HIERARCHICAL MOBILE IP NS-2 EXTENSIONS FOR MOBILE AD HOC NETWORKS

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Abstract—This paper describes and evaluates extensions for the support of the hierarchical Mobile IP protocol in the Network Simulator (ns-2). These extensions allow for the definition of multi-level hierarchies while allowing for automatic configuration of simulation scenarios. The hierarchical organisation of the Mobile IP infrastructure aims to enhance its scalability and to accelerate handovers that result in low packet loss. Furthermore, hierarchical Mobile IP and the interworking with ad hoc protocols such as AODV are presented in this study. This paper provides an overview of the implementation of hierarchical Mobile IP in ns-2 accompanied by initial results with a focus on protocol overhead.

Keywords— Hierarchical Mobile IP, Ad hoc, AODV, Network Simulator (ns-2), handover.

I. INTRODUCTION

The combination of cellular networks and Internet Protocol (IP) based Wireless Local Area Networks (WLAN) systems is considered as a major challenge in the near future. The development and extension of existing routing protocols are the most important issues for supporting seamless mobility for mobile Internet users. Within the IPonAir project a wide range of standards that provide mobility support in infrastructure and non-infrastructure communications environments are investigated.

One aspect of the IPonAir project is the development of an overall IP infrastructure which combines cellular networks with WLAN systems such as Hot Spots or non-infrastructure domains, i.e., ad hoc networks. In the IPonAir perspective, ad hoc networks will offer coverage extension of cellular networks and network connectivity to other ad hoc nodes. For this, the system architecture is mainly based on Mobile IP [1], [2] and its Hierarchical Mobile IP extension [3]. Hierarchical Mobile IP provides localised registration management which tends to reduce the registration period, hence the packet loss suffered during hand-offs. This is an important issue for the provision of QoS services to mobile nodes. In addition, limiting the registration signalling within the boundaries of a hierarchy reduces the signalling and routing overhead.

II. PROBLEM DESCRIPTION

For the investigation and simulation of extended wireless IP infrastructures the Network Simulator (ns-2) [4], [5] is an appropriate candidate to simulate IP communication infrastructures with new capabilities and protocol extensions. Currently, there is a list of various ns-2 extensions available, including a wide range of Mobile IP protocol extensions for micro mobility support such as Cellular IP, HAWAII, and Hierarchical Mobile IP [6]. Concerning the complexity of various system architectures and new features, such as the support of hierarchical network domains and the integration of ad hoc networks, these implementations are not sufficient and missing important functions. However, such implementations such as CIMS are the source for extensions of new features and capabilities. In the following section, the extension of a hierarchical concept for ns-2 is described that aims to provide a simulation environment for Hierarchical Mobile IP investigations.

III. HIERARCHICAL MOBILE IP

In Mobile IP, a mobile node roaming between IP administrative domains (sub networks) is required to register with its Home Agent (HA) each time it changes its care-of address. If the distance between the visited network and the home network of the mobile node is large, the signaling delay for these registrations may be long.

Approaches to reduce the registration delay introduce a Mobile IP hierarchical structure whereby registrations are handled within the hierarchy and do not need to be communicated to the HA. From this, two types of Mobile IP mobility are defined, namely micro-mobility (within a hierarchy) and macro-mobility (between hierarchies).

Fig. 1 illustrates the operation of Hierarchical Mobile IP. It shows the difference between normal and regional registration. It can be seen that the first have to traverse the whole of the network fabric to the HA while the others have to reach a local entity, termed in the figure as Gateway Foreign Agent (GFA).

