSPF is aware of all links between all routers of an Autonomous System. In this, routers maintain a map of the whole network that is updated if a change in the network topology is detected. Based on this knowledge, routers in OSPF calculate shortest/best path from source to destination.

Border Gateway Protocol (BGP) [15] provides connectivity between different Autonomous Systems and also provides sharing of routing information by one Autonomous System with other Autonomous System. It exchanges routing tables to other Autonomous Systems on demand.

## 3. MANET-INTERNET Connectivity

Whenever a MANET node is to send packets to a fixed network, it must transmit the packets to a gateway. A gateway acts as a bridge between a MANET and the Internet. Therefore, it has to implement both the MANET protocol stack and the TCP/IP suite. In the physical and data link layer, a mobile Ad Hoc node runs protocols e.g. (IEEE 802.11 DCF) that have been designed for wireless channels. In the network layer, either an IP based Ad Hoc routing protocol e.g., Ad Hoc On Demand Distance Vector Routing (AODV) protocol [20] is used, or this layer is divided into two sub layers, namely the usual IP layer over a non IP based Ad Hoc routing protocol that transports the IP packets in the ad network in an encapsulated manner. Gateway contains protocols of both the fixed Internet and the wireless Ad Hoc network. On the Internet side, it runs the usual Internet protocols. On the Ad Hoc side, it sends and receives packets using an Ad Hoc routing algorithm. Mobility management is performed using Mobile Internet Protocol [14]. The basic protocol stacks for mobile nodes, Internet gateways and Internet hosts are depicted in Fig. 2.

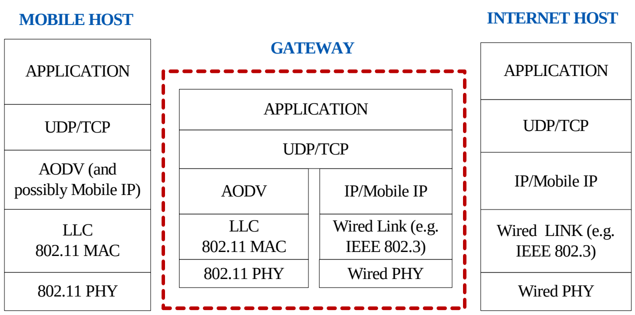


Fig 2. Protocol stack for MANET-Internet connectivity

The Internet gateway provides an illusion to the outside world that the MANET is simply a normal IP subnet.

## 4. Address Autoconfiguration

Once a mobile node has chosen one gateway, all packets sent over this Gateway to the Internet need a source address with the same prefix as the Gateway. Ad Hoc node needs an address auto-configuration mechanism in order to configure a global routable and topological correct address in order to avoid other solutions like Network Address Translation (NAT). IPv6 defines two fundamental principles for auto-configuration: stateful and stateless configuration. In stateful auto-configuration [3], the IP address of a node is assigned by a central entity (e.g., a Dynamic Host Configuration Protocol [DHCP] server residing in the gateway). It automatically assigns addresses to requesting mobile nodes and manages the address space. However, centralized approaches are not suitable for MANETs due to possible network partitions, although it has been considered in some works [16]. Another option is to use stateless auto-configuration (addresses generated by the nodes themselves) [17,18,9]. In this approach, the gateway can advertise within its control messages a network prefix from which the nodes can derive an IP address. By integrating the auto-configuration information into gateway discovery messages, the overall overhead is reduced. However, the network might still be periodically flooded with prefix information, which consumes precious resources. It is advisable to configure the nodes with an IP address belonging to the subnet of its default gateway. This guarantees that the access router does not need to perform network address translation (NAT) to get messages routed back from the Internet.

Once a node has an IP address, it may check whether other nodes use that address. If two mobile nodes are using the same address, then the address should be deallocated and the node should try to get another one. This procedure is known as Duplicate Address Detection (DAD) [19] and can be performed by asking the whole MANET if this address is already in use. When a node receives one of those messages requesting an IP address which it owns, then it replies to the originator in order to notify the duplication.

