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Ad Hoc Networks 3 (2005) 351–370

Ad Hoc Networks

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A survey of Mobile IP in cellular and Mobile Ad-Hoc Network environments

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Received 6 January 2003; received in revised form 17 August 2003; accepted 26 September 2003
Available online 29 November 2003

Abstract

The Internet has become ubiquitous and there has been tremendous growth in wireless communications in recent years. Many wireless communication techniques are commercially available, such as the Wireless LAN, Bluetooth, GSM, GPRS and CDMA. Because an all-IP network will be a trend, access to the Internet via wireless communication devices has become an important issue.

To reduce power consumption and reuse the limited radio spectrum resources, a cellular network was formed. Cell size is one of the factors in the channel reuse rate. Basically, the channel reuse rate in a smaller cell size is higher than the channel reuse rate in a bigger cell size. Micro-mobility is therefore the inevitable direction for future mobile systems. Frequent and fast movements usually characterize micro-mobility. A cellular architecture would then present a challenge to the frequent handover procedures for a smaller cell size would usually induce a higher handoff frequency.

In addition to cellular networks, the ad-hoc network is another network architecture for wireless networks. The ad-hoc network is a non-infrastructure architecture; in which nodes can access services from one another regardless where they are. An excellent routing protocol is crucial for an ad-hoc networking to function at high performance. The main difference between a cellular environment and ad-hoc network is that the ad-hoc method has no fixed infrastructure, allowing nodes to communicate with one another at any time and anywhere.

We have mentioned that micro-mobility in a cellular environment would introduce a greater number of handoffs than before. The handoff probability drives the mobile IP mechanism due to signal changes. Using the Mobile IP mechanism, handoff breaking would take place within a micro-mobility environment. Therefore, in this paper, some handoff strategies that take the advantage of the ad-hoc mechanism to improve the handoff performance are investigated.

Keywords: Mobile IP; Ad-hoc; Handoff; CMIv6; Neighbor Assisted Agent (NAA); Cellular

1. Introduction

Access to the Internet via the wireless communication has become important due to the IP network trend. Mobility support in the Internet Protocol provides a standard solution for mobility at the IP layer. A cellular network is formed to

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doi:10.1016/j.adhoc.2003.09.011

reduce the power consumption and reuse the limited radio spectrum resources.

The ad-hoc network is another wireless architecture used in cellular networks. An excellent routing protocol is important for ad-hoc networking to operate at high performance. Numerous researches have been proposed for the ad-hoc routing, such as the Dynamic Source Routing (DSR) [1], Zone Routing Protocol (ZRP) [2], Ad-hoc On demand Distance Vector (AODV) [3] routing. Mobility in a cellular environment introduces a greater number of handoffs than before due to the micro-mobility trend. A mobility protocol that would provide a seamless micro-mobility scheme should preserve the following properties:

1. Manage local movements without informing the core network.
2. Decrease the update traffic for new locations.
3. Limit the diffusion of update messages.
4. Minimize the delay in the new location update.
5. Eliminate packet losses during handovers.
6. Provide superior QoS and support real time services.
7. Define optimal radio resource use.
8. Support paging.
9. Interact with Mobile IP.
10. Be independent of the radio technology.
11. Insure the robustness.
12. Be scalable.

This paper attempts to introduce the current integrated Ad-Hoc and cellular support strategies based on the Mobile Internet Protocol. Both the Mobile IP and Mobile Ad-Hoc Network (MANET) routing protocols are presented. We will point out the short-falls using Mobile IP and try to emphasize protocols for mobile management schemes that optimize high speed mobile stations moving among small wireless cells with Ad-Hoc functions. A comparison between these schemes will be introduced.

2. Mobile IP version 6

In this section the Mobile IPv6 according to the IETF draft Mobility Support in IPv6 is reviewed [4]. Mobile IPv6 defines four new IPv6 destination options. These options are used in IPv6 to carry additional information that is examined only by a packet destination node.

Under the Mobile IPv6, built-in route optimization eliminates triangle routing. The foreign agent is no longer necessary, packets are sent to a mobile node that can be tunneled to the mobile node using an IPv6 router header instead of IP encapsulation.

2.1. Mobile IPv6 operation

According to the IETF INTERNET DRAFT [4], the basic operation of the Mobile IPv6 mechanism is explained using Fig. 1:

1. The mobile node (MN) discovers its home agent (HA) using the Home Agent Discovery mechanism. The Home Agent Discovery mechanism will be described in Section 2.2.
2. The mobile node moves to foreign link-A, obtains a care-of address (CoA), CoA-A, and sends Binding Update messages to the HA to update its binding cache.
3. The CN sends packets to the MN's home address. The HA forwards the packets to the MN according to the CoA-A.
4. The mobile node moves to foreign link-B, obtains a new CoA-B and sends Binding Update (BU) messages to the HA and the correspondent node (CN) to update their binding cache.
5. After receiving the BU message, the CN replies to the MN with a Binding Acknowledgement (BA) message, and sends packets directly to the MN.

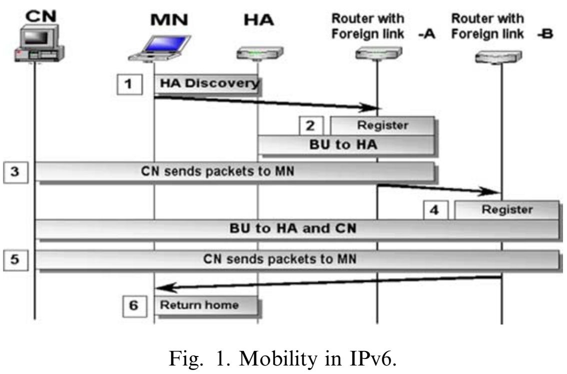

Fig. 1. Mobility in IPv6.

6. The MN returns to its home network, the HA stops encapsulating and tunneling for the MN.

2.2. Home Agent Discovery mechanism

Normally, a home agent sends out Router Advertisement message periodically, or in response to a Router solicitation. A mobile node can obtain its home agent's address using the modified Router Advertisement from the Router Advertisement used in the Neighbor Discovery for IPv6 [5].

The modified Router Advertisement from the Neighbor Discovery for IPv6 is shown in Fig. 2. It is used for the Home Agent to advertise its availability.

2.3. Dynamic Home Agent Discovery

Mobile IPv6 supports a Dynamic Home Agent Address Discovery mechanism that allows a mobile node to dynamically obtain its home agent's address [4]. This is necessary when the mobile node does not know its home agent or the mobile node's current home agent is shut down or the home network is reconfigured.

If a mobile node cannot obtain its home agent's address using the Home Agent Discovery mechanism, it can execute the Dynamic Home Agent Address Discovery mechanism as described below to obtain its home agent's address, as shown in Fig. 3:

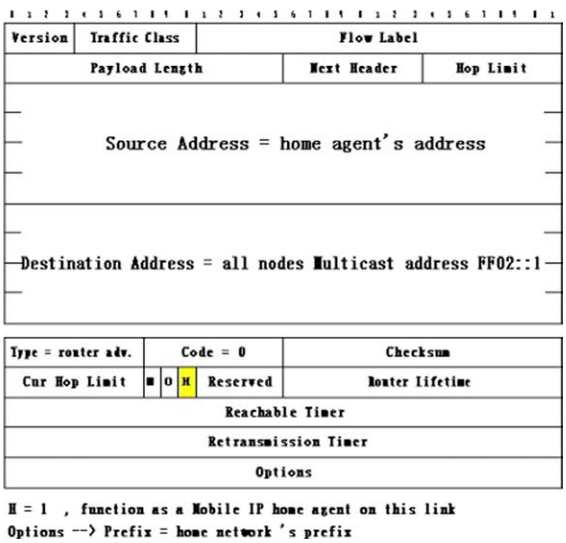

Fig. 2. Modified Router Advertisement.

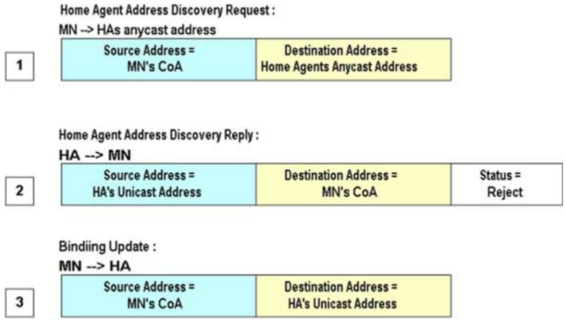

Fig. 3. Basic operation of the Dynamic Home Agent Discovery.

1. The mobile node sends a Dynamic Home Agent Address Discovery request message to the "Home-Agents anycast address" for its own home subnet prefix.
2. The home agent on the home link returns a BA with a reject status but includes a HA List.
3. The mobile node sends a BU to one of the home agents listed in the HA List and waits for the matching BA.

2.4. Mobile IPv6 Destination Options

The Mobile IPv6 Destination Options carry some information required for the nodes to exchange and examine additional information during Mobile IPv6 operation.

In Mobile IPv6, every IPv6 node has a Binding Cache that is used to hold the binding information of other nodes. If a fresh Binding Update message arrives, it will be added to the Binding Cache. When sending out a packet, a node looks into its Binding Cache to search for the node's care-of address. In this way, triangle routing can be avoided. Four new Destination Options are defined in Mobile IPv6.

2.4.1. Binding Update Option

A mobile node uses the Binding Update Option to notify other nodes of its new care-of address.

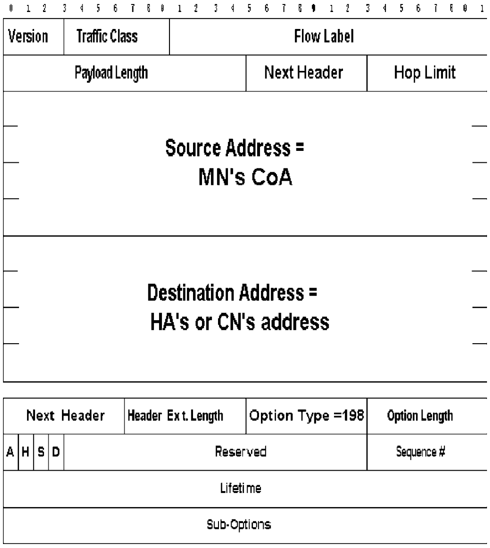

Fig. 4. BU destination option.

Any packet including a Binding Update Option must also include either an Authentication Header [6] or Encapsulating Security Payload header [7]. Fig. 4 shows the Binding Update Option.

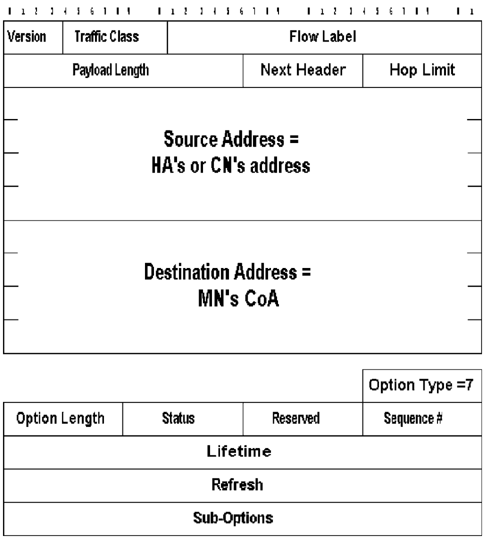

Fig. 5. BA destination option.

2.4.2. Binding Acknowledgement Option

When a node receives a packet containing a Binding Update Option with the Acknowledge (A) bit set, the node must then reply with a Binding Acknowledgement message to acknowledge Binding Update Option receipt. Either an Authentication Header [6] or Encapsulating Security Payload header [7] must be included in the Binding Acknowledgement Option packet. Fig. 5 shows the Binding Acknowledgement Option.

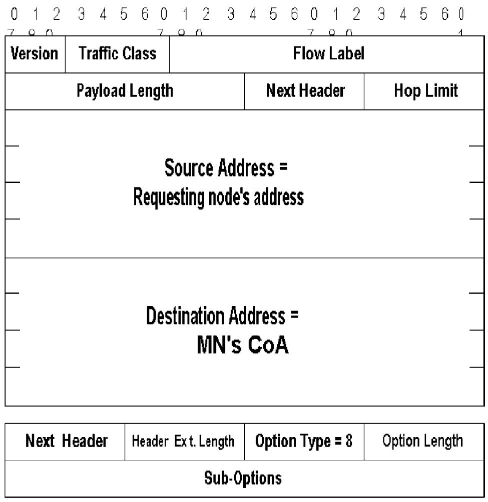

Fig. 6. Binding request destination option.

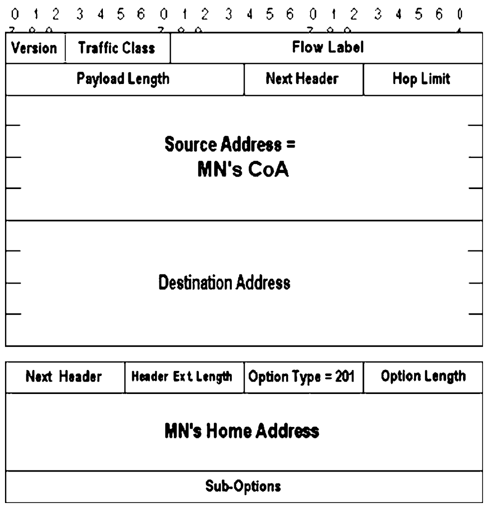

Fig. 7. Home address destination option.

2.4.3. Binding Request Option

Once a mobile node receives the Binding Request Option, the mobile node must return a Binding Update Option packet with the current care-of address to the requesting node. Fig. 6 shows the Binding Request Option.

2.4.4. Home Address Option

A mobile node uses the Home Address Option in a packet to inform the receiver of this packet about the mobile node's home address. Fig. 7 shows the Home Address Destination Option.

3. Issues in the MIPv6

As illustrated in Fig. 8, there are two disruption points during the handoff period. The problems involving the two breaking points in the MIPv6 have been explored in the literature [8]. Here, we briefly review the issue of the breaking about the MIPv6 with high-speed movement in a cellular network, using Fig. 8.

The "MN-BS1" term indicates that the mobile node is attached to base station 1 in cell 1. "MN-BS2" represents the mobile node attached to base station 2 in cell 2. The "t_{Beacon}" term represents the time between two successive beacons. The average time for a beacon is equal to half of the t_{Beacon}. The $t_{stateless}$ term represents the time that the mobile node spends executing the Stateless Address Configuration mechanism to obtain a new IP address. The t_{RF} term is the latency time for the wireless link. The t_{BU_CN} term is the time from the mobile node sending the Binding Update to the corresponding node receiving the BU message.

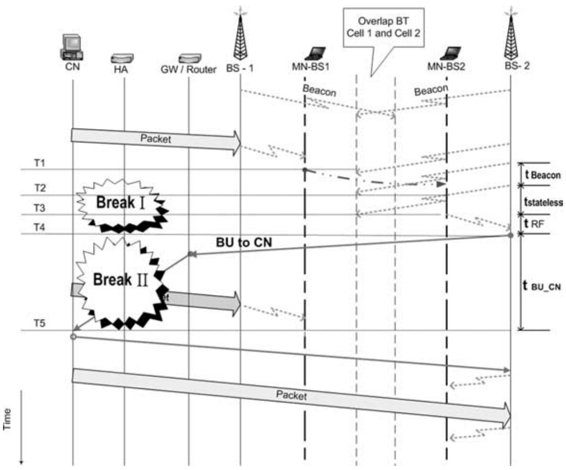

Fig. 8. Timing chart of the MIPv6.

Before time T1, the mobile node, MN, within the coverage of the base station 1, BS-1, is communicating with the corresponding node, CN.

During time T2, the mobile node moves through the overlap between cells 1 and 2, then moves out of the original cell and goes into the neighboring cell, cell 2, at high speed. At this time, the MN cannot maintain communications with BS-1. The MN waits for BS-2's beacons. The average wait time for the beacon is half of the t_{Beacon}.

During time T3 and T4, the MN obtains a new care-of address. This is the first phase of handoff breaking, Breaking I. The duration for Breaking I is equal to $\frac{1}{2}t_{Beacon} + t_{stateless} + t_{RF}$. This time is not often too long. It depends on the speed of the mobile node, the size of the overlap, the interarrival time of the beacons, the stateless configuration mechanism and the wireless link's latency [9].

At time T4, the MN begins the Binding Update with the CN and the HA. The second phase of handoff breaking occurs from time T4 to time T5, before the BU message reaches the CN. This break time is much longer than that in phase one due to the congestion and the path creation in the Internet.

After time T5, the CN updates its Binding Cache. Packets will be destined to the proper address of the MN with the new care-of address. The CoA-2 Handoff occurs more frequently in a cellular network. The communication breaks become very serious, especially for a mobile node moving at high speed.

4. Rim of the cell

Making use of the channel efficiently and reducing transmitter power consumption is a trend for cellular architecture network development. The cellular network is composed of several smaller cells. This introduces frequent handoffs. A handoff is often initiated by a cell boundary crossing or by any degradation in the signal quality. In a cellular system an overlapping region exists between two adjacent cells; the size this overlapping region affects handover performance. Generally speaking, the wider the overlap region, the more efficient the handover performance will be. However, more power is consumed by a signal far away from the base station.

Fig. 9 shows the signal propagation ranges [10,11]. The middle range of the base station is called the "transmission range". Communication is possible and a low bit error rate occurs. The "detection range" is out of the transmission range. In this region signal detection is possible but the communication quality is not suitable. The outer range is called the "interference range". A signal in this region might not be detected. Noise and the signal would be mixed together to form interference. The power strength at the rim of the cell is the weakest region. The handover trigger point is frequently stimulated near the boundary of the communication region.

In this circumstance, the negotiation for handover in the boundary is worse than near the base station. It may take more time to complete the handover process due to the higher probability of retransmission. This will cause handoff breaking in these areas to become more evident, especially for a mobile node that is moving at high speed.

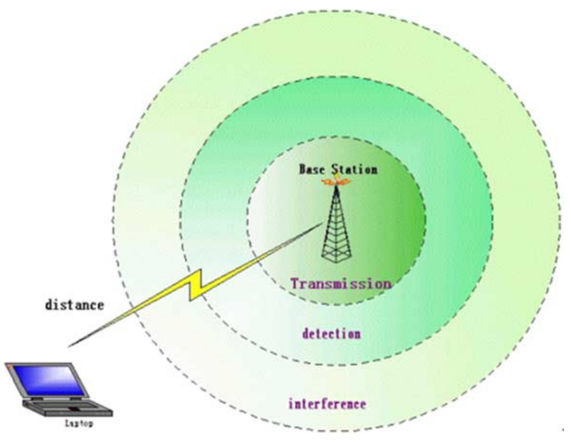

Fig. 9. Signal propagation ranges.

5. Mobile Ad-Hoc Network (MANET) routing protocol

A MANET is defined as a collection of mobile platforms or nodes in which each node is free to move about arbitrarily. The term MANET describes distributed, mobile, wireless, multihop networks that operate without the benefit of any existing infrastructure except for the nodes themselves. A MANET is an autonomous system of mobile nodes that operates in isolation. Each node's position and transmitter and receiver coverage patterns with transmission power levels and co-channel interference levels exists only between the nodes. This MANET topology may change with time as the nodes move or adjust their transmission and reception parameters.

MANETs have several characteristics [12]:

- Dynamic topologies.
- Bandwidth-constrained, variable capacity links.
- Energy-constrained operation.
- Limited physical security.

5.1. DSDV [12–14]

The Destination-Sequenced Distance-Vector Routing Protocol was designed ad hoc with a table-driven routing protocol. This is a hop-by-hop distance vector routing protocol requiring each node to periodically broadcast routing updates. The key advantage of DSDV is that it guarantees loop-freedom. If a node cannot access any base stations, the DSDV routing protocol allows a path along which data can be exchanged with all nodes. A sequence number is used with the basic Bellman–Ford mechanism to each route table entry. When the network topology is modified with decreased frequency little routing table data is exchanged.

5.2. CGSR [12–14]

Cluster-Head Gateway Switch Routing is similar to the DSDV routing protocol. In Cluster-Head Gateway Switch Routing (CGSR) the nodes form clusters. A cluster head is selected. All nodes within the cluster head's radio transmission range

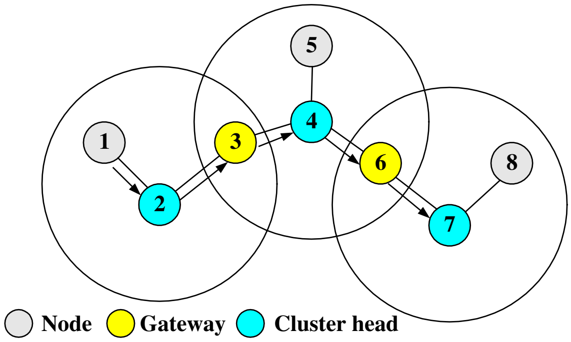

Fig. 10. CGSR: routing from nodes 2–4, 6 and 7.

form a single cluster. A cluster head is selected for every department. A gateway node can communicate with two or more cluster heads (Fig. 10).

5.3. AODV [12–14]

Ad Hoc On-Demand Distance Vector Routing offers a pure distance-vector approach. It does not maintain a routing table. AODV is a purely "on demand" method that follows a route request and reply discovery cycle when the nodes communication with other nodes. Fig. 11 shows the AODV format. The AODV routing table will record a message with a destination sequence number (as with DSDV) to avoid a routing loop and produce the latest new routing topology.

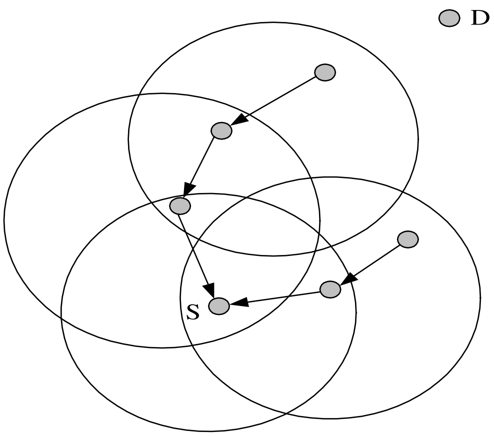

Fig. 11. AODV: reverse path formation.

5.4. DSR [15]

The Dynamic Source Routing (DSR) protocol presented in Fig. 12 is an on-demand routing protocol based on the source routing concept. When mobile nodes request communications, the DSR protocol will search for a path. Mobile nodes are required to maintain route caches that contain the source routes of which the mobile is aware. Entries in the route cache are continually updated as new routes are learned. The DSR protocol is similar to AODV and uses the source broadcast method as the DSR is shown in Figs. 12 and 13.

5.5. TORA [16]

The Temporally Ordered Routing Algorithm (TORA) is a highly adaptive loop-free distributed routing algorithm based on the link reversal concept. TORA is designed to operate in a highly dynamic mobile networking environment. There are three steps in the TORA protocol: Route

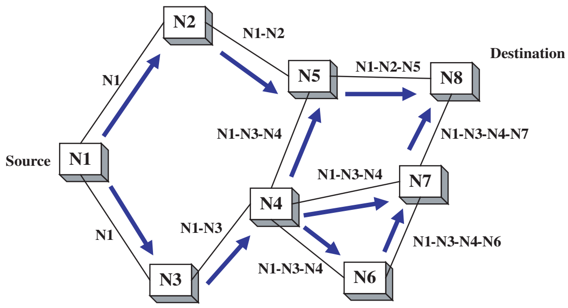

Fig. 12. DSR: route request.

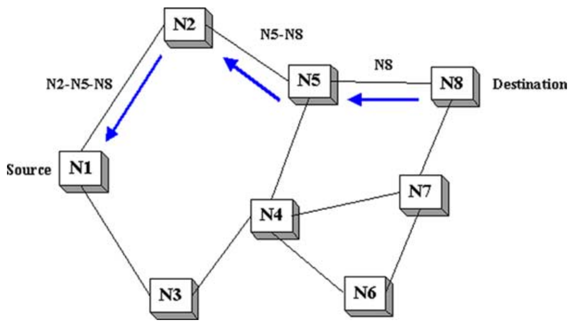

Fig. 13. DSR: route reply.

Creation, Route Maintenance and Route Erasure. During the route creation and maintenance phases, the nodes use a "height" function. This algorithm does not make changes to other routes when the topology is modified, as shown in Fig. 14.

5.6. ABR

The Associatively Based Routing (ABR) protocol is defined as a new routing metric for ad hoc mobile networks. It uses the associatively stability concept. Each node periodically generates a beacon to signify its existence. When this beacon is received by neighboring nodes, their associative tables are updated. For each beacon received, an associative tick in the current node occurs with respect to the beaconing node's increment. The ABR then establishes a stable path.

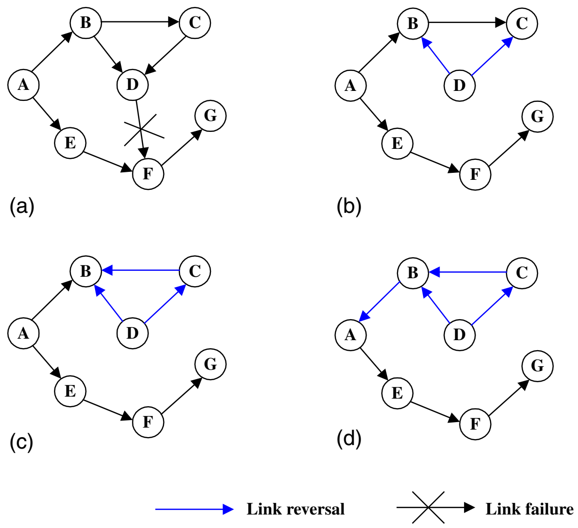

Fig. 14. TORA: route maintenance (A: source, G: destination).

5.7. ZRP [17–19]

The Zone Routing Protocol (ZRP) combines reactive and proactive functions. ZRP uses zones that are similar to clusters. Instead of using hierarchical routing between the clusters, special border nodes are dynamically selected that connect adjacent zones. A zone radius parameter dynamically adjusts the size of the zone. The network topology changes according to the number of hops. A different routing protocol can be used between zones compared to the one used within a zone (Fig. 15).

5.8. Comparisons

Comparisons of the three routing protocol characteristics, table-driven characteristics and On-Demand MANET characteristics are given in Tables 1–3, respectively.

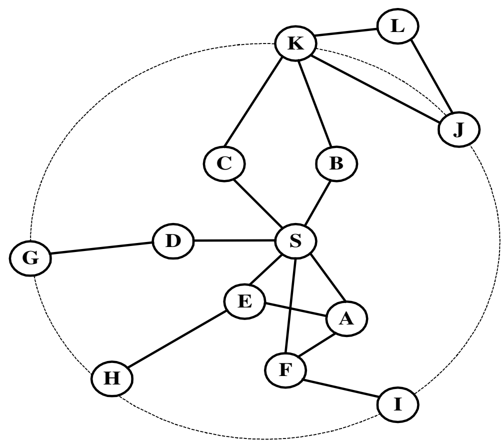

Fig. 15. ZRP: a routing zone with radius = 2 (hops).

Table 1
Comparisons of the three routing protocol characteristics

	Proactive (table-driven)	Reactive (on-demand)	Hybrid
Routing protocols	DSDV, CGSR	AODV, DSR, TORA, ABR	ZRP
Route acquisition delay	Lower	Higher	Lower for intra-zone, higher for inter-zone
Control overhead	High	Low	Medium
Power requirement	High	Low	Medium
Bandwidth requirement	High	Low	Medium

Table 2
Comparisons of the table-driven characteristics

Table-driven	DSDV	CGSR
Routing philosophy	Flat	Hierarchical
Loop-free	Yes	Yes
Number of required tables	2	2
Frequency of update transmissions	Periodically and as needed	Periodically
Updates transmitted to	Neighbors	Neighbors and cluster head
Utilize hello messages	Yes	No
Critical nodes	No	Cluster head

Table 3
Comparisons of the on-demand MANET characteristics

On-demand	AODV	DSR	TORA	ABR
Overall complexity	Medium	Medium	High	High
Overhead	Low	Medium	Medium	High
Routing philosophy	Flat	Flat	Flat	Flat
Loop-free	Yes	Yes	Yes	Yes
Multicast capability	Yes	No	No	No
Beaconing requirements	No	No	No	Yes
Multiple route support	No	Yes	Yes	No
Routes maintained in	Route table	Route cache	Route table	Route table
Route reconfiguration methodology	Erase route, notify source	Erase route, notify source	Link reversal, route repair	Localized broadcast query
Routing metric	Freshest and shortest path	Shortest path	Shortest path	Associatively and shortest path and others

6. Proposals for minimizing service disruption during handoff

In the previous sections the problems involved in applying Mobile Ipv6 into a cellular system were discussed. Numerous researchers have focused on resolving these problems. Section 6.1, 6.2–6.8 presents those schemes using enhanced Mobile IPv4 or IPv6 standards to solve the handoff problems. Section 6.9, 6.10–6.15 introduce those schemes with the help of Ad-hoc mechanism.

6.1. Cellular Mobile IPv6: a low latency handoff algorithm for voice over IP traffic in packet-based cellular networks [8]

In this research, the author proposed a new algorithm, Cellular Mobile IPv6 (CMIv6), which was migrated from Mobile IPv6 for mobile nodes moving among small wireless cells at high speed. CMIv6 is designed to solve the handoff breaking problem in a cellular network.

The major component in this algorithm is the Foreign Home Agent (FHA) as illustrated in Fig. 16. Although its function is similar to the foreign agent (FA) used in IPv4 (forwarding packets), its role is not the same as the FA.

When a mobile node moves from subnet-A into subnet-B, the mobile node enters the binding update state and executes a binding update with the HA and CN. Packets from the CN are still destined to subnet-A before being informed of the mobile node's current new location by the binding update packet. This situation results in a handoff break. At this time, the FHA can redirect these packets destined to the old destination address to the mobile node's current location and solve the handoff break. Another mechanism that the author proposes in this research is Cellular Multicast. Cellular Multicast can solve the problem of frequent handoffs within a short period.

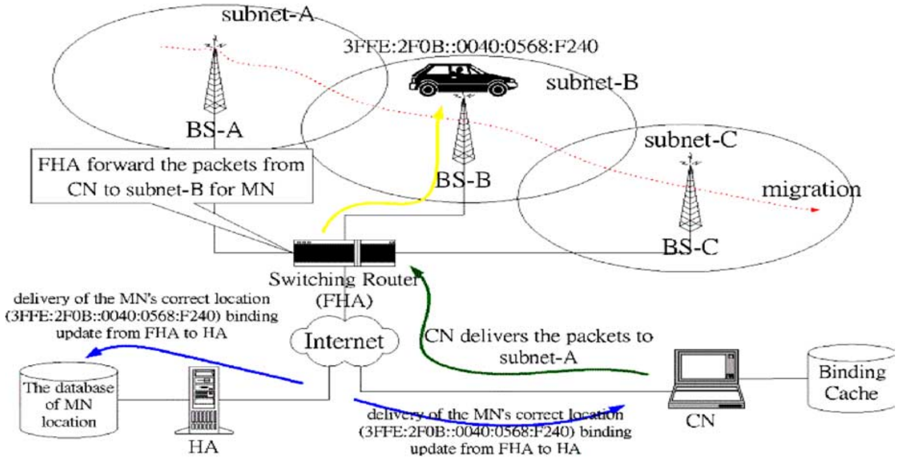

Fig. 16. Foreign Home Agent uses the tunneling to forward the packet to subnet-B link [8].

6.2. Mechanisms and hierarchical topology for fast handover in wireless IP networks [20,21]

In [20], as shown in Fig. 17, they propose two mechanisms to handle micro-mobility and inter-subdomain mobility in a hierarchical topology network. In [21], the author evaluated the performance of their proposed protocols and Mobile IP.

When mobile device handovers occur within the same domain, called micro-mobility, the base sta-

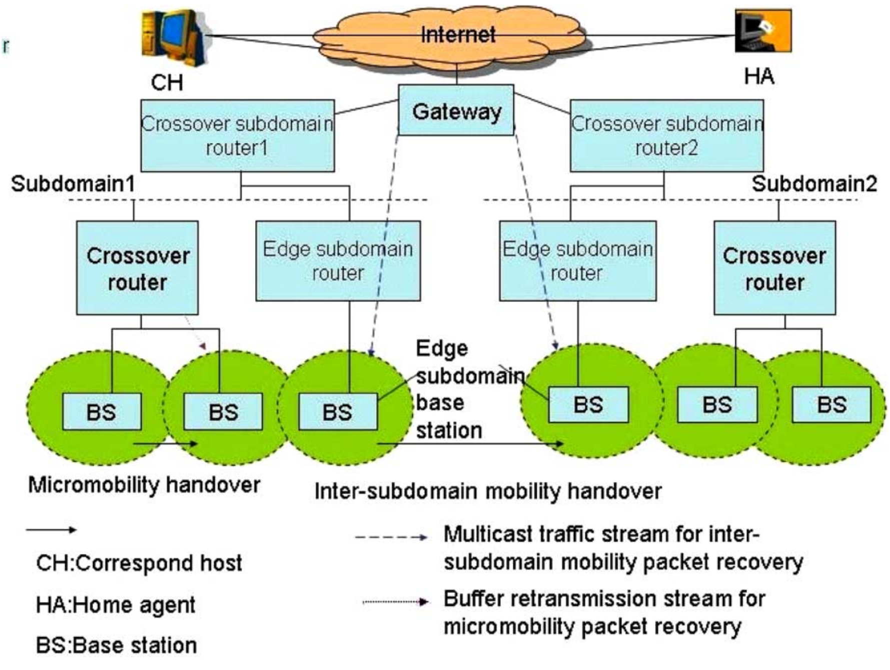

Fig. 17. Proposed architecture for a hierarchical wireless network [20].

tion retransmits packets buffered in the old BS to the new BS and forwards them to the mobile device.

If inter-subdomain mobility occurs after the mobile device moves into the edge-subdomain, another proposed mechanism would enable multicasting to multicast packets to the two adjacent domains.

These two components, multicasting and buffering, are used to minimize service disruption during mobile IP handoffs.

This research assumed that the BS has the capability to buffer packets during handover to recover lost packets.

6.3. IDMP-based fast handoffs and paging in IP-based cellular networks [22]

The Intra-Domain Mobility Management Protocol (IDMP) uses a two-level hierarchy to manage node mobility in future IP-based cellular networks, as shown in Fig. 18. It is designed to eliminate the Intra-Domain location update delay and the mobility signaling traffic. The Mobility Agent (MA) is similar to the gateway foreign agent (GFA) introduced in the Mobile IP Regional Registration. It provides the MN a stable global care of address and provides the MN a domain wide point for packet redirection. The Subnet Agent (SA) is similar to the foreign agent (FA) in Mobile IP. It provides subnet-specific mobility services. The MN obtains two concurrent care of addresses, LCoA and GCoA. One has local scope and the other has domain-level granularity.

The key points in the IDMP-based Cellular Networks include two mechanisms. First, the MA uses a proactive packet multicasting scheme to multicast in-bound packets to the set of SAs (subnet Agent). Second, the SAs cache multicast packets for a specified duration to minimize packet loss. Another mechanism implemented in this architecture is the Paging system. It is similar to the implementation in the Cellular IP architecture. From the above description, the IDMP is similar to a HMIP and CIP combination. This is another example using multicasting and buffering to improve the handoff efficiency.

6.4. Neighborcasting: a fast handoff mechanism in wireless IP using neighboring foreign agent information [23,24]

The author in [23] proposed a NeighborCasting mechanism for fast handoff, as shown in Fig. 19.

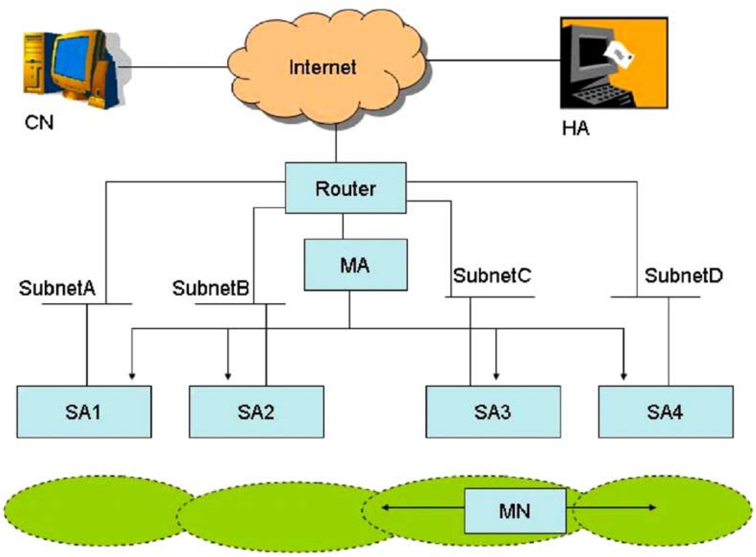

Fig. 18. IDMP: fast handoff [22].

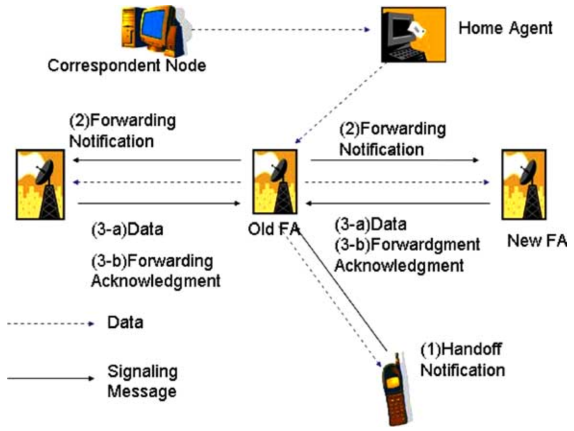

Fig. 19. NeighborCasting handoff scenario [23].

The NeighborCasting mechanism uses a wired bandwidth between foreign agents to cast information about the neighboring foreign agent to the possible new foreign agent when the mobile node initiates the link layer handoff procedure. This minimizes the handoff latency. This policy executes the layer two and layer three handoff simultaneously to shorten the handoff latency.

The important idea is that each foreign agent (FA) can learn about its neighbor FAs from the MNs because the MNs move around and come from the neighboring FAs. That is, the MN maintains the address of the old FA and transmits this identity to the new FA every time it hands over from one FA to another FA. The new FA then learns about one of its neighbor FAs and notifies the neighbor about itself. This way a FA can learn about all of its neighboring FAs as time goes by and many handoffs occur.

In this NeighborCasting mechanism, the Neighbor FA Discovery Mechanism is a key idea like our key idea in our Neighbor Assisted Agent (NAA) Discovery mechanism. As time goes by and many handoffs occur, the neighboring FA can access information about its adjacent FA from the MN while it roams everywhere. The new FA, which learned about the old FA from the MN, informs its old FA about itself. In this way, the neighboring FAs can be found.

6.5. An efficient handoff method to support real time services in a mobile IP environment [25]

The network structure presented in Fig. 20 is a hierarchical network. This network is composed of several clusters. Each cluster includes a number of

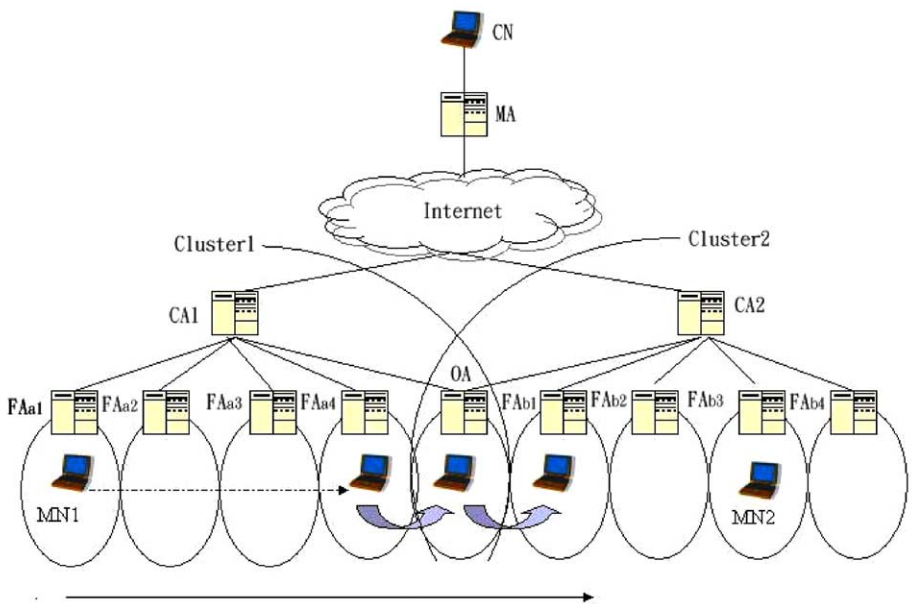

Fig. 20. The OA network structure [25].

foreign agents (FA). One cluster is managed by a Cluster Agent (CA) located in the parent node of the network tree. Two kinds of handoffs are classified, the Local-Handoff (LH), which occurs in a cluster and the General-Handoff (GH), which occurs between clusters. If a handoff occurs within a cluster, the Mobile Host's (MH) registration need not update the MA's cache. Handoff in a cluster can thus shorten the registration path.

When a handoff occurs between clusters, an Overlap Agent (OA), located midway between clusters is needed. The OA registers the MH to the neighboring CA before handoff occurs in this OA and pre-contacts the Real time Services path.

The function of the OA between two clusters is a bit similar to the NAA we propose in our research. However, the OA is extra wired equipment located between two clusters. This would be an extra cost for this network architecture.

6.6. Handover solution for next generation IP-networks [26]

This paper [26] gives an overview of the major problems in IP layer handover for next generation IP networks and proposes some solutions for these problems. All of the considerations are based on cellular technology. The IP based protocols are being enhanced to provide handovers for user access during the course of user mobility. The handover procedures provided at the IP layer are commonly referred to as Layer 3 (L3) handover. The L3 handover is required to provide at least the same performance as the cellular handover. The cellular handovers are link layer specific and referred to as a Layer 2 (L2) handover. From this paper, we can see the problem that exists in the handover mechanism. This stimulates us to design more solutions for these problems. Three problems with the pure Layer 3 handovers.

The first problem is ''Latency in New CoA (Care of Address) Allocation''. In the next generation IP protocol, the address auto-configuration for both statefull and stateless address allocation will add latency to the overall handover procedure. The typical statefull address allocation needs at least four message exchanges with the DHCP servers. The CoA allocation, using the stateless mechanism, requires a duplicate address detection mechanism to verify the uniqueness of the new CoA [26].

The second problem is ''No coordination with Layer 2 Handover''. Layer 3 handovers without considering Layer 2 result in performance degradation. If Layers 3 and 2 can coordinate, the handover time can be shortened.

The last problem is ''Delay in the New Routing Setup''. This problem is derived from resetting the routing path every time a handover takes place.

The solution to the first problem is pre-allocating a pool of IP addresses for handover purposes at an access router.

Another solution to the second problem is to design a well-defined coordination method between Layers 3 and 2 to make the Layer 3 handover occur concurrently with the Layer 2 handover.

Splitting the handover into two steps to eliminate setting up a complete new routing path every time a handover takes place solves the last problem. These methods were proposed in Mobile IPv6 Regional Registrations [27] and Hierarchical MIPv6 mobility management (HMIPv6) [28].

6.7. Optimized smooth handoffs in Mobile IP [29]

The author, Charles E. Perkins, proposed strategies that are compatible with rout optimization and its security model, shown in Fig. 21. Foreign agents are used to buffer packets for a mobile host and send them to its new location when it leaves. With these buffers, duplicate packets are eliminated.

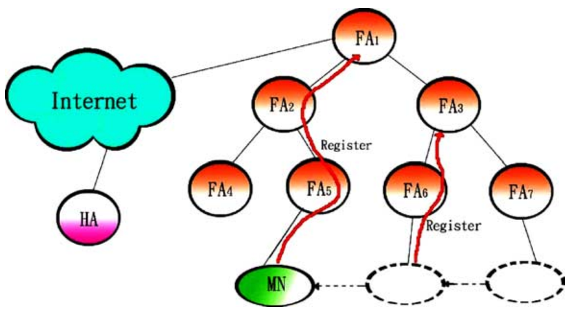

Fig. 21. Hierarchical FAs with buffer [29].

The author proposes to alleviate the frequent local handoff problem by using a hierarchical foreign agent management scheme. With a hierarchy of FAs, small changes in location can be handled by one of the FAs in the hierarchy within whose coverage range the MH remains. This extends the registration and authentication process in the base Mobile IP so that it is independent of the physical configuration of the foreign network and provides the same level of security as the base Mobile IP. The author proposes a buffering scheme at the FAs to reduce data loss during a handoff.

A hierarchical foreign agent management architecture is also to reduce the administrative overhead of frequent local handoffs. They implemented an extension of the Mobile IP registration process to maintain security.

By implementing the hierarchical and buffer mechanism, a smooth handoff and duplicate packet elimination are provided.

6.8. Low-latency handoff for cellular data networks [30]

This research is a dissertation aimed at examining the problem of producing fast handoffs in cellular data networks. The authors have shown that multicast-based handoff algorithms take best advantage of the knowledge provided by the handoff predictions. The multicast routing allows us to perform the equivalent of pre-fetching and caching packet routing for mobile hosts. Before data rerouting was actually requested. We establish a route for the new base station using multicasting. Similarly, the base stations that are part of the multicast group compose a cache for handoff targets. As with memory caching, requests are completed more quickly if they have been correctly predicted. In our system, handoffs are completed more quickly when the target base station has already joined the multicast. The primary cost of this solution is backbone network bandwidth.

This paper developed several techniques to improve handoff. The hints to predict handoff come from location information in the cellular wireless system. Multicasting based on these hints efficiently establishes routing in advance of a handoff. The intelligent buffering, enabled by the data multicast, reduces data loss without the need for complicated forwarding. The state replication enabled by multicasting avoids explicit state transfers during the handoff process.

The primary cost of the proposed algorithms in improving handoff latency is excess bandwidth on wired backbone networks. This is a trade off between handoff performance and wired cost. However the author believes that this would be an advantage in the future because the wired bandwidth will increase.

6.9. IPv6 flow handoff in ad hoc wireless networks using mobility prediction [31]

This research was performed in an ad hoc environment. In an ad hoc network, mobile nodes act as moving routers and the network topology is constantly changing due to node mobility. This research proposes a new protocol, the Flow Oriented Routing Protocol (FORP), for routing real time flows in highly mobile ad hoc wireless networks.

They introduced a new concept, the multihop handoff, to anticipate topological changes and perform rerouting. In this way, the flow disruption due to the changing topology is reduced.

To rebuild a flow route prior to a routing change, they proposed a scheme that uses the mobility information obtained from the mobiles to predict topological changes. This method can give us some idea how to search for the movement direction.

6.10. MADF: a novel approach to add an ad-hoc overlay on a fixed cellular infrastructure [32]

The author proposed an architecture called mobile-assisted data forwarding (MADF). In this system, as illustrated in Fig. 22, they added an ad-hoc overlay to the fixed cellular infrastructure and used special channels, forwarding channels, to connect users in a hot, and its surrounding cold cells, without going through the hot cell's base station.

Data may hop through more than one forwarding agent before a base station receives it. Under a certain delay requirement, the throughput in one cell can be improved.

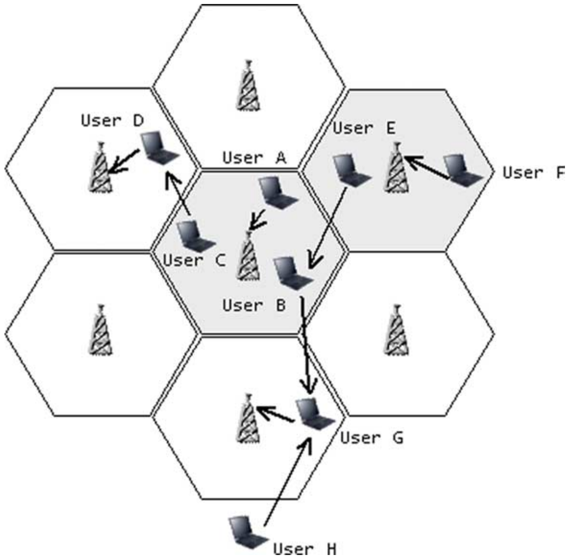

Fig. 22. A wireless data network with data forwarding [32].

This mobile-assisted data forwarding idea is similar to the NAA in our research. The main differences are that the MADF is used for forwarding data packets, but the NAA is used for transmitting control packets. Data packets will occupy more wireless bandwidth in the neighboring node than control packets do. Another difference is that the MADF may forward packets through more than one hop. The NAA operates under a one-hop protocol without the complexity path routing issue.

6.11. Integrated cellular and ad hoc relaying systems: iCAR [33]

Another integration of the cellular infrastructure and modern Ad-hoc relaying technologies is proposed as shown in Fig. 23. The key device in this architecture is the Ad-hoc relay stations (ARS). A number of Ad-hoc relay stations are placed at strategic locations.

In this architecture, ARS are placed by the system before the system initiation. This system does not needs to implement an ARS discovery algorithm. The ARS is just like an active router. Depending on the ARS system, the traffic load balance between cells is maintained by relaying traffic from on cell to another cell.

The author estimated that the maximum number of seed ARSs needed is at most $3n - \lfloor 4\sqrt{n} - 4 \rfloor$ to ensure that a relay route can be established between any BTS and MH located anywhere in any cell.

6.12. Evaluation of mobile ad-hoc network techniques in a cellular network [34]

This study evaluated the performance of some routing protocols, developed for Mobile Ad-hoc Network (MANET) networks, i.e., AODV, DSR, DSDV and the Temporal-Ordered Routing algorithm.

A MANET is an autonomous system, shown in Fig. 24, that has gateways to a fixed network. To enhance the capacity, the author proposes a combination of cellular and ad-hoc networks.

The authors discussed the applications for the above MANET protocols and announced that DSR is the best ad-hoc routing protocol when integrating cellular and ad-hoc networks.

6.13. Dynamic adaptive routing for heterogeneous wireless network [35]

The HWN integrates a cellular network with an ad hoc network to enlarge the communications scope for the ad hoc network and improve the

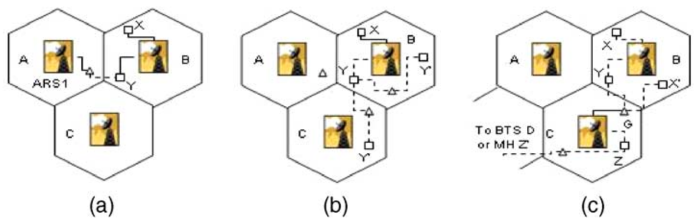

Fig. 23. An integrated cellular and ad-hoc relay system [33].

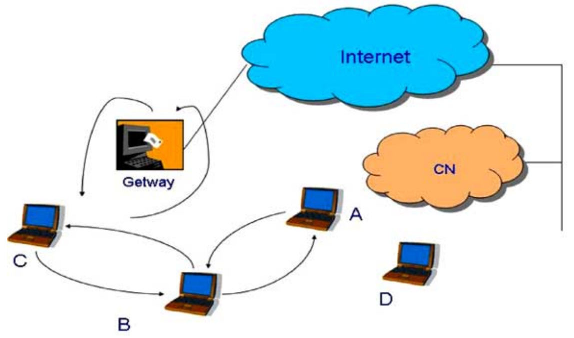

Fig. 24. Mobile Ad Hoc network, where A is communicating with the gateway to the Internet through B and C [34].

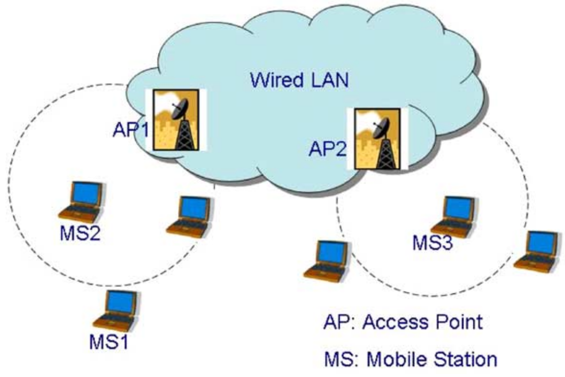

Fig. 26. Multihop wireless LAN [36].

throughput for the cellular network. They also proposed a dynamic adaptive routing protocol (DARP) to fit a heterogeneous wireless network.

Under this network architecture, shown in Fig. 25, number of base stations can be reduced and connections can be made without the help of the base stations. The base station in this architecture can be seen as a part of the mobile ad-hoc nodes. This is accomplished in the ad hoc routing algorithm.

6.14. Multihop wireless IEEE 802.11 LANs: a prototype implementation [36]

The multihop wireless network is composed of the traditional single-hop cellular network and an ad-hoc network. This method reduces the number of required base stations and improves the throughput performance.

The major component in this architecture is the bridging protocol, BMBP (Base-driven Multilhop Bridging Protocol). The access points and mobile stations use the BMBP to enable multihop routing and roaming.

The operation procedures are illustrated in Fig. 26. The MS1 cannot communicate with MS3. MS2 can help MS1 to forward packets to AP1. The AP1 knows where MS3 is located through the help of the AP2. Finally, the MS1 can communicate indirectly with MS3.

6.15. A new mechanism for smooth handoff in an integrated ad-hoc and cellular IPv6 network under high speed movement [37]

The Neighbor Assisted Agent (NAA) is a general mobile node. This node is located within a neighboring cell that the moving mobile node is ready to move into. Every mobile node in the adjacent cell has a chance to be a NAA only if the candidate mobile node conforms to certain conditions. As shown in Fig. 27, mobile nodes in

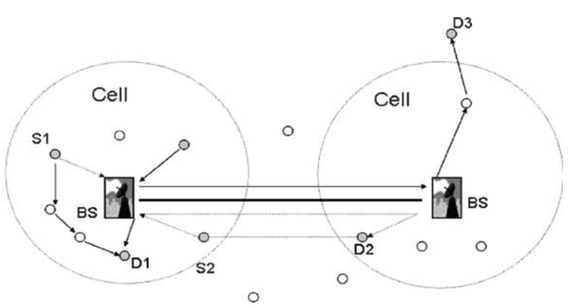

Fig. 25. Heterogeneous wireless network [35].

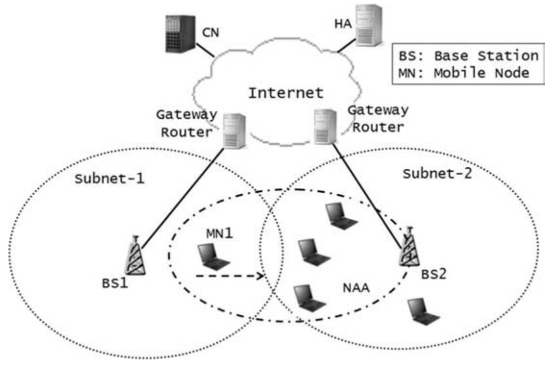

Fig. 27. Integrated ad-hoc and cellular network with NAA [37].

Table 4
Summary of the proposals

Topic	For IPv4/IPv6	Network topology	Proposed mechanism	Transmission type	With buffer	Other miscellaneous	Major cost
CMIv6 [8]	IPv6	H/Cellular	FHA (wired) (IA)	Redirt./Multicast		Cellular Multicast	Overhead for processing FHA functions
Hierarchy Fast HO [20]	IPv4	H	Edge Router (wired) (IA)	Re-tx/Multicast	Yes		Edge Router
Fast HO & paging [22]	IPv4	2-Level H/Cellular	MA, SA (wired) (IA)	Multicast	Yes	IDMP	MA
Fast HO using NFA information [23]	IPv4	Any	NFA (wired) (DA)	Neighbor Casting			Flooding in backbone
Efficient HO [25]	IPv4	H	CA OA (wired) (IA)	Forward		OA Pre-registration	OA
HO Solution for IPng Network [26]	Above IPv4	Any	IP address Pool L2–L3 Coordination. Two step HO				
Optimized Smooth HO [29]	IPv4	H	Hierarchy FAs (IA)	Re-tx	Yes	Security Consideration	Hierarchy FAs
Low Latency HO [30]		Cellular	Intelligent Buffering techniques	Multicast	Yes	Path pre-setup	Backbone BW
IPv6 Flow HO [31]	IPv6	Ad-hoc Network	Multihop Routing/FORP	Routing		Predict Topology change	
Ad-hoc on a Fixed Cell [32]		Ad-hoc/Cellular	MADF (wireless) (DA)	Forward		Special channel	Special channel
Ad-hoc Relaying System [33]		Ad-hoc/Cellular	ARS (wireless) (IA)	Relay			ARS
Evaluation Ad-hoc Routing in Cellular Network [34]		Ad-hoc/Cellular	MANET routing protocols	Routing		Proving DSR is better	
Dynamic Adaptive Routing [35]		Ad-hoc/Cellular	DARP (DA)	Relay			
Multihop Wireless LAN [36]		Ad-hoc/Cellular	BMBP (DA)	Forward			
Network Assisted Agent Based HO Scheme [37]	IPv6	Ad-hoc/Cellular	NAA (wireless) (Dynamic assigned, DA)	Relay/Wired Multicast	No (yes is better)	NAA Disc. Mechanism Movement Detection Binding Management Security Consideration Path pre-setup	Neighbor's control channel, Base station's management

H: Hierarchy, Redirt.: Redirection, Disc.: Discovery, Tx: Transmission, MA: Mobility Agent, SA: Subnet Agent, IDMP: Intra-Domain Mobility Management Protocol, HO: HandOff, FA: Foreign Agent, BW: BandWidth, FORP: Flow Oriented Routing Protocol, MADF: Mobile Assisted Data Forwarding, ARS: Ad-hoc Relay Station, DARP: Dynamic Adaptive Routing Protocol, BMBP: Base-driven Multihop Bridging Protocol, DA: Dynamic Assigned (the device is assigned dynamically during system operation), IA: Initial Assigned (the author assigned the device before initiating the system).

subnet-2 are normal nodes. They are members of subnet-2, the cellular network infrastructure. They communicate with the correspondent node using a RF interface through the base station-2 (BS2) to the wired network or with each other. When a mobile node (MN1) in subnet-1 is moving toward subnet-2 at high speed, moving into a neighboring cell, the mobile node (MN1) can select another mobile node in subnet-2 according to certain conditions to help itself deal with some part of the handoff and path setup procedures between the correspondent node (CN) and the base station-2 (BS2) before the mobile node (MN1) is handed-over to subnet-2.

During the period for selecting an assistant mobile node, the mobile node (MN1) and the candidate mobile nodes should operate in the ad-hoc mode to exchange control packets with one another. After the mobile node (MN1) moves into the neighboring cell, the MN1 must notify the CN with a packet containing authentication, or the MN1 must register with the correspondent node (CN) by itself if the confirmation packet coming from the NAA is lost.

From this discussion we can see that nearly all of the proposals for ad hoc network integration with the wired network are similar. The main differences are the routing algorithm used to discover the routing path. Table 4 summarizes the features of the methods discussed above.

7. Summary

This article presented an overview of the issues encountered in providing a solution for wireless Internet access in a cellular environment with the assistance of an Ad-Hoc mechanism. Table 4 shows that nearly all of the major components in the handoff solution involve Multicasting and Buffering. Nearly all of the major Agents are built in the system initialization. Agents are assigned manually and no Discovery Algorithm is needed to determine the major Agent selection except for the NFA in [31].

The NAA Mechanism [37] has a detailed procedure in the Discovery Algorithm. Multicasting in this paper is different from the multicasting used in other proposed papers. Wired multicasting stops at the Base station. It is never broadcast through the air interface to reduce wireless bandwidth. Most of the integrated ad-hoc and cellular networks use more than one ad-hoc mobile node to act as a relay node. These ad-hoc mobile nodes may introduce a broadcast storm problem for routing discovery in the ad-hoc environment. NAA Discovery does not introduce the broadcast storm problem because the source node can discover the NAA. The NAA can then communicate with the base station directly. The path from the source to the neighboring base station is very clear. Important considerations that highlight mobility management are a smooth and fast handoff.

To fully expose IPv6's advantages, it might also be a good idea to impose an Ad-Hoc mechanism into the enhanced CMIv6 [38]. Since the CMIv6 takes advantage of the "flow label" within the standard IPv6 header. It will be easier to merge into the future MPLS based All-IP mobile system.

Acknowledgements

This paper is a partial result of project no. NSC 90-2219-E-259-002 conducted by National Dong Hwa University under the sponsorship of the National Science Council, ROC.

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