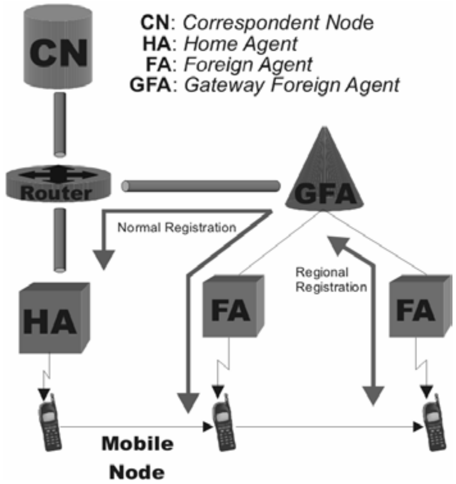

Figure 1: Regional management of HMIP registrations

For the purposes of managing hierarchical tunnelling the location register is maintained in a distributed form by a set of Mobility Agents (MA), i.e. GFAs, RFAs, in the access network. Each MA reads the original destination address of the incoming packets and searches its visitor list for a corresponding entry. The entry contains the address of the next MA one level lower in the hierarchy. Such entries are created and maintained by registration messages transmitted by mobile nodes. Hierarchical tunnelling schemes rely on a tree-like structure of MAs whereby encapsulated traffic from an HA is delivered to the root MA, termed as Gateway FA (GFA). As a mobile node moves between different points of attachment, location updates are issued at the optimal point on the tree, tunnelling traffic to the new point of attachment.

IV. AD HOC NETWORKS

An Ad hoc network is an autonomous, infrastructureless system of mobile nodes (simultaneously hosts and routers) connected by wireless links [7]. The mobile nodes are free to move randomly and organize themselves arbitrarily. Thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet. In the last case, a mobile node that has been permanently allocated an IP address from within its home network will expect to be able to establish and maintain communications as if it where in its home network. This can be achieved by providing MIP services to mobile nodes receiving Internet connectivity through an ad hoc network.

Ad hoc On-Demand Distance Vector Routing (AODV) is a reactive ad hoc routing protocol that means that a route is desired only when the traffic is initiated by source node to the destination node [8]. This leads to lower routing overhead and higher data delivery ration compared to a table-driven proactive protocol like Optimized Link State Routing Protocol (OLSR) [9].

V. SYSTEM ARCHITECTURE

The extension of the current Hierarchical Mobile IP implementation for ns-2 is needed to investigate the overall IP system architecture which has been defined within the IPonAir project. The system architecture consists of a Hierarchical Mobile IP approach to support a scalable and flexible communication infrastructure which combines current cellular network systems and IP based wireless networks. As an example, the combination of wireless LANs (WLANs) and cellular networks is more efficient due to the fact that mobile users can roam between such networks without communication loss. Mobile IP is responsible for providing users with seamless connectivity while their mobile devices vary their point of attachment to the Internet. With the help of a hierarchical organization of HMIP it is possible to accelerate HMIP/IP level handovers with low or even no packet loss.

The deployment of packet services in wide-area cellular networks accompanied by a rollout of standards for license free personal and local area communication networks are a strong indication that future mobile Internet communication systems will be built upon heterogeneous wireless overlay networks. This development makes all the more important the introduction of considerations for the hierarchical organization of the core network. This is illustrated in Fig. 2 that depicts the system architecture. It was designed with an eye on the investigation of handovers between different IP administrative (subnets) wireless domains. These domains are wireless networks, cellular systems, Hot Spots, or ad hoc networks interconnected via a Hierarchical Mobile IP core network. Its aim is to provide fast and efficient handovers for nodes varying their point of attachment with minimal impact on active transport layer communications.

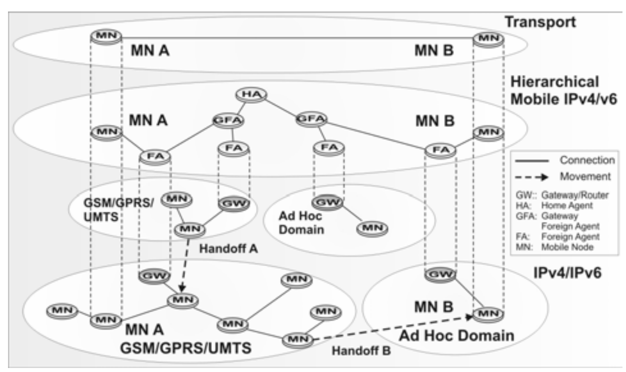

Figure 2: IPonAir system architecture

The aforementioned system architecture is developed to investigate the following three scenarios which have been identified as the main use cases based on the integration of cellular and IP based wireless networks:

1. Handovers from/to Hot Spots
2. Policy based Handover
3. Coverage Extension

The first scenario investigates the requirements for handovers between Hot Spots and cellular networks. In this scenario mobile users roam between these network domains while having an active communication link. In the Hot Spot the users can share the infrastructure of a WLAN or an ad hoc domain which is more cost efficient for the users. Furthermore, local communication between users can be handled locally within the domain.