## 5. Internet Gateway Discovery Approaches

For access to global services, an Internet Gateway (IGW) in the access network can provide Internet connectivity for nodes in the MANETs. Mobile nodes from Ad Hoc network can use this route to send/receive packets addressed to or from Internet. As mentioned before, the standard Ad Hoc routing protocols do not provide the functionality of detecting Internet gateways, thus the protocols have to be extended. The extensions to the standard Ad Hoc routing protocols are based upon special Ad Hoc routing messages. The gateway discovery can be realized in three different ways: reactively, proactively, or in a hybrid way.

### Reactive Discovery Approach

The reactive gateway discovery only provides the gateway information if a particular Ad Hoc node requests the gateway to get access to the Internet. In this case, mobile node broadcasts a Gateway Solicitation (GWSOL) message within the entire Ad Hoc network. The GWSOL is piggybacked on route request (RREQ) message of MANET routing protocols. Intermediate nodes rebroadcast this special route request message (RREQ_I). If the gateway receives the GWSOL, it sends special route reply (RREP_I) message back to the mobile nodes offering its services and IP address (or IP prefix address), so that the requesting node can set up a route to the gateway.

### Proactive Discovery Approach

In this approach, every Internet gateways periodically broadcast their services and IP prefix address throughout the MANET. Any mobile node that wants to interact with the Internet nodes detects this packet and begins registration. When a mobile node connected to an Internet gateway receives an advertisement from another Internet gateway, it may decide to connect to the new Internet gateway, if it provides a better service. The proactive discovery mechanism reduces the average delay compared to the reactive discovery but incurs higher communication overhead.

### Hybrid Discovery Approach

This uses a mixture of both the above approaches, which provides a trade-off i.e., between the advantages of proactive and reactive approaches, providing good connectivity while keeping the overhead costs low. In this approach, the periodical Internet gateway advertisements are not flooded throughout the whole Ad Hoc network but only sent to mobile nodes that are in the vicinity of the Internet gateway, i.e., the time to live (TTL) of those advertisement packets is limited. Nodes that are further away have to solicit advertisements reactively.

Two kinds of information are needed by MANET node for routing packets via an Internet gateway. The first one is the address of the Internet gateway. To route data packets and control messages to the Internet gateway, Ad Hoc nodes must be aware of the gateway's Ad Hoc routable address. The second one is, a default route pointing to the Internet gateway. All packets that are destined to the Internet are routed via the default route. For gaining the gateway information, i.e. the gateway's address and route to the gateway, either the advertisement based (proactive) or the solicitation based (reactive) approach may be utilized.

## 6. Analysis of Different Internet Connectivity Proposals for MANETs

When the Ad Hoc network is interconnected to an IP network, mobile nodes in the Ad Hoc network need global addresses to communicate with the Internet and node mobility should be properly dealt with [21,22]. Especially, when mobile nodes move to another area, their subnet changes and a new IP address must be obtained. Several solutions have been proposed to deal with the integration of MANETs to the Internet. Most of the proposed solutions require the addition of gateways and differ in the design and functionality of the gateways, number of occurrences, and the routing protocols used within the Ad Hoc network. Since Internet gateways have two interfaces they are part of the Internet and the Ad Hoc network simultaneously. They understand the Internet protocol (IP) as well as a MANET routing protocol (e.g. AODV). Mostly, the existing approaches consider only fixed gateways to connect MANET nodes to the wired Internet. We briefly discuss solutions for both fixed Internet gateways and mobile Internet gateways [5].

### 6.1 Fixed Internet Gateway Approaches

Bin et al. [23] proposed an adaptive gateway discovery scheme that can dynamically adjust the TTL value of Agent Advertisements (GWADV messages) according to the mobile nodes to Internet traffic and the related position of mobile nodes from Internet gateway with which they registered. This protocol provides Internet access to MANET mobile nodes using mobile IP [14,37]. The protocol uses foreign agents to track and forward packets to and from mobile nodes. Foreign agent periodically calculates the average hops conveyed by RREQ_I message or registration request sent by mobile nodes requesting Internet connectivity. So the broadcast radius of Agent Advertisements can be adjusted dynamically according to real time demand for the Internet access and the factual network conditions.

Ratanchandani et al. [24] proposed a hybrid gateway discovery approach to discover gateways that limits the effects of broadcast overhead. AODV and two Mobile IP [14,37] foreign agents are used to interconnect MANET and the Internet. However, the TTL of the foreign agent's advertisements is limited to only a few hops. Thus, only mobile nodes that are close to one of the foreign agents receive the agent advertisements. Nodes that are further away have to solicit advertisements reactively. Intermediate nodes are allowed to reply on a solicitation with agent advertisements and to eavesdrop and cache agent advertisement information that is sent by unicast to the requesting mobile node. The performance of this approach depends on the Time-To-Live (TTL) value, which is set for a particular scenario and network condition under considerations. In order to switch between foreign agents, the MIPMANET Cell Switching algorithm [21] is used.

Hamidian et al. [27] gave a solution, which provides Internet connectivity to Ad Hoc networks by modifying the AODV routing protocol. An "I" flag is added as an extension to AODV RREQ and RREP to locate the fixed node. If after one network-wide search without receiving any corresponding route replies, the mobile node assumes that the destination is a fixed node, which is located in the Internet and thus delivers the packets through a gateway. Three methods of gateway discovery for a mobile node to access the Internet are provided: proactive, reactive and hybrid approach. All of them are based on the number of physical hops to gateway as the metric for the gateway selection.

Rosenschon et al. [7] proposed a proactive gateway discovery method in which gateway periodically sends HELLO messages that contain a special option called PROAGW option. This option has all information about the gateway that is needed to set up a route to it. All Ad Hoc nodes that have received the PROAGW option can add the option to their own hello messages. If multiple gateways are available, then mobile node receives multiple answers. The Ad Hoc node has to decide which gateway it should use. For selection of best Internet gateway, parameters that can be considered are hop count, congestion, overload, available bandwidth, delay etc. In both approaches, the MANET is flooded with routing messages.

Sun et al. [25] discussed the performance of the integration of the Ad Hoc On-Demand Distance Vector (AODV) routing protocol and Mobile IP [14,37]. It presents a method for enabling nodes within an Ad Hoc network to obtain Internet connectivity when one or more nodes is within direct transmission range of a foreign agent or more specifically an Internet Gateway/Access Router. In their approach, an Ad Hoc network is connected to a foreign agent, which basically has the same functionality as an Internet gateway (IGW). Internet Gateway assigns a global prefix for the Ad Hoc network, which makes it possible for mobile nodes in Ad Hoc network to communicate with Internet. While AODV is used for route discovery and maintenance within MANET, Mobile IP [14,37] provides mobile nodes with care-of-addresses. However, handoff occurs only if a mobile node has not heard from its foreign agent for more than one beacon interval, which is the time between two successive agent advertisements, or its route to a foreign agent has become invalid.

Broch et al. [26] proposed a solution for the integration of MANET with Mobile IP [14,37] using a source routing protocol. They introduced a border router, which has two interfaces. Routing on Internet gateway's interface internal to the Ad Hoc network is accomplished using dynamic source routing (DSR) [35] protocol, while its interface connected to the Internet is configured to use normal IP routing mechanisms. Mobile nodes in an Ad Hoc network are assigned home addresses from a single network. The nodes within range of the foreign agent act as gateways between the Ad Hoc network and the Internet. As a reactive approach, foreign agent discovery is only done when required. Traditional IP routing is used on the Internet side while within MANET DSR protocol is used. Foreign agents are responsible for connecting the Ad Hoc network with the Internet.

In [21], Jonsson et al. proposed a method, called MIPMANET based on AODV [16], but it provides Internet access by using tunneling and Mobile IP [14,37] with foreign agent care-of addresses. Fig. 3 depicts the layered architecture of Mobile IP [14,37] and Ad Hoc routing functionality. Mobile nodes that want Internet access register with a foreign agent and tunnel all packets destined for the Internet to the registered foreign agent. The packets destined for the Internet are tunneled to the foreign agents, which in turn forward the packets to the destination in the Internet. The hosts that do not require Internet access see the Ad Hoc network as a standalone network. The tunneling approach also enables MIPMANET to incorporate the default route concept into on-demand routing. The Ad Hoc on demand distance vector routing protocol AODV [20] is used within the mobile Ad Hoc network and delivers packets between mobile nodes and foreign agents. MIPMANET allows a visiting node to switch from its current foreign agent to a new one, a phenomenon known as handoff, only if it is at least two hops closer to the new one. It utilizes a new algorithm, called MIPMANET Cell Switching (MMCS), to determine when mobile nodes in the Ad Hoc network should register with a new foreign agent. In this solution, it is assumed that a mobile node that wants Internet access has been assigned a home address that is valid on the Internet [22]. Authors identified the benefits of using the closest gateway and proposed a gateway selection algorithm based on hop count. A simulation study indicates the benefits of broadcasting agent advertisements compared to using unicast solicitation/advertisement.

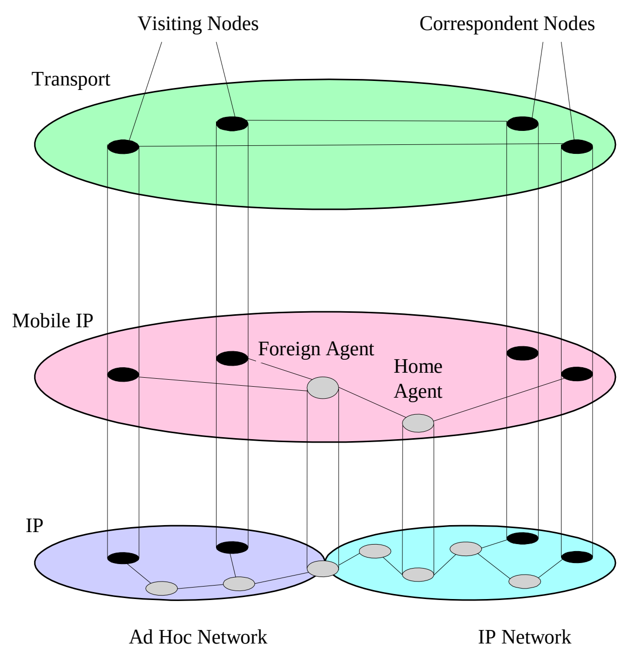


Fig 3. MIPMANET conceptual view

Lee et al. [30] proposed a hybrid gateway discovery scheme and compared it to a reactive one. It requires a source routing protocol in the Ad Hoc network. A gateway only sends out new advertisements when it detects any topology change in the Ad Hoc network. Moreover, advertisements are only forwarded to nodes that are either connected to the Internet or that have actually moved. Advertisements are only generated if the ratio between the number of Internet joining nodes and the number of advertisement forwarding nodes exceeds a certain value. In addition to the adaptive advertisements, conventional advertisements are broadcasted with a relatively long time interval. They rely on a source based routing protocol, which limits the applicability to particular type of routing protocol.

Tseng et al. [31] proposed a dynamic mobile agent service coverage scheme by integrating DSDV [4] and Mobile IP [14,37]. They presented a solution where MANETs are treated as Internet subnets (Fig. 4). The existence of each home agent (HA)/foreign Agent (FA) is known only up to N wireless hops away from the agents as the agent advertisement can only traverse up to N hops. Mobile nodes which are more than N hops away from HA/FA are required to broadcast agent solicitation messages to search for a gateway. Similarly, the number of physical hop is used as the only metric to determine which ideal HA/FA the mobile node should connect with. The paper does not include any evaluation of the system or a comparison to other solutions. The proactive approach gives a high overhead when mobility is high and the hop count gateway selection could cause problems.

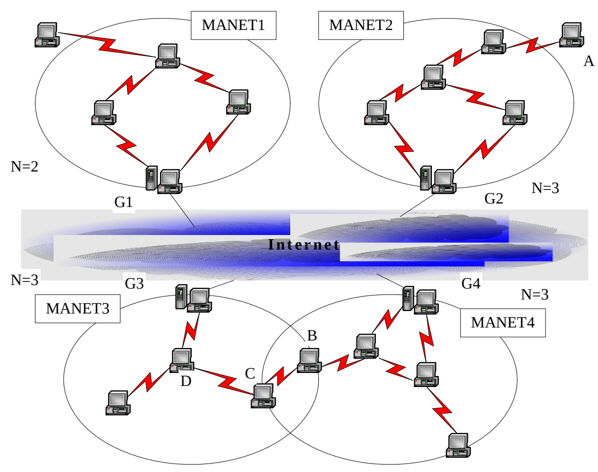


Fig 4. The proposed network architecture extending each access point to a MANET

Xie [40] et al. proposed an enhanced DSDV (EDSDV) protocol for mobile Ad Hoc networks for providing global bi-directional MANET-Internet connectivity. The EDSDV protocol integrates with Mobile IP [14,37] for supporting bi-directional global connectivity for mobile nodes by using Foreign Agent as the mobile IP proxy. Mobile IP protocol provides the global mobility for a mobile host to access Internet resources while visiting a foreign network.

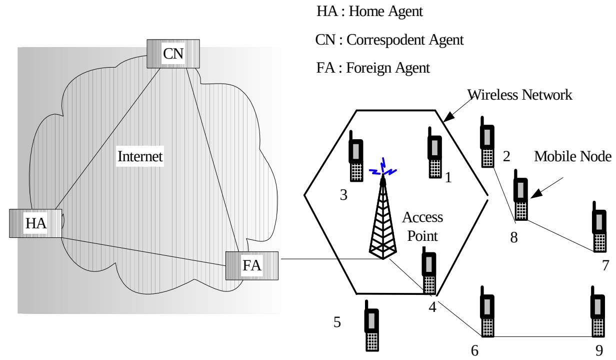


Fig 5. Proposed MANET- Internet integration architecture

Fig. 5 shows how Mobile IP and Ad Hoc routing protocols coordinate for building connectivity across heterogeneous networks. The proposed protocol includes three components namely enhanced DSDV routing protocol, mobile IP proxy and connection management. Performance metrics chosen for proposed protocol evaluation are packet delivery, overhead and packet latency.

Wakikawa et al. [28] define both proactive and reactive schemes, which are not dependent on any routing solution. They proposed an approach to global Internet connection over the IPv6 MANET environment, where mobile nodes in the Ad Hoc network are configured with new globally routable IP addresses based on the neighbor discovery protocol (NDP) of IPv6 or route searching procedure of on-demand routing protocol. This paper defines two different mechanisms to discover Internet gateways: periodic flooding of gateway advertisement (GWADV) messages from the gateways and reactive flooding a gateway solicitation (GWSOL) messages from nodes. The gateway advertisement message contains the global IPv6 address of the gateway, the network prefix advertised by the gateway, the prefix length and the life time associated with this information. They specify a stateless auto-configuration mechanism, which is based on network prefixes advertised by Internet gateways. The nodes concatenate an interface identifier to one of those prefixes in order to generate the IP address.

In [29], E.M. Belding-Royer et al. proposed Mobile IP, which was supported by IPv4 Ad Hoc networks with AODV routing protocols. The proposed scheme has a proactive agent solicitation procedure with AODV route search to register to Mobile IP. It distinguishes the location of destination nodes using F-RREP of FA, when a packet is sent to the Internet. In addition, it is capable of packet routing using default routing of FA. However, this proposal does not consider the selection between multiple FAs. Also, it delays the connection setup time because this proposal first needs to conclude that the destination is not within the Ad Hoc network before a mobile node can use the FA.

C. Jelger et al. [32] proposed a proactive approach in which Internet gateways periodically advertise their presence by flooding information (GW_INFO) messages. This proposal uses a restricted flooding scheme, which is based on the idea of prefix continuity to limit the overhead of the proactive gateway discovery. The prefix continuity guarantees that every node shares the same prefix and each gateway only receives IPv6 data packets belonging to its prefix. A mobile node selects only one of the GW_INFO messages according to some metrics. Then the node configures an IPv6 address based on the advertised prefix and sends only the GW_INFO including the selected prefix. However, if the approach is unified with a reactive routing protocol, then a node in the network must discover a route otherwise it causes a break of the connection because of the feature of the reactive routing protocol. They specify a stateless auto-configuration mechanism, which is based on network prefixes advertised by gateways. The nodes concatenate interface identifier to one of those prefixes in order to generate the IP address. A mobile node selects the best path towards the gateway using one of the metrics such as distance, stability, or delay from all the gateway information messages received.

In [34] the scalability of both approaches (proactive and reactive) is compared with respect to the number of Internet Gateways by Ghassemian et al. The fixed access network together with the Ad Hoc fringe constitutes a multihop access network as depicted in Fig. 6.

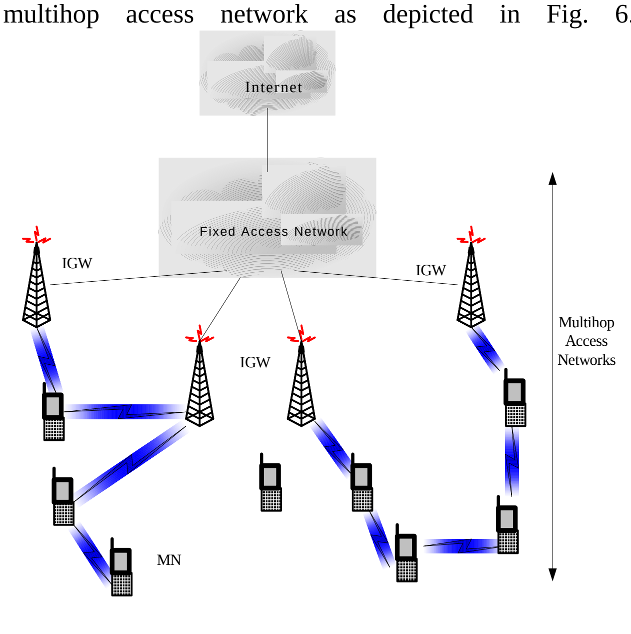


Fig. 6 Multihop access network

The simulation results show that the proactive approach is more advantageous because the packet delivery ratio is higher and, although the signaling overhead is larger too, it is reduced for a higher number of Internet gateways, because the amount of periodical gateway advertisements is increased but more data packets are transmitted successfully. The hybrid Internet gateway discovery approach is also compared that shows the average packet delay and the packet delivery ratio. The hybrid gateway discovery represents a balance between the reactive and the proactive approaches.

In [8], AODV routing protocol for Ad Hoc networks has been modified to offer enhanced Internet connectivity and then in depth investigation has been carried out on the three Internet gateway discoveries i.e. reactive, proactive and hybrid for providing inter-connectivity between Ad Hoc networks and Internet. The performance metrics chosen are throughput, average end-to-end delay, packet loss and average jitter. Simulation has been carried out for two different cases (number of active sessions i.e. sources either 3 or 6). When number of sessions and data rates is less, all the three Internet gateway discoveries had a significant advantage, providing higher and more stable throughput, lower packet loss and end-to-end delay. But as the number of sessions and data rates increase, it lowers throughput because more links break occur due to congestion and buffer overflow. Average end-to end delay and packet loss also increases as traffic increase in all the three discoveries. However, CBR packet jitter decreases as traffic in the network increases.

Lei et al [37] gave a proactive approach, a method for integrating the Ad Hoc routing protocol with Mobile IP routing Protocol. This integration results in a combined route table. Routing within Ad Hoc domain is provided by routed, a modified version of RIP (routing Information Protocol), which is implemented on each mobile node. This integration enables foreign agents to participate in the Ad Hoc network routing.

In [33] the author gave an analytical analysis on Internet gateway discovery algorithms. Routing overheads for the proactive and reactive and hybrid methods are derived. Authors also proposed an “adaptive gateway advertisement” with a dynamically adjustable TTL with an optimum value of two. However, the authors did not show the performance with varying interval times and additional traffic within the MANET cluster and do not give results of gateway discovery and handover times

Hossam El-Moshrify et al. [6] proposed a solution in which mobile nodes can access the Internet via a stationary gateway node or access point. Three proposed approaches for Internet gateway discovery are implemented and investigated. Also, the effect of the mobile terminals speed and the number of gateways on the network performance are studied and compared. A mobile node uses no load balancing approach to efficiently discover an Internet gateway in this proposal.

Rafi U Zaman et al. [38] proposed two gateway load balancing strategies for Integration of Internet and MANET which are based on load balanced routing protocols called WLB-AODV and Modified-AODV. The proposed strategies have been simulated using ns-2 simulator. Their simulation results show that the strategy based on WLB-AODV performs better than the one based on Modified-AODV.

### 6.2 Mobile Internet Gateway Approaches

In [36], Ammari et al. proposed a mobile gateway based on three-layer approach using both Mobile IP protocol and DSDV Ad Hoc routing protocol (Fig. 7). The first layer contains Mobile IP foreign agents; the second layer includes mobile gateways and mobile Internet nodes, which are one-hop away from Mobile IP foreign agents; the third layer has all MANET nodes and visiting mobile Internet nodes that are at least one-hop away from mobile gateways. The second layer is to provide Internet connectivity to MANET nodes and, thus to help establish interaction between MANET nodes and the Internet. Mobile gateways are powerful MANET nodes and are designed in a way to use both Mobile IP protocol when they communicate with the Internet. The DSDV protocol is used for routing within the MANET. The integration framework considers using some border MANET nodes to connect the rest of MANET nodes to the Internet. These MANET nodes are referred as mobile gateways. A mobile gateway selects a closest and/or a least loaded foreign agent based on the distance and the load criteria. MANET nodes select a closest and/or least loaded mobile gateway.

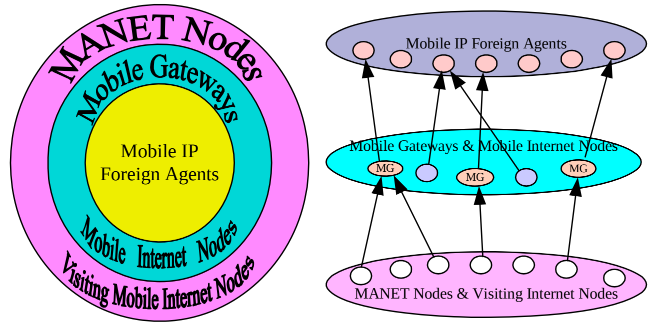


Fig 7. Three layered mobile gateway based architecture

Khan et al. [11] proposed a new approach for integrating MANET with the Internet by devising a protocol named Efficient DSDV (Eff-DSDV). The proposed framework uses one of the Ad Hoc mobile nodes as a Mobile Internet Gateway (MIG), which acts as a bridge between the two networks. The MIG runs the Eff-DSDV protocol and takes care of the addressing mechanisms to ensure the transfer of packets between MANET and Internet. This strategy does not require the flooding of the gateway advertisements for registration of mobile nodes with MIG. Ad Hoc routing protocol EFF-DSDV and Mobile IP coordinate with each other to provide the connectivity. Eff-DSDV follows the conventional DSDV, however it reduces the packet loss due to broken links.

## 7. Summary of Current Proposals

Table 1 summarizes some of the main features of proposed architectures.

Table 1: Summary of Features of Existing Proposals

| ***Proposed Architecture/ Protocol*** | ***Gateway Discovery Approach*** | ***Mobile IP Support*** | ***Ad Hoc Routing Protocol*** | ***Multiple Gateways support*** |
|---|---|---|---|---|
| Bin et al. [23] | Reactive | YES | AODV | YES |
| Ratanchandani et al. [24] | Hybrid | YES | AODV | YES |
| Hamidian et al. [27] | Proactive, Reactive, Hybrid | NO | AODV | YES |
| Rosenschon [7] | Proactive | --- | AODV | YES |
| Sun et al. [25] | Proactive, Reactive | YES | AODV | YES |

| | | | | |
|---|---|---|---|---|
| Broch et al. [26] | Reactive | YES | DSR | NO |
| Jonsson et al. [21] | Proactive, Reactive | YES | AODV | YES |
| Lee et al. [30] | Hybrid (RMD based) | YES | DSR | YES |
| Tseng et al. [31] | Proactive, Reactive | YES | DSDV | YES |
| Xie et al. [40] | Proactive | YES | DSDV | NO |
| R. Wakikawa [2,28] | Proactive, Reactive | IPv6 | Generic | YES |
| E.M. Belding-Royer [29,18] | Proactive | YES | AODV | NO |
| C. Jelger et al. [32] | Proactive approach | - | - | YES |
| Ghassemian [34] | Proactive, Reactive | - | AODV | YES |
| Rakesh Kumar et al. [8] | Proactive, Reactive, Hybrid | NO | AODV | YES |
| Lei et al [37] | Proactive | YES | Modified version of RIP | YES |
| Ruiz [33] | Hybrid (MBC) | NO | AODV | NO |
| Hossam El-Moshrify et al. [6] | Proactive, Reactive, Hybrid | NO | AODV | YES |
| Rafi U Zaman et al. [38] | Reactive | - | AODV | YES |
| Ammari et al. [36] | Reactive | YES | DSDV | YES |
| Khan et al. [11] | Proactive | YES | DSDV | YES |

## 8. Conclusions and Future Works

In this paper, we analyzed Internet connectivity of MANETs via fixed and mobile Internet gateways and pointed out limitations in the existing approaches. It provides a good insight to the research community for further modification and review. Mobile nodes can connect to Internet gateways of different types. Several approaches have been proposed for integrating MANETs with Internet in recent years. Fixed and mobile gateways are used to achieve the integration task. Some existing proposals do not consider multiple gateways and hence lack mechanisms for load balancing and scalability. We have reported technical solutions proposed for Internet connectivity of MANETs via Internet gateways. The proactive gateway discovery consumes excessive network resources due to the frequent advertisement flooding. Though, many researchers have proposed proactive gateway discovery solutions, it lacks load balancing, hence there is a need to propose a gateway discovery protocol that takes into consideration about path load. The solicitation is a broadcast, which consumes network resources, just as the flooding of advertisement does. Currently, no existing scheme ever considers the disadvantages of broadcasting solicitations. In case of hybrid gateway discovery approaches, a significant disadvantage is that in the proposed approaches some roaming nodes beyond the TTL scope of the Internet gateway may never receive gateway advertisements. Moreover, some mobile nodes that have registered with the gateway can not receive the latest advertisement broadcast to update registrations with their home agents.

There are many challenges in the integration of MANETs and the Internet such as mismatches regarding their infrastructure, topology and mobility management mechanisms. Based on the results of this work, we believe that an interesting future research topic is the work on adaptive and mobile Internet gateway discovery mechanism. In addition to adaptive gateway discovery and address autoconfiguration, there are other areas related to interworking with fixed networks in which there is still a lot to do. These areas include among others, selection of an optimal Internet gateway, improved DAD (Duplicate Address Detection) mechanisms, efficient support of DNS, discovery of application and network services, network authentication, an integrated security mechanisms and providing Quality of Service (QoS), load balancing, avoiding dead zones and seamless roaming, pricing/billing for such combined network.

In this paper we have given the critical review of various key techniques existing so far for MANET-Internet interconnectivity and Internet gateway discovery. The gaps in the existing works have been identified and highlighted as and where needed.

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