

Review

# Integrating IP Mobility Management Protocols and MANET: A Survey

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**Abstract:** The Mobile ad hoc Network (MANET) is a collection of mobile devices that forms a self-created, self-administered, and self-organized network. It is an infrastructureless network that does not require an existing infrastructure to operate. MANET suits scenarios where a temporary network is needed, such as emergency rescue, the military field, and disaster areas. MANET is an isolated network, and communication is restricted to the participating nodes' transmission coverage. In order to increase its connectivity and its application scope, however, MANET requires integration with other networks, forming a hybrid MANET. The integration of MANET and IP networks raises many challenges and issues. Mobility management is one of the main challenges. Traditional mobility management protocols provide seamless mobility in a single hop infrastructure network. Consequently, mobile nodes can maintain their global connectivity without interrupting the ongoing sessions. Mobility management becomes more challenging in a network that relies on multi-hop communication, such as MANET. This paper presents a survey of the use of mobility management systems when integrating MANET with the internet, with the objective of serving as a handy reference in this field of research. It presents, analyzes, and discusses existing mobility management solutions for integrated MANET networks. It also investigates their shortcomings and provides a comparative study of the surveyed proposals.

**Keywords:** MANET; integration; gateways; mobility management; mobile IP

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## 1. Introduction

The Mobile ad hoc Network (MANET) is an autonomous collection of mobile devices that forms a self-created, self-administered, and self-organized network. The topology of MANET is dynamic, and it is therefore susceptible to unpredictable changes. MANET nodes collaborate with each other to route traffic between themselves. As mobile nodes are characterized by their limited transmission range, multi-hop communication is required to enable out-of-range communication. MANET is an infrastructureless network and can be deployed easily, hence, it suits scenarios where a temporary network is required, such as emergency rescue, the military field, disaster areas, and Unmanned Aerial Vehicles (UAVs), which are commonly known as drones. Additionally, MANET can interact with other technologies in smart environments such as Internet of Things IoT and Wireless Sensor Networks (WSN) [1] making it more economically appealing. Such smart environment can be complemented using Blockchain [2] to improve privacy, reliability, and security [3].

MANET is a standalone network, and communication is restricted to the nodes' transmission coverage area. To increase its connectivity and its application scope, however, MANET can be connected to the IP network, forming a hybrid MANET. The integration of MANET with the IP network provides many advantages for both networks. The integration reduces communication and deployment costs and helps to extend the coverage of the existing infrastructure. It also provides additional services for the MANET. The integration provides MANET nodes with internet access, and thus increases the

application scope for MANET. This would then allow MANET users to access web services that are not available in the traditional stand-alone MANET. Moreover, the recent development in the cellular network technology enhances the feasibility of integrating MANET with the Internet. Fifth-generation 5G technology, for example, comes with its merit of increased bandwidth and reduced delay, which ease the integration of ad hoc networks and IP networks [4–6].

MANET networks and IP networks were originally designed for different environments and use different setup and routing protocols. Due to the inconsistency between the two architectures, gateway nodes have been used to ease integration, acting as interfaces between the heterogeneous networks. Integrating these networks undoubtedly raises many challenges and issues. Gateway discovery, gateway selection, quality of services, load balancing, security, and mobility management are the main issues when connecting MANET to the internet.

Traditional mobility management protocols provide seamless mobility in single hop wired infrastructure. Mobile nodes can thus maintain their global connectivity without interrupting ongoing sessions. Mobility management becomes more challenging, however, in a network that relies on multi-hop communication, such as MANET. The topology change in a MANET–internet integrated network is not caused by the source and destination nodes mobility alone but can also occur when intermediate nodes along the path used change their location. A mobility management system therefore plays a key role when integrating MANET with the internet to support the mobility and connectivity of MANET nodes.

A number of MANET–internet integration surveys have been published in recent years. Some are more general and cover any integration proposals without paying attention to a particular challenge [7,8]. Others have a different focus with respect to the ad hoc network technology, such as focusing on Wireless Sensor Networks based on 6LoWPAN Technology [9,10] or vehicular networks [11]. More similar surveys to that presented in this paper were published more than 10 years ago [12], however, a large number of solutions have been proposed since then. It is thus necessary for a renewed look at recent solutions.

This paper focuses on the use of mobility management systems when integrating MANET with the internet. It presents, analyzes, and discusses existing mobility management solutions for integrated MANET networks over the last two decades. The surveyed proposals are all placed into three main categories based on the adopted gateway discovery mechanism: Proactive gateway discovery-based mobility management solutions, reactive gateway discovery-based mobility management solutions, and hybrid gateway discovery-based mobility management solutions. A comparative analysis is also provided for each category using a table form.

The rest of the paper is divided into four sections. Section 2 provides an overview of traditional mobility management solutions. Section 3 highlights common MANET routing protocols, especially those that have been commonly used in the surveyed solutions. A review of existing mobility management solutions for integrated MANET, along with the comparative study is presented in Section 4.

## 2. IP Mobility Management Protocols

Several mobility management protocols have been proposed in order to support IP mobility in a wireless network. IP mobility protocols can generally be classified according to various criteria. They can be classified according to the network perspective into host-based mobility systems and network-based mobility systems. A host-based mobility approach is when a mobile node changes its point of attachment. Examples of this category are Mobile Internet Protocol version six (MIPv6), Hierarchical MIPv6 (HMIPv6) [13], and Fast Handover for HMIPv6 (FHMIPv6). Network mobility systems are concerned with cases where a whole subnet changes its point of attachment, and so mobile nodes are not involved in any mobility related signaling. An example is when a whole network containing a router and mobile devices changes its point of attachment. Network-based mobility

scheme scenarios can be seen in military applications. Proxy MIPv6 (PMIPv6) and Fast PMIPv6 (FPMIPv6) are mobility solutions that support network-based mobility [14,15].

Host-based mobility and network-based mobility solutions address hierarchical networks and are logically centralized. They share common mobility management functions: Anchoring functions, internet work location management function, and forwarding management function [16].

From a mobility perspective, mobility management systems can be classified into two main categories: IP macro mobility management protocols and IP micro mobility management protocols. The macro-mobility management approach is used to manage mobile device movement on a large scale between different network domains, while maintaining ongoing connections. Mobile IP [17] has different versions; Mobile IPv4 and Mobile IPv6 are the best known and adopted protocols for cross domain mobility management. IP micro mobility protocols involve the management of mobile nodes movement on a local scale within the local domain. Mobile IP is not a good solution for mobility management when the movement is relatively frequent, because of the mobility signaling overhead caused by this mechanism when Mobile IP tunneling introduces high network overheads. Micro mobility solutions therefore aim to minimize the handover delay and keep signaling overhead to a minimum. They manage the local movement of mobile nodes without registration between mobile nodes and other distant home agent nodes, and so they manage to reduce binding updates for the distant home agent, delay, and packet loss during handover procedure. Several protocols were proposed in this category, such as HMIP [13], HAWAII [18], and cellular IP [19]. Figure 1 shows HAWAII architecture that depicts macro and micro mobility levels of mobile nodes within and across different domains. In this paper, mobility management solutions are classified from the mobility point of view into macro mobility management and micro mobility management, which are introduced in the following subsections.

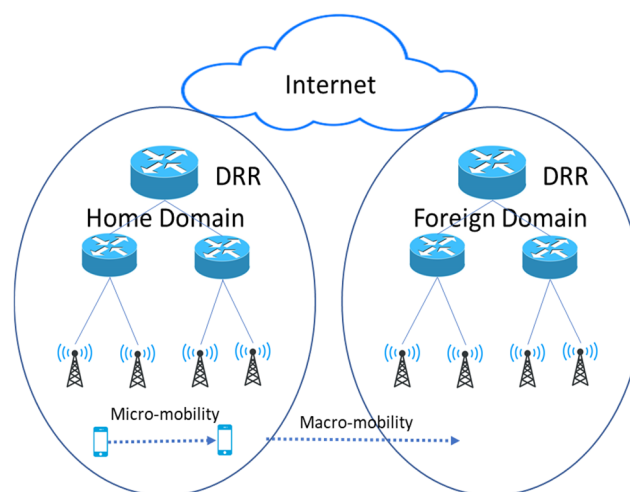


Figure 1. Micro versus macro mobility.

### 2.1. Macro Mobility Management Solutions

**Mobile IPv4:** Mobile IPv4 is the most popular protocol used for mobility management. Mobile IPv6 is the successor version that was developed to manage mobility for next generation IPv6 networks. A Mobile IPv4 mobile node has two IP addresses; the home address and the Care of Address (CoA). The home address is static, and it links the mobile node to its home network. A network entity from outside the home network uses this address to communicate with the mobile node. The mobile node registers its static home address with an agent known as the Home Agent (HA). The CoA, on the other hand, is a dynamic address that is given to the mobile node as it moves to another network known as the Foreign Network (FN). It reflects the physical location of the mobile node.

The process of handoff begins when the mobile node moves to the FN where it registers with a Foreign Agent (FA) similar to its HA, but in the new network. The mobile node notifies its HA in

its HN of the obtained CoA by itself directly or through the FA. Any packets destined to the mobile node from a Corresponding Node (CN) will arrive at the HA, which will tunnel the traffic to the CoA (see Figure 2). The FA then detunnels the traffic and sends it to the mobile node. This procedure is repeated whenever the mobile node moves to a new network and has a new CoA.

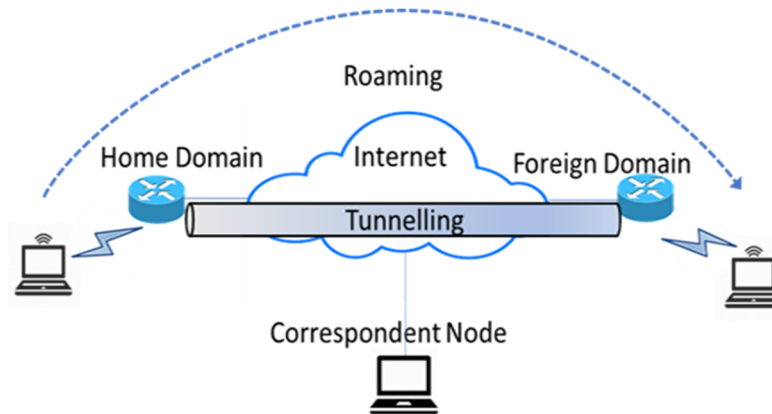


Figure 2. Mobile IPv4.

**Mobile IPv6** was developed to provide mobility for IPv6 networks. It considers all the problems experienced in the previous mobile IPv4. Mobile IPv6 eliminates the use of the FA functionality, where a moving mobile node to a FN obtains its CoA using an auto configuration procedure. This is in contrast to use of the periodic broadcast advertisement and registration mechanism used in mobile IPv4. Upon obtaining the CoA, a mobile node sends a binding update (BU) to its HA and the CN. In response to the BU, the HA and the CN reply to the mobile node with an acknowledgement, and thus use the new binding for the following communication with the mobile node. Mobile IPv6 has therefore developed the design of mobile IP to eliminate the use of FA and provide route optimization by establishing a direct communication channel between the CN and the mobile node, as shown in Figure 3. The CN thus sends any future traffic directly to the mobile node. Overall, the MIPv6 design has reduced network load and brought route optimization, but it still depends on access point discovery and HA communication.

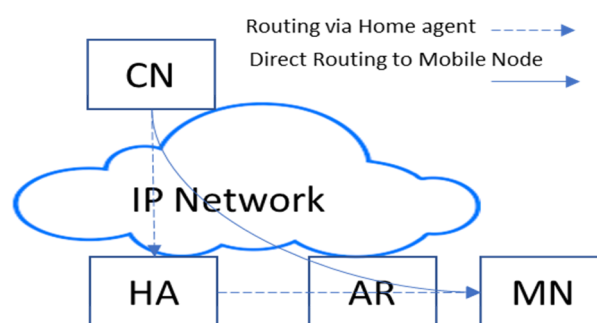


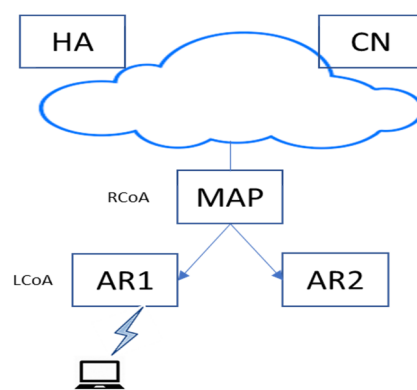
Figure 3. Route optimization in Mobile IPv6.

### 2.2. Micro Mobility Management Solutions

Mobile IP suffers excessive signaling overhead in its two variant versions when there is a frequent handoff within the wireless network. This is a result of the required control messages, whether between the mobile node and its HA, as in MIPv6, or between the mobile node and its HA and FA, as in MIPv4. This, however, leads to a need for mobility management protocols to handle mobility for scenarios where mobile nodes move and change their point of attachment frequently. The solution should provide a fast and seamless handover. In the following, we highlight some of the common mobility management protocols proposed for such micro mobility management.

**HMIP** was introduced to enhance the performance of MIPv6 while minimizing the impact on it. HMIP aims to reduce signaling cost and binding updates resulting from frequent user mobility, and thus smooths and speeds up the handover process. It introduces a new functional node called the Mobility Anchor Point (MAP), which is located at a higher level of the hierarchical network structure. Figure 4 shows the HMIP hierarchical structure. The MAP is not required to be located at a top of each single subnet. It is intended to reduce the number of control messages that are usually sent outside the local domain. A MAP node is supposed to serve a domain consisting of multiple access routers. A mobile node is required to register with an access router to get an On-Link Care of Address (LCoA), and registers with a local MAP to get a Regional Care of Address (RCoA). The RCoA is the address used for communication with any CN node. If the mobile node moves into the coverage of a new access router within the local MAP, it registers with the new router, obtains a new LCoA, and notifies its MAP of the new LCoA. It will not inform the CN node of the new address since the RCoA is used for connection with the external node. When the MAP receives any traffic destined for the mobile node, it forwards the traffic to the appropriate access router according to its mapping knowledge.

**Cellular IP** was designed to handle mobility between subnets within the same domain. It can interwork with the IP mobility protocol to provide macro-mobility between different domains. The main components of cellular IP are the Base Station (BS), working as an access point, and the gateway router that is the boundary between a cellular IP network and the internet (see Figure 5). Gateways are used by the cellular IP to link subnets to the internet, and its IP address is used as the CoA for all mobile nodes within the cellular network. For location and routing purposes, cellular IP maintains two distributed caches by mobile nodes and cellular IP nodes. Packets sent by mobile nodes are used to update the cellular IP node cache. Mobile nodes maintain a map to the available cellular IP base stations. Mapping entries are updated through regular route-update messages. Cellular IP provides two approaches for handoff, hard handoff and semi-soft handoff, to allow mobility within a local domain. The first approach is fast and simple but comes with potential packet loss. In the semi-soft handoff, when a mobile node receives a signal from a new base station, it sends a semi-soft packet and returns to listen to the old base station. This will update the mapping cache. The final handoff takes place after a delay called a semi-soft delay.



**Figure 4.** Hierarchical Mobile Internet Protocol (MIP).

**HAWAII:** The Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) is another micro-mobility protocol to manage mobility within a domain. HAWAII builds a home domain following a hierarchy approach as illustrated in Figure 6. Each home domain consists of the Domain Root Router (DRR), which acts as a gateway linking the local domain to the external network. The DRR covers several base stations and routers, which in turn serve mobile nodes. Each mobile node is given an IP address and home domain, however, when a mobile node moves to a foreign domain, it follows the mobile IP scheme for such interdomain mobility. The node then obtains the CoA from the foreign domain.

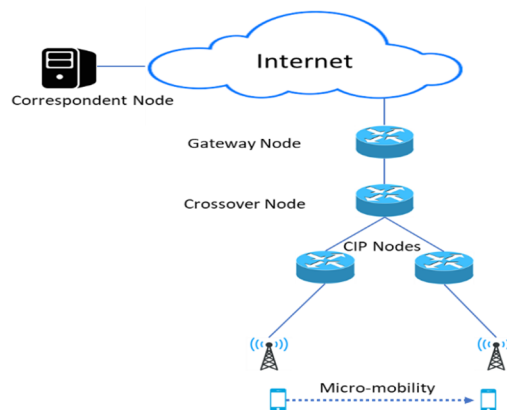


Figure 5. Cellular IP Architecture.

A base station frequently sends agent advertisement messages that can be used by moving mobile nodes within the home domain to detect the new base station. Once a mobile node detects the existence of a new base station, it sends a registration request that starts the HAWAII path set up procedure. In order to maintain routing to mobile nodes in the home domain, HAWAII uses path setup update messages; power-up, refresh, and update. These messages are used to build host-based routing entries in selected routers within the domains. Mobile nodes frequently send path refresh messages to keep the host-based routing entries updated in the home base station. Aggregated refresh messages are then sent up the overlay tree to update intermediate routers and the main DRR. If there is a failure to send the frequent path refresh messages, a mobile node host-based routing entry is removed from the base station.

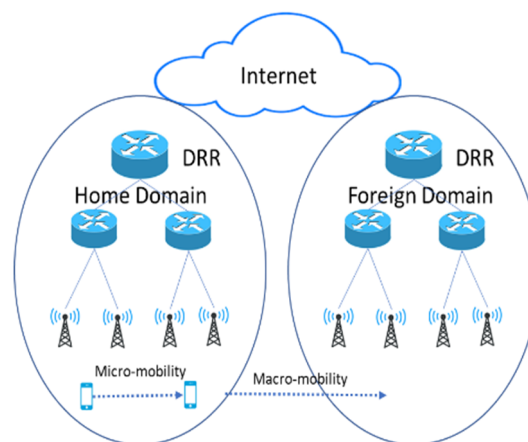


Figure 6. Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) hierarchy based on domains.

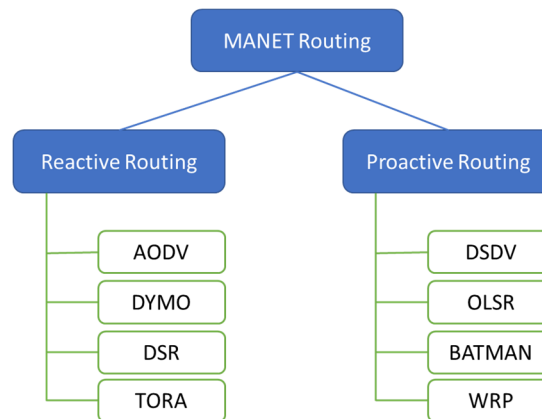
### 3. MANET Routing Protocols

MANET is defined as a set of mobile devices that can communicate with each other using radio channels. It does not require an existing infrastructure to operate. MANET is a dynamic network where mobile devices can freely move, causing disruption and inconsistency in the network. Moreover, MANET is a self-configured network that does not require centralized components for its management. Mobile devices can organize themselves and cooperate with each other to guide network packets to their final destinations. A MANET node plays the role of both an end system and a routing router.

There are several surveys of MANET routing in the literature. The most recent surveys concentrate on particular MANET aspects, such as power efficient routing [20], hybrid routing mechanisms [21], congestion awareness and adaptive routing [22], or ant colony-based routing [23]. A comprehensive and detailed survey was published by Alotaibi and Mukerjee [24], however, for the purpose of this

paper, the focus is only on the major classification of MANET routing. For a more detailed review, please refer to the above-mentioned papers.

MANET routing can generally be classified into reactive and proactive routing; however, these can be further divided to include categories such as hybrid routing, hierarchical approaches, geographical systems, multi-path, multicast, and geocast categories [25]. Reactive and proactive routing, AODV and DSDV, respectively, are the most commonly used routing systems when integrating MANET with the internet. Therefore, the AODV and DSDV are introduced as representative for the reactive and proactive routing in the following subsections. Figure 7 shows the adopted taxonomy for MANET routing categories in this paper.



**Figure 7.** Taxonomy of Mobile ad hoc Network (MANET) routing protocols.

### 3.1. Reactive MANET Routing

Protocols under this category work on demand. Routes from sources to destinations are only discovered when needed. When a node wants to send a packet to a destination, it checks its routing table. If no route to the destination was found, the source node starts the process of route discovery. Ad hoc On-Demand Distance Vector (AODV) [26], Dynamic MANET On-Demand Routing (DYMO) [27], Dynamic Source Routing (DSR) [28], and Temporally-Ordered Routing Algorithm (TORA) [29] are the typical routing protocols for reactive MANET.

**Ad hoc On-Demand Distance Vector (AODV):** This is a reactive routing protocol that does not use source routing. Source routing is used by some MANET protocols where the source node includes the complete route to a destination. AODV instead stores the next hop address for each route entry in the routing table. In order to discover a route to a destination, AODV broadcasts an RREQ message that includes source address, destination address, recent known sequence number of the destination, and unique ID. Such information is used to guarantee loop-free operation. If an intermediate node that knows the address to the required destination or the destination itself receives the RREQ, then a RREP will be generated and sent in a unicast mode to the initiator. Mobile nodes on the route of the RREP will use the RREP to update the sequence number of the required destination.

AODV uses a hello message to discover neighbor connectivity, and thus to maintain active routes. A node expects a frequent hello message from its neighbors. If the hello message stops arriving, a link failure is assumed. The node will broadcast RERR to distribute a topology change. If the node still requires the route to a destination that uses the failing neighbor, the node must start new route discovery procedure.

### 3.2. Proactive MANET Routing

Proactive routing schemes build routing entries for each existing node in the network in advance of their usage. Each MANET node maintains its routing table by exchanging routing information with other nodes. When a node wants to communicate with another node, it immediately consults

its own routing table to get a route towards the destination. This is possible since each node maintains a complete knowledge of the network. Examples of proactive routing protocols are Destination-Sequenced Distance-Vector (DSDV) [30], Optimized Link State Routing (OLSR) [31], Wireless Routing Protocol (WRP) [32], BATMAN [33], and Source Tree Routing (STAR) [34].

**Destination-Sequenced Distance-Vector (DSDV):** This is a table-driven protocol based on the distributed Bellman–Ford algorithm. In a table-driven routing, each node maintains the next hop node on the shortest path to each existing node in the network. A DSDV node stores a number of hops, the next hop node, and the most current sequence number for each entry in its routing table. An increasing sequence number is used to distinguish the stale routing entries from the new ones and to avoid loops. In order to maintain up-to-date routing tables, DSDV applies time-driven and event-driven update mechanisms. In a time-driven update, each node sends its routing table frequently to its immediate neighbors. The sent routing table is then forwarded throughout the network. In the event-driven update, a node sends its routing table whenever a significant change has taken place in its table since the last transmitted update.

#### 4. IP Mobility Management in MANET and Comparative Summary

This section introduces the solutions contributed in the literature that incorporate mobility management techniques to provide mobility support and roaming capability for integrated MANET–internet networks. The proposed solutions can generally be classified based on the adopted gateway discovery approach into three main classes: Proactive gateway discovery-based mobility management solutions, reactive gateway discovery-based mobility management solutions, and hybrid gateway discovery-based mobility management solutions.

The surveyed systems are presented and analyzed according to these categories in the following subsections. The proposals in each category are summarized in a table that covers the main features and characteristics of the schemes, the mobility protocol used, MANET routing protocol used, handover metrics used, and how the proposed systems were evaluated, including the number of mobile nodes and gateways.

##### 4.1. Proactive Gateway Discovery-Based Mobility Management Solutions

Proposals under this category share the common use of an agent advertisement message to disseminate gateway information and presence proactively. Similar to Mobile IP, these systems configure foreign agents or mobile gateways to broadcast gateway advertisement message periodically. Table 1 shows a summary of the proactive gateway discovery-based mobility solutions. It highlights the characteristics, functionalities, design, and evaluation of these systems. An overview of 11 different proposals under this category is provided below.

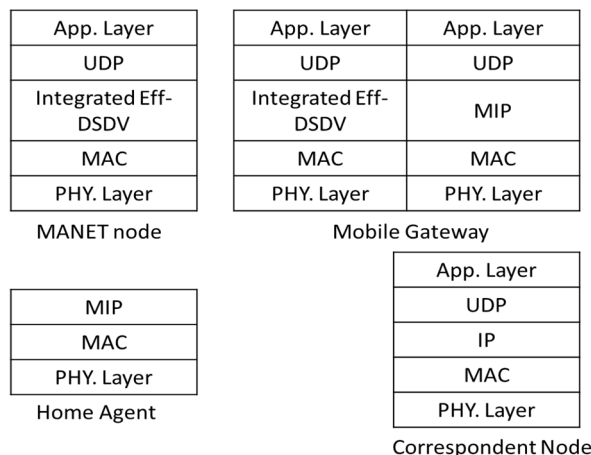
**Performance evaluation of mobile IP on mobile ad hoc networks using NS2** [35] evaluates the performance of MIPv4 over different MANET routing categories. They combine MIPv4 with three MANET routing protocols; AODV, AOMDV, and DSDV to evaluate mobility management for MANET mobile nodes. No modifications were introduced to the original MIPv4. Proposed architectures were evaluated using the NS2 Network simulator and the paper suggested that plain MIPv4 works better when used with the reactive MANET routing protocol (AODV and AOMDV).

**Performance evaluation of mobile IP with DSDV routing protocol using NS2** [36] similarly evaluated the performance of MIPv4 over a DSDV MANET routing protocol. The combination was evaluated using NS2 without any modification of the MIPv4. The paper concluded that the overall performance of the MIPv4, as a mobility management solution for MANET, decreases as the size of MANET increases (only 25 mobile nodes were used).

**An efficient integrated routing protocol for interconnecting mobile ad hoc networks and the internet** [37,38] proposed a system that incorporate MIPv4 and an extended version of DSDV named Eff-DSDV [39] (Figure 8). The proposed system uses the proactive nature of the DSDV to serve as registration with the Mobile IP proxy agent. It uses the routing update messages of DSDV to inform



participating MANET nodes of the existence of a Mobile IP agent. After that, a MANET node will be able to send its registration request to the agent, which in turn forwards the registration to the home agent. The home agent then replies to the Mobile IP proxy agent, which forwards the reply to the MANET node. This system is proposed to work using only one gateway. This may be a drawback of the system since a single gateway means a single potential point of failure.



**Figure 8.** An efficient integrated routing for interconnecting mobile MANET and the internet.

*MIPAD* [40] is a system that modifies Mobile IPv6 to provide for efficient mobility management when an ad hoc node moves from one subnet to another. It aims to reduce the signaling overhead, handover latency, and packet loss rate when using Mobile IP over an AODV MANET. It splits the network into various service regions depending on the coverage of the access routers. When a mobile node moves into an overlapping area, it decides whether to stay connected to the previous foreign agent or to register with the new one. The decision depends on the calculation of proposed equations that include several parameters; registration cost with the foreign agent, registration cost with the home agent, the hop count to the home and foreign agent, average residence time at a subnet, traffic load, and the packet arrival rate. If the calculated value is less than a predefined threshold, the mobile node would stay connected to the current agent and no handover would take place. The paper does not explain how these metric parameters can be exchanged, however, and the evaluation scenario only has one mobile node, which did not offer a suitable environment to demonstrate all of the mentioned metrics.

*Thorough protocol extensions for integrating DSR-based mobile ad hoc networks with the internet* [41] proposed a system that extends the DSR MANET routing protocol to connect MANET to the internet using Mobile IP. The proposed architecture (Figure 9) consists of multiple gateways that advertise their existence periodically (proactive) or on demand (reactive). A gateway with its connected mobile nodes (directly or through multi hops connection) constitutes a mobility domain. A mobile node is only entitled to register with one gateway to avoid duplicated binding to different foreign agents, which results in duplicated packets arriving to the foreign agents and thus to the mobile nodes. The proposed system enhances the DSR protocol to propagate mobile IP advertisements and registration messages. It attaches the signaling messages to DSR source routing information. It also extends the DSR to support external route discovery and external route maintenance functions. The external route discovery is used to distinguish between internal and external nodes. It also provides mobile nodes with information about all existing gateways in the network. This information is only used to identify whether the required address is local or external, however, and help the node to choose a gateway based on hop count metrics. More information related to QoS could be passed via the process of external route discovery, however, to improve mobile node selection of a gateway.

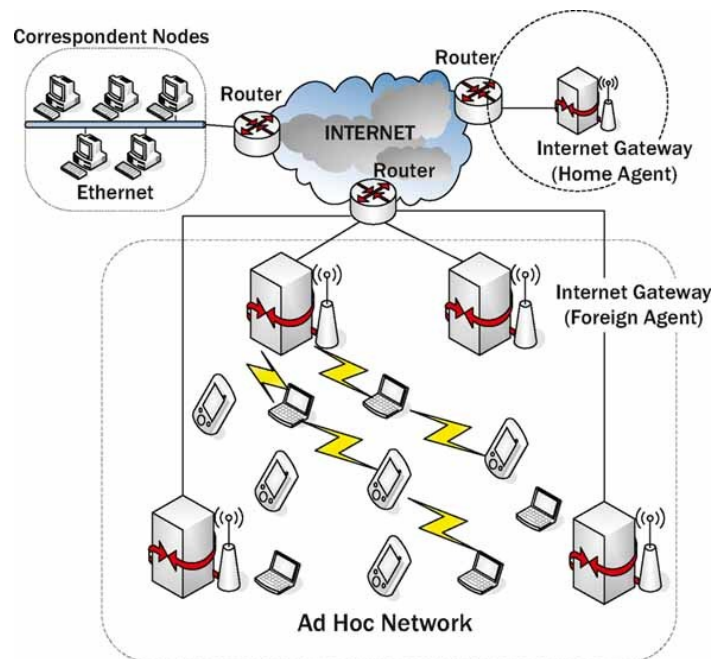
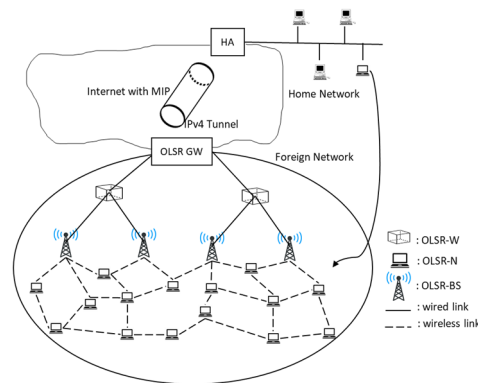


Figure 9. Integrating DSR-based mobile ad hoc networks with the internet [41].

*Global connectivity for mobile IPv6-based ad hoc networks* [42] proposed an IPv6-based MANET architecture that organizes MANET nodes into a tree structure in order to configure their IPv6 addresses. It uses Mobile IPv6 to support node mobility between different MANETs. The formed tree structure is rooted to an access router that acts as the internet gateway. The proposed system then uses a routing protocol based on the longest prefix matching. The proposed routing protocol does not require a path to be found to a destination prior to sending the traffic. Each mobile node instead maintains information about its parent and child nodes. The traffic is then forwarded following the longest prefix matching mechanism. The proposed system was applied to a small network size with low mobility to control the routing overhead. However, the proposed system relies on the root node of the tree structure, which is the gateway. If the gateway fails, the whole network will collapse.

*Integration of mobile-IP and OLSR for a universal mobility* [43] proposed a hierarchical architecture (Figure 10) to connect MANET to the internet that handle mobile nodes mobility at different levels; macro mobility level (inter-domain) and micro mobility level (intra domain). The mobile IP protocol and the OLSR routing protocol were used to support large-scale mobility (macro-management) and local scale mobility (micro-management) respectively. The proposed system uses an OLSR gateway to interconnect each OLSR-IP subnet to the internet. An OLSR gateway is a router that plays the role of a foreign agent for visiting mobile nodes and the role of home agent for local network. It also uses an OLSR base station underneath the OLSR gateway in the hierarchical architecture, which is wired to the OLSR gateway and uses the OLSR routing protocol on the other interface to facilitate routing between the two networks. Each OLSR-IP network contains multiple OLSR base stations to offer load balancing for a local network. The proposed system also introduces another entity called OLSR-W, which is placed in the middle between the OLSR gateway and the OLSR base station, which acts as a traffic controller. A mobile node in the proposed structure is required to implement Mobile IP to be used for mobility management in case of mobile node movement to another OLSR-IP network. The system relies on the Mobile IP tunneling procedure to deliver traffic to a mobile node outside its home network, however the proposed system does not detail how the OLSR-W would contribute toward load balancing since all the routing follows the OLSR shortest path procedure.



**Figure 10.** An OLSR-IP access network interconnected to a Mobile-IP [43].

*Dynamic agent advertisement of mobile IP to provide connectivity between ad hoc networks and internet* [44] proposed a dynamic advertisement scheme for MANET–internet integrated networks using Mobile IP and AODV with the goal of reducing routing overheads. A mobility agent that resides in between the two networks is set to advertise information using two different lifetimes and two different values for coverage zone. The first type of advertisement is an Agent Advertisement message with Short beacon Interval AASI. AASI is identical to the agent advertisement message of the Mobile IP with the scope set to one hop. The second type is an agent advertisement message with long beacon interval AALI. The AALI is similar to the Mobile IP advertisement except for the lifetime, which was suggested by the proposed system to be 300 s and 200 hops, respectively. The proposed system consists of three main entities: Foreign agents, inner nodes, and outer nodes. A foreign agent takes the role of routing between the two networks and broadcasts AASI periodically to its one hop neighbor. It also floods the whole network with AALI. Nodes inside the one hop scope of the foreign agent are considered inner nodes, and nodes outside the one hop scope of the foreign agent are known as the outer nodes. Upon receiving a mobility advertisement, a mobile node is required to register with the mobility agent using the traditional Mobile IP registration procedure. Despite the fact that the system was proposed to reduce integration routing overhead, the approach of using two types of gateway advertisement would increase the overheads.

*MARs* [45] proposed a generic solution for mobility management using Hierarchical Mobile IPv6, which could work with reactive or proactive MANET. It divides the network into parts, based on the HMIP. Each part consists of multiple access routers (AR) that are managed by a Mobility Anchor Point (MAP). A mobile node is required to register with two of the existing ARs and obtains a Local On-Link Care-of-Address (LCaA) for each AR. The discovery of AR can be done via a broadcasting gateway advertisement message by the ARs, or by explicitly asking the ARs to send the gateway advertisement messages. Upon receiving gateway information, a mobile node chooses the two best AR based on the hop number from the same MAP, then sends a registration packet to all available ARs notifying them to update their records. ARs in turn forward the registration packet to their MAP to update its own record as well. Once a mobile node finds a new AR in the same MAP that is two hops closer than one of its ARs, it starts the handoff by sending a new registration packet. When a mobile node finds two ARs that are two hops closer than its current ARs, and which belong to different MAP, it starts a new registration procedure. The system is deployed over DSDV and AODV. The proposed system is quite generic, however, and floods the mobility management traffic over the existing MANET routing traffic. This would consequently result in higher overheads.

*Mobile IP enriched wireless local area network architecture (MEWLANA)* [46] presented a mobile-enriched wireless local area network architecture with two versions to extend Mobile IP functionality to MANET. These are MEWLANA-TD, which is based on DSDV protocol, and MEWLANA-RD, which uses the proposed table-based bidirectional routing (TBBR). The proposed architecture consists of three domains. The first domain is the internet cloud that contains home agents and corresponding nodes. The second is the foreign agent domain, which lies between the internet

and MANET domains, and consists of foreign agents and mobile nodes one hop away. A foreign agent is not part of MANET and therefore does not operate MANET routing protocol. The third domain is the MANET network. Foreign agents broadcast a periodic agent advertisement, as in Mobile IP, that contains a care of address and source address and hop counts. A mobile node, which is in the foreign agent domain, alters the source address of the received agent advertisement message to itself and rebroadcasts it, so other mobile nodes in the MANET domain can use this node as an access point. Thereafter, MANET nodes can register with the home agent through recently discovered foreign agents. This version of MEWLANA optimizes the DSDV routing table information where MIP floods the advertisement message only if the routing table has a new entry for a node that just joined the network. However, firing mobility traffic in addition to DSDV traffic is seen as a drawback of the proposed system, and instead the DSDV traffic should be used to deliver mobility traffic.

The other version of MEWLANA is *MEWLANA-RD*, which is based on a proposed root driven routing algorithm TBBR. MANET nodes and the foreign agent are organized as a tree structure with the foreign agent as the root of the tree. Beaconing from the foreign agent is used to form the tree structure and each mobile node has a depth level number, which is the hop count of the arriving beacon. A mobile node can only process a beacon with a hop count less than its depth level number. After construction of the tree structure, each mobile node registers with the foreign agent by sending a multi-level registration request to its parent in the tree structure. Mobile IP is used to route traffic to its destination. If two mobile nodes are in the same MANET domain but in different tree structure, the traffic destined between them needs to go through home agents and then foreign agents. The system is claimed to suit a large MANET with low internal traffic, however, the use of a root node at the top of the structure would make the gateway susceptible to congestion and therefore a single point of failure.

*MIPMANET* was proposed by [47]. MIPMANET provides mobility management services for MANET networks connected to the internet. It incorporates traditional Mobile IP with an AODV routing protocol. Mobile IP foreign agents are used as access points for MANET nodes. MIPMANET uses the Mobile IP agent advertisement scheme to announce access point presence. Each foreign agent is required to broadcast an agent advertisement in every five second period, compared to one second in the traditional Mobile IP. Mobile nodes that wants internet access are required to register with one of the foreign agents based on the distance metric. For routing purposes, MIPMANET uses the default route concept in AODV routing tables, where a mobile node sets its foreign agent as its default route entry. However, the default route is only used after a node broadcasts an AODV route discovery message and finds no route to the desired destination. The OADV route discovery message is also used in the proposed system to find a route to the foreign agent. Roaming between different foreign agents is supported in MIPMANET using the hop counts criteria. A mobile node can register with a new foreign agent if it is two hops closer to the new foreign agent than the current foreign agent. The proposed system can experience long delays before a node can connect to other entities on the internet, however. This is due to the delay in discovering the gateway, when a node must search the whole network and if no route is found, the default route will be used. The delay can also be seen as a result of the high frequency of firing the gateway advertisement.

Table 1 shows a summary of the proactive gateway discovery-based mobility solutions.

**Table 1.** Proactive gateway discovery-based mobility management solutions.

Scheme	Features	Mobility Scheme	MANET Routing	Handoff Metrics	Gateways	Evaluation\Simulation
Ofosu et al. [35]	No modification to MIP.	MIPv4	AODV-AOMDV-DSDV	-	4 foreign agents	Evaluated using NS2, 175 nodes.
Alsaied and Modatheir [36]	No modification to MIP.	MIPv4	DSDV	-	3 routers covering 4 fixed foreign agents.	Evaluated using NS2 - 1, 5, 10, 15, 20 and 25 nodes.

Table 1. Cont.

Scheme	Features	Mobility Scheme	MANET Routing	Handoff Metrics	Gateways	Evaluation\Simulation
Khan et al. [37]	Uses route update message to propagate gateway existence. Gateway acts as foreign agent	MIPv4	Eff- DSDV	Gateway sends De-registration message to HA when the route entry to a node is lost.	1 gateway	Evaluated using NCTUns simulator, 20 nodes, compared to [48].
MIPAD [40]	Divides network into service subnets, each is covered by an access router. A mobile node with high mobility will not register with a new router, stays with old router to reduce signaling.	MIPv6	AODV	Registration cost with HA and FA, hop counts, residence time, traffic and packet arrival rate.	2 access routers as gateways.	Simulated in NS2, 2 access router and 1 mobile node moving between the service regions, compared to Hierarchical MIP.
Ding [41]	DSR routing message is piggybacked with MIP signaling message. Designs comprehensive external route judgment to judge locality of a destination.	MIPv4	DSR	Hop counts	4 gateways	Simulated in OPNET, 100 nodes, 10 are mobile nodes. Compared to another version of the system that uses traditional external route construction.
Wang et al. [42]	No modification to MIP.	MIPv6	Proposes routing protocol uses tree topology, longest prefix matching.	-	1 access router	Five notebooks were used, one is the access router and other acts as mobile nodes.
Benzaid et al. [43]	Uses hierarchical structure consisting of 3 levels. MIP is used to support macro mobility and OLSR for micro mobility. MPR Nodes rebroadcast any received agent advertisement message.	MIPv4	OLSR	Hop count	3 access routers linked to another router which is one step up in the hierarchy.	Testbed of 3 MANETs, each has one mobile node and managed by an access router known as OLSR-GW.
Jung et al. [44]	Gateway broadcasts 2 types of advertisement message; one with one hop lifetime and the other with 200 hops and 300 s lifetime. Extends RREP of AODV carries gateway information.	MIP	AODV	Hop count	2 gateways	2 MANET simulated in NS2, each has 4 mobile nodes.
MARs [45]	Relies on mobility anchor point that serves several access routers. Registration with 2 access routers is required.	Hierarchical MIP	DSDV-AODV	Hop count	2 access routers belonging to one MAP.	Simulated in NS2, one MAP, 2 access routers, each serves 5 nodes. No simulation for the HMIP. 50 nodes in another scenario.

Table 1. Cont.

Scheme	Features	Mobility Scheme	MANET Routing	Handoff Metrics	Gateways	Evaluation\Simulation
MEWLANA-TD [46]	Dynamic beaconing (MIP initiates beaconing if there is a node joining a network). Registration is required after each beacon. Uses tunneling.	MIP	DSDV	Hop count	Not specified	Simulated in NS2, 4, 8, 32, 64 and 128 having 1-10 traffic sources. Both were compared to MIPMANET.
MEWLANA-RD [46]	Formation of routing table is based on MIP entities. Constructs tree topology. Uses tunneling.	MIP	TBBR	Depth level number	Not specified.	
MIPMANET [47]	Access point acts as FA. Broadcast advertisement every 5s. FA is used as a default route.	MIP	AODV	Hop count (2 hops closer)	2 foreign agents	Simulated in NS2, 15 mobile nodes. Compared to another version that does not broadcast advertisement message.

#### 4.2. Reactive Gateway Discovery-Based Mobility Management Solutions

Solutions under this category deploy a mobility management protocol over MANET and enable mobile nodes to take over the responsibility for discovering gateways. In order to discover gateways, nodes broadcast or unicast solicitation messages that can be answered or forwarded by intermediate nodes. In response, gateways send a reply message to the initiators to notify them of their existence. The main goal of this approach is to cut the overhead of proactive approach, however it comes with a cost of increasing the discovery delay. This section introduces five proposals in this category that use mobile IP. Table 2 summarizes the characteristics of those proposals.

**QoS-based gateway selection in MANET with internet connectivity [49]** integrates MANET and the internet, using MIPv4 to support mobile nodes mobility between ad hoc networks. The AODV protocol was used for MANET routing. The proposed system focuses on the gateway selection process to enhance the feasibility of integrated MANET. The gateway selection procedure is based on three metrics; gateway load, path quality between MANET nodes and the gateway, and finally, the hop counts along the used path. The system is based on reactive discovery approach, where MANET nodes broadcast a solicitation message and gateways reply with the advertisement message in a unicast mode. The paper does not explain the handover procedure, however. It can be seen that the selection of gateway will take place only when a node connects to the internet for the first time. This would be the case especially when a gateway advertisement is unicast to the initiator of the gateway solicitation message.

**Robust and flexible internet connectivity for mobile ad hoc networks [50]:** Figure 11 proposed a system for flexible and robust internet connectivity. The proposed system was designed to work over AODV routing protocol, however the authors claimed that the procedure used could be adopted to work with any MANET routing protocol with minor modification. Their proposed procedure is mainly based on extending the AODV route discovery mechanism to serve gateway discovery in addition to route setup. Mobile IPv4 was used to provide mobility management for mobile nodes. The mobile IP agent discovery task was eliminated from the implemented MIP, however. The functionality of agent discovery was assigned to the AODV and included within the route request mechanism. The gateway is responsible for checking destination locality using a prefix check or visitor list. The system, however, does not support intermediate node replies for internet destination discovery, as stated by the authors, and therefore nodes need to flood the network with route request messages.

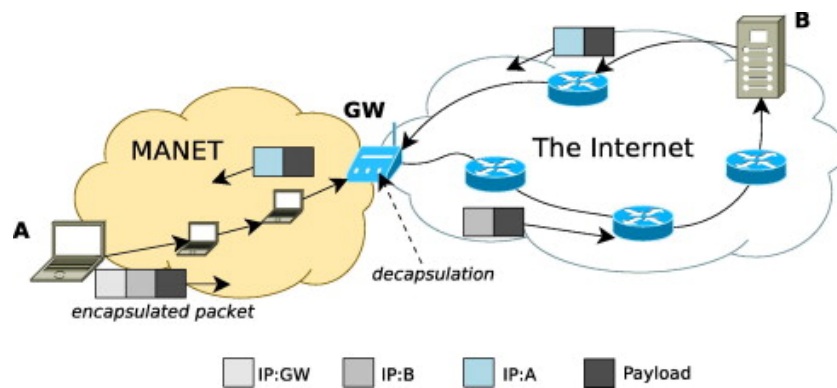


Figure 11. Robust and flexible internet connectivity for mobile ad hoc networks [50].

*Adaptive discovery of internet gateways in mobile ad Hoc networks with mobile IP-based internet connectivity* [51] designed a Mobile IP based access scheme that provides internet connectivity for MANETs. The designed system is based on the AODV routing protocol. Mobile IP foreign agents are used as gateways and run the AODV protocol to forward traffic inside and outside MANET, although they are proposed not to broadcast agent advertisement messages so as to reduce overhead. Mobile nodes therefore have to discover the routes to gateways. This is done via modifying AODV to broadcast a route request message to find all available gateways. The proposed system also introduces a dynamic gateway algorithm according to which a mobile node can calculate the value for each gateway and then select the optimal gateway. The formula includes the hop count between a mobile node and a gateway as well as the number of registered mobile nodes with that gateway. The system does not provide any further information on mobility management or reregistration with gateway nodes. The handover procedure and the ability of mobile nodes to detect other gateways while moving are not considered.

*CATBR* [52] proposed a system that uses Mobile IP to connect MANET to the internet. The proposed system eliminates the use of gateway registration and focuses on the process of selecting a route towards the gateway to the internet. It claims that the determining factor in obtaining a quick connection to the internet is the MANET routing protocol itself. The paper therefore proposed a routing protocol for MANET that follows a tree-based structure rooted to the gateway node. A hierarchical routing is used to deliver internet traffic from a mobile node to the gateway. The proposed routing protocol uses cross-layering between the link layer and network layer to enhance congestion-awareness and determine congestion along the path to the gateway. It introduces four metrics to determine the congestion: The contention metric, which is measured through the link layer using request to send (RTS) and clear to send (CTS); the queue metric at any given node along a path; the self-metric, which is calculated based on the contention metric and queue metric; and a final metric to measure congestion along the path. The overall tree-based structure of the network is built (parent–child relationship) upon the final metric, where a mobile node gets its hierarchical position based on the least congested path. The use of a root gateway to all MANET nodes will decrease the performance of the gateway, however, which becomes a bottleneck for the whole integrated network. Moreover, the proposed solution does not support soft state routing between adjacent nodes, where neighboring nodes must contact each other through the hierarchical structure.

*Integration of mobile ad hoc networks and the internet using mobile gateways* [53] proposed a mobile gateway-based three-layer approach that uses DSDV and Mobile IP to integrate MANET and the internet. The first layer includes the Mobile IP foreign agents; the second layer constitutes the gateway nodes and mobile nodes, which are one hop distance from the gateways; and the third layer includes the normal MANET nodes. The second layer is in the middle of the other two layers and runs both Mobile IP and DSDV. For normal MANET nodes, access transparency to the foreign agents is provided through gateways where they take the responsibility of choosing the appropriate foreign agent for a MANET node. Mobile nodes are required to register with a gateway node, and

gateway nodes are required to register with a foreign agent. The proposed system applies two criteria for registration; distance from the gateway for mobile nodes and distance from the foreign agent for the gateways. The second criterion is the load, which is the number of served nodes or gateways in respect to the foreign agent. The proposed system follows the reactive gateway discovery scheme, where a mobile node needs to broadcast a mobile gateway solicitation. Any gateway willing to serve would reply with a gateway advertisement. Although the system is based on a proactive MANET routing protocol, it does not utilize the exiting routing traffic. Instead, it applies the broadcasting of a gateway discovery message in addition to the DSDV traffic, which can be seen as a drawback of the system. The use of redundant registration also increases the complexity of the system where mobile nodes need to register with a gateway and gateways themselves need to register with a foreign agent.

**Table 2.** Reactive gateway discovery-based mobility management solutions.

Scheme	Features	Mobility Scheme	MANET Routing	Handoff Metrics	Gateways	Evaluation\Simulation
Yan et al. [49]	Use simple additive weighting technique to calculate QoS. Solicitation message is broadcast by nodes to discover gateways.	MIPv4	AODV	Traffic load, path quality and hop count.	5 gateways	Simulated in NS2, 50 nodes, 15 are traffic sources, compared to variants of the system: minimal hops selection based, traffic selection based and path quality based.
Nordstorm et al. [50]	Eliminates gateway advertisement from Mobile IP. Extends AODV Route discovery for gateway discovery.	Mobile IPv4	AODV	-	2 gateways	20 nodes simulated in NS2. Two variants of the system were compared; one uses tunneling and the other uses a default route forwarding strategy. It also implements a testbed consisting of 7 mobile nodes.
Bo et al. [51]	No gateway advertisement in MIP and assigns it to mobile nodes by broadcasting route request message to discover gateway.	MIP	AODV	Number of registered nodes with a gateway and hop count.	3, 4, 5, 6 and 7 gateways	30 nodes simulated in NS2, compared to traditional MIP over AODV and modified OLSR.
CATBR [52]	No gateway registration. Hierarchical routing to deliver data to internet. Cross-layering between link and network layers to enhance congestion awareness.	MIPv6	Modified TBR	Contention metric, queue metric, self-metric and congestion along the path.	Not specified	Simulated in NS2, 10-50 nodes, compared to integration based on DSDV and TBR.
Ammari and El-rewini [53]	Gateways differ from foreign agent. Requires node registration with gateway. Requires registration with foreign agents.	MIP	DSDV	Hop count and load, metrics are applied for gateway selection and for foreign agent selection.	2 foreign agents. 1-12 gateways	Simulated in NS2, 20 and 50 nodes. Number of mobile nodes connecting to the internet is 1,3 and 5 only, evaluated with different number of sources. No comparison to other systems.

### 4.3. Hybrid Gateway Discovery-Based Mobility Management Solutions

The hybrid gateway discovery approach combines the proactive and the reactive approaches to create a balance between gateway advertisement overhead and the delay of discovering gateways. In such an approach, the nearby mobile nodes are provided with gateway advertisement, however distant nodes must use solicitation messages to discover gateways. This section has introduced six proposals that use Mobile IP and follow the hybrid gateway discovery approach and they are summarized in Table 3.

**Mobile IP support in ad hoc networks with wireless backbone** [54] proposed agent discovery and route discovery schemes to enable Mobile IPv4 in on demand ad hoc networks. It uses stationary internet gateways and wireless routers to support mobility management. In order to reduce broadcasting overhead in the network, the proposed solution limits agent advertisement broadcasting and utilizes proxy agent advertisement instead. It employs destination address caching in internet gateways and



proxy route reply to reduce delay while discovering external destination. The proposed system applies a priority-based route request rebroadcasting scheme during the route discovery procedure to allow a mobile node to select more stable routes. Since the proposed system limits the rebroadcasting of agent advertisement, a mobile node that is multi-hops away should broadcast an agent solicitation message to discover the internet gateway. A wireless router can reply to the agent solicitation on behalf of the internet gateway. A roaming mobile node is required to identify a foreign agent and registers with its home agent using the foreign agent. Any traffic destined to the mobile nodes will be tunneled to the new foreign agent. The proposed system introduces a wireless router entity in addition to the internet gateway to the structure of the integration, which comes with expenses. There is also no explanation of the interoperability between a MANET protocol and Mobile IP, and the system was not evaluated.

**Integrating mobile IP with ad hoc networks** [55] proposed an architecture (Figure 12) that connects MANET to the internet using Mobile IP and DSDV. The architecture is divided into multiple MANETs, each connected to the internet using a fixed gateway node. The border of each individual MANET is defined by its gateway. Gateways use Mobile IP to operate as foreign agents for local MANET nodes. They advertise their presence via the periodic broadcasting of an agent advertisement message. Mobile nodes use the agent solicitation message scheme as well in case they do not receive the periodic advertisements. In order to define the service scope for each gateway, the proposed system associates a parameter  $N$  with each gateway. So, a mobile node that is within  $n$  hops of a gateway can be served by this gateway. If a mobile node is within the service scope for more than a gateway, it selects its gateway based on the shortest path criteria. It also introduces another parameter called  $M$ , associated with each DSDV node to define the maximum distance to which a node can forward traffic. If the traffic needs to be forwarded to a destination that is greater than  $M$ , the traffic must go through the internet. The proposed system uses Mobile IP registration for mobility management. A mobile node that moves to the scope of another gateway would register with the new gateway and its traffic will be tunneled by its previous gateway to the new one. However, the use of a defined parameter to form the scope of a gateway can be seen as limitation of this system since the proposed system does not prevent a mobile node from rebroadcasting the same advertisement message many times. The actual scope of a gateway will therefore not be met. Furthermore, the relay of MANET traffic using the external network is a drawback of the system, where more burden is placed on the gateway.

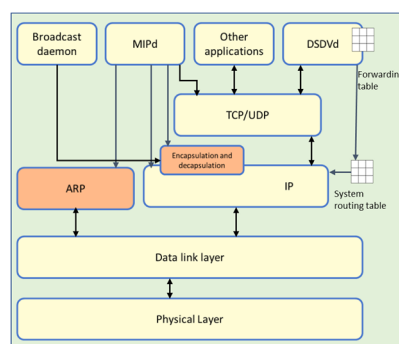


Figure 12. Integrating mobile IP with ad hoc networks [55].

**A hybrid approach to internet connectivity for mobile ad hoc networks** [48] provides internet connectivity and node mobility management for internet-MANET integrated networks using Mobile IP and AODV. Foreign agents were used to relay traffic between MANET nodes and their corresponding node on the internet. Similar to Tseng [55], the proposed system is based on limiting the propagation of agent advertisement messages to avoid flooding the network with Mobile IP excessive control overheads. It is claimed that the limited broadcasting of agent advertisement message contributes to reducing control overhead where a reduced number of solicitation messages would be sent by MANET nodes. For determining whether a destination is in the MANET or external, the proposed system uses foreign agent route reply message FA-RREP to reply to any received route request from

MANET when a foreign agent happens to have no route to it. The FA-RREP will be understood by the initiator as a non-local destination that is on the internet. A mobile node is required to register periodically with a foreign agent to maintain up-to-date route entry to a gateway using the broadcast agent advertisement messages. However, far-away mobile nodes from foreign agents will not receive the agent advertisement message as the broadcasting of the advertisement is limited, and therefore such mobile nodes use solicitation to discover foreign agents. Upon receiving a solicitation message, any intermediate node that has a route to the foreign agent would reply with the advertisement to the initiator of the solicitation. The system also uses ring search method to reduce flooding the network with solicitation where the solicitation initially sent with TTL is equal to one and increased up to seven, and after that, solicitation is flooded throughout the network. However, the system does not specify the process of handoff. The ring search method can also lead to a long delay until a mobile node can discover a route to a foreign agent.

*Internet connectivity for ad hoc mobile networks* [56] incorporates Mobile IP with AODV to provide internet connectivity and mobility management for MANET. Mobile nodes and foreign agents are configured to maintain a foreign agent list and mobile node registration lists, respectively. For agent advertisement, foreign agents in the proposed system broadcast advertisement messages periodically, which is additionally used to propagate routing information to allow mobile nodes to get the route to foreign agents. MANET nodes that desire a connection to the internet should process the advertisement message and re-broadcast it. On the other hand, the proposed system supports the mobile node discovery of foreign agents. Mobile nodes can issue and broadcast a route request with an agent multicast group address as the destination of the message in order to discover available foreign agents. Once a mobile node receives a route reply, it can then unicast a solicitation message to the foreign agent. The proposed system requires mobile nodes to register with a foreign agent to access the extended network. The registration procedure takes place after the agent advertisement is received, using a registration request and registration response message. Like MIPMANET, but with a few changes, the system uses a cell switching algorithm to manage mobility. A mobile node can register with a new foreign agent as long as it is two hops closer to the new foreign agent than the current one. The proposed system claims to piggyback routing information to the gateway advertisement messages, however the piggybacking procedure is not explained.

*Mobility management in hybrid ad-hoc networks and the internet environment* [57,58] proposed an architecture based on Mobile IP that consists of three layers; internet domains that contain home and foreign agents and corresponding nodes, mobile gateway nodes as the second layer, and MANET nodes as the third layer. The proposed architecture uses a distributed buffer management approach to provide reliable data delivery. Foreign agents are equipped with buffers to store traffic coming from the internet and the mobile gateway buffers are used to store MANET traffic that can be distributed later within the MANET or towards the foreign agents. The proposed architecture uses reactive and proactive gateway discovery, although there are no details about how the gateway discovery operates. It also uses a registration process to entitle a mobile node to register with a gateway node. The registration process takes a multi-layer registration approach. A mobile node initiates a registration request and sends it up the layer architecture to the gateway, then to the foreign agent, and finally to the initiator's home agent. The home agent creates the corresponding mobility binding and sends the registration confirmation down the architecture to the mobile node, which can then complete the registration with the gateway. The system supports handover between different gateways (micro mobility) and between different MANETs (macro mobility). It proposes three variant handover mechanisms: Mobility management with force handover, mobility management with optimized handover, and mobility management with prediction. The first is used if a mobile node loses its connection with its gateway. The second mechanism is used for handover where a mobile node finds a shorter route to another gateway and its route to its current gateway is still valid. The third mechanism combines prediction with the optimized handover. The handover decision is based on the shortest path and predicted gateway signal strength.

**MG-AODV** [59] modifies Mobile IP and AODV to provide MANET–internet connectivity. The Mobile IP agent advertisement procedure was replaced by an AODV modified hello message. Some of the MANET nodes are set as gateways (foreign agents). They flood the network with modified hello message that contain a mobile gateway bit set to one. For registration, a mobile node should find a gateway to forward its registration request to its home agent. If no gateway is found, the mobile node has to broadcast a solicitation message to discover available gateways. Once it finds more than one gateway, the mobile node selects the appropriate gateway based on the hop distance and the payload of the gateway. The system also uses a different registration maintenance mechanism from that used in traditional Mobile IP. It uses a conditional registration renew mechanism according to which the renew procedure is only started when the route to the gateway is broken. The proposed system also modifies AODV to maintain two new tables. The first is maintained by a mobile gateway to store MANET nodes that have already sent solicitation or registration requests to this gateway. The second table is used by each MANET node to store available gateways in the network. A drawback of the system is that it propagates gateway advertisement to one hop neighbors only, and for faraway nodes it uses the ring search method strategy, similar to [48], to discover a gateway. A distant MANET node will thus experience longer delays to discovering routes to a gateway.

This section has introduced six proposals that use Mobile IP and follow the hybrid gateway discovery approach and they are summarized in Table 3.

**Table 3.** Hybrid gateway discovery-based mobility management solutions.

Scheme	Features	Mobility Scheme	MANET Routing	Handoff Metrics	Gateways	Evaluation\Simulation
Shin et al. [54]	Agent advertisement broadcasting is limited. Uses gateway caching and proxy route reply. Uses tunneling.	MIPv4	Reactive MANET (not specified)	-	-	Not evaluated
Tseng et al. [55]	Gateway advertisement is associated with a parameter to limit its scope. Uses tunneling.	MIPv4	DSDV	Hop count	Not specified	Prototyped but not evaluated.
Ratanchandani and Kravets [48]	Based on limiting the propagation of gateway advertisement. Uses the ring search method when broadcasting solicitation.	MIP	AODV	Hop counts	2	Simulated in NS2, 50 and 100 nodes, evaluated by varying mobility speed and TTL.
Sun et al. [56]	Nodes broadcast a route request with agent multicast group address destination. Uses cell switching algorithm for mobility management.	MIP	AODV	Hop count (3 hops closer to the new gateway).	1,2	Simulated in NS2, 10-20-50 nodes, 5 are sources, evaluated with different numbers of gateways and nodes.
Denko [57]	Employed distributed buffer management approach in foreign agent and gateways. Proposed force handover, optimized handover and handover with prediction.	MIP	Not specified	Hop count and predicted gateway’s signal strength.	2 gateways for each MANET	Simulated in NS2, 4 FA for 4 MANETs, each MANET has 50 nodes, evaluate the 3 handover mechanisms.
MG-AODV [59]	Replaced MIP advertisement by modified hello message. Uses conditional registration renewal mechanism based on broken route.	MIP	AODV	Hop count and gateway payload	Up to 6 gateways	Simulated in NS2, 30 nodes, compared its performance to [48].

## 5. Conclusions

Mobility management in single-hop infrastructure networks is provided using traditional mobility management protocols, however it is more challenging when applied to multi-hop and infrastructureless

networks such as MANET. This paper surveys the existing efforts in the literature to provide mobility management solutions for MANET integrated with the internet.

The survey reviews more than 20 proposals and classifies them into three main categories: Proactive gateway discovery-based mobility management solutions, reactive gateway discovery-based mobility management solutions, and hybrid gateway discovery-based mobility management solutions. The surveyed solutions have been investigated and their limitations have been discussed and pointed out. The survey also compares proposals in each category based on metrics such as system features, mobility scheme, MANET routing, handoff metrics, number of gateways, and how the proposed solutions were evaluated.

Despite the fact that many solutions have been proposed, there are still many open research issues that need to be further investigated, such as the quality of service based on the MANET application priority when managing mobility handover, optimizing solicitations and gateway advertisement control overheads, and investigating the feasibility of other MANET underlays such as OLSR and BATMAN to better meet the needs of an integrated network.

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