The second scenario is the policy based handover which is needed to control handovers between two or more access interfaces. This is due to the fact that mobiles in the future will have for example a WLAN interface, a cellular access, and Bluetooth interface. To provide the best connection qualities a cost function has to be developed to generate the handover.

The third scenario is the coverage extension that is based on ad hoc networks which can be used if the mobile user is outside of the coverage of a cellular network. The user has an additional access interface to an ad hoc domain and can establish a multi-path connection to another ad hoc user or ad hoc gateway which provides access to a cellular system.

The three scenarios which are described above are mainly based on the integration of IP based wireless networks and cellular systems with the help of Hierarchical Mobile IP. In the following the simulation capabilities of ns-2 and its hierarchical simulation environment are described in more detail.

VI. THE COLUMBIA IP MICRO MOBILITY SUITE

The Columbia IP Micro-Mobility Suite (CIMS) includes an ns-extension that supports the following micro-mobility protocols [6]:

- Cellular IP
- HAWAII
- Hierarchical Mobile IP

The Cellular IP implementation supports hard and semi-soft handover, and IP paging. The Hawaii implementation supports unicast non-forwarding (UNF) and multiple stream forwarding (MSF) schemes. Hawaii's IP paging capability is currently not supported.

The CIMS v1.0 implementation of Hierarchical Mobile IP does not currently support IP paging. CIMS has been used to provide a simulative performance comparison of the aforementioned protocols for a series of publications. However, it was found that the CIMS implementation of hierarchical Mobile IP is inadequate for an investigation of the protocol.

Fig. 3 illustrates a NAM screenshot of a CIMS hierarchical Mobile IP simulation. It can be seen that the HA is missing from the topology. Moreover, it can be seen that the simulation provides only a single level of hierarchical MAs since all intervening entities below the GFA are simple routers and as such cannot perform tunnel management. Further investigation of the code led to the conclusion that the GFA provided by CIMS is nothing more than a normal HA renamed to a GFA for the purpose of forming a hierarchical organisation. The CIMS documentation stated that extending the code to support multi-level hierarchies would require a small modification. As will be presented in following section modification of the CIMS ns-extension required a great deal of effort in the way routing entries are managed to provide multi-level Mobile IP hierarchies.

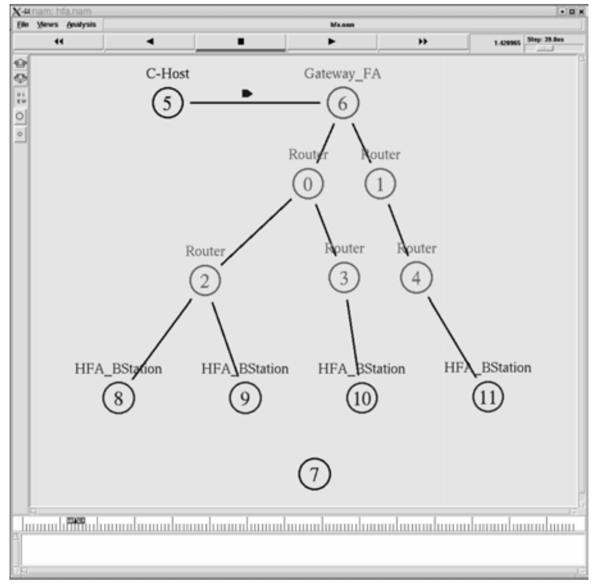

Figure 3: NAM screenshot of a CIMS hierarchical Mobile IP simulation

VII. NETWORK SIMULATOR HIERARCHICAL ROUTING

Hierarchical routing was mainly devised, among other things, to reduce memory requirements of simulations over very large topologies. The table size is reduced from n^2 for flat routing, to about $\log n$ for hierarchical routing. However, as the number of hierarchy levels increases hierarchical organizations also tend to generate their own overheads. A topology is broken down into several layers of hierarchy, thus downsizing the routing table Optimum results were found for 3 levels of hierarchy and the current ns implementation supports up to a maximum of 3 levels of hierarchical routing. Each ns node is required to maintain a table termed as classifier for each level of hierarchies in the simulation.

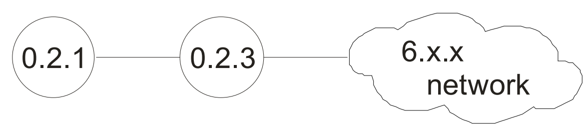

Figure 4: Level hierarhcial classifiers of node with address 0.2.1

The status and configuration of these classifiers reflects the topology of the simulation. For example, a node with hierarchical address 0.2.1 participating in the network illustrated in Fig. 4 would maintain the hierarchical classifiers illustrated in Fig. 5.

The reason for maintaining a hierarchical structure is to reduce the amount of information contained in every node in the ns-2 simulation. For this, the hierarchical structure requires that nodes maintain only knowledge of other nodes that participate in the same network. For all other nodes only knowledge of a gateway that will eventually lead to that node is required. Fig. 4 illustrates the status of the classifiers of node with address 0.2.1, where it is shown that the node maintains at the third level of classifiers a direct reference to the node with address 0.2.3. Considering that the same node acts as a gateway for the 6.x.x network a reference to the node is made at the 6th position at the first classifier level. As such, whenever the node with address 0.2.1 wishes to deliver traffic to a node with an address in the 6.x.x network then it will deliver all such traffic to the node with address 0.2.3 (see Fig. 5). However, during the implementation of the hierarchical Mobile IP protocol it was found that this behavior caused several problems that led to routing inconsistencies.

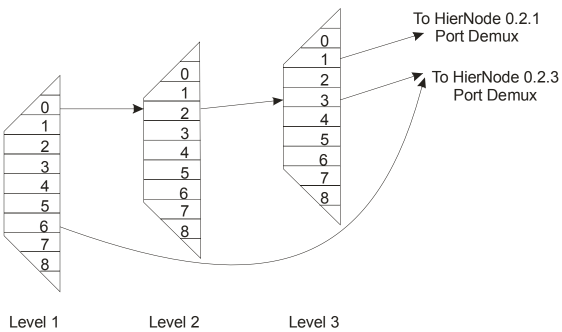

Figure 5: Example topology: node 0.2.3 is the gateway to the 6.x.x network for node 0.2.1

As was presented in the "Hierarchical Mobile IP" section, all mobility agents within a hierarchy are required to decapsulate and then reencapsulate data packets as they are forwarded down the tree toward the mobile node. This means that each mobility agent must maintain a tunnelling endpoint as well as a tunnelling start-point for each mobile node to which it provides services and this must be reflected at their hierarchical classifiers. However, by default and in compliance with the hierarchical organisation, mobility agents do not have a direct reference to individual mobile nodes but rather to gateways that may have such a direct reference. This would mean, that for the introduction of hierarchical consideration in the Mobile IP ns-2 model it would be required for all hierarchical Mobile IP entities to maintain in their classifier a direct reference to mobile nodes with which they maintain no direct link. That entry would eventually point to the encapsulator module rather than to a gateway or the mobile node itself. It can be understood that ns did not provide the facilities for this behaviour. This problem was alleviated by managing major changes to the hierarchical classifiers every time a mobility agent wished to add or remove a tunnelling start-point.

Fig. 6 illustrates a NAM screenshot of a hierarchical Mobile IP simulation based on the ns extension that resulted on the work performed on CIMS. It can be seen that the resulting model allows for the existence of HAs as well as multi-level hierarchies of MAs. Among others the new extension provides:

- Multi-level Mobile IP hierarchies
- Automatic configuration of hierarchical mobility agents, i.e. the user does not need to configure

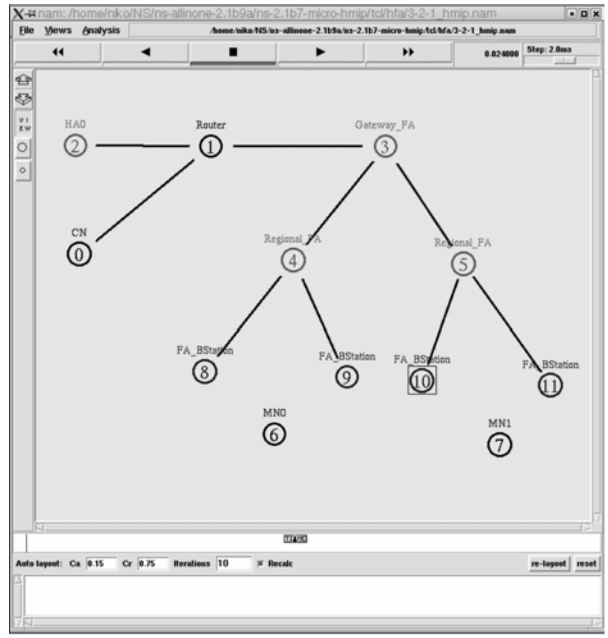

Figure 6: NAM screenshot of a hierarchical Mobile IP simulation

- Hierarchical MAs to acquire knowledge of MAs above and below them in the hierarchy tree.
- Script for automatic generation of scenarios. The script generates
    - Topologies (MNs, CNs, HAs, backbone routers, Mobile IP hierarchies of various depths and sizes)
    - Mobility scenarios with respect to the desired number of mobile nodes
    - Connection scenarios with respect to desired connection type and number of defined mobile nodes.
- Statistical analysis with the help of the Communication Networks Class Libraries (CNCL)

The individual options that can be altered to simulate different scenarios allow various investigations of Hierarchical Mobile IP infrastructures. In the following simulation results are described and show a solution of a multi-level hierarchy.

VIII. Interworking Concept of HMIP and AODV

In ns-2 Mobile IP and its extension only support single mobile user. For this reason an interworking concept to combine HMIP services with ad hoc networks for the mobility of single ad hoc users and also the mobility of entire ad hoc networks has been developed. Therefore only the Foreign Agents and the mobile nodes have to contain the HMIP and the AODV layer for interworking. To support HMIP services to other mobile nodes which are not in coverage of the Foreign Agent a mobile node has to provide AODV for ad hoc connectivity. The interworking concept is realized by AODV rebroadcasts of agent advertisements to inform other nodes about Mobile IP services. The rebroadcasts are carried out via several hops termed as multihop to supply the entire ad hoc network.

Another feature of this interworking concept is that HMIP service discovery by mobile nodes can be classified as proactive or reactive:

- Proactive means that agent advertisements from the FA flood the entire ad hoc network to provide HMIP services. Flooding is a broadcast mechanism to reach all mobile nodes and thus it consumes more network bandwidth than reactive discovery.
- Reactive means that mobile nodes send only an agent solicitation to reach the Foreign Agent or other mobile nodes if HMIP services are needed. In this case, agent advertisements are not required.

These concepts are still under discussion at the MANET WG. In this study the reactive approach is evaluated by the interworking of HMIP and AODV.

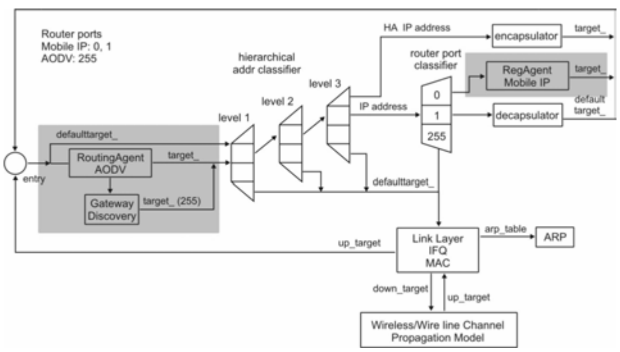

Figure 7: Foreign Agent and Mobile Node structure of HMIP and AODV extension in ns-2

In Fig. 7 the Foreign Agent and mobile node structure of HMIP and AODV extension in ns-2 is described. This extension is needed to provide the interaction of HMIP and AODV in the ns-2 node. The modules which have to be extended and implemented are:

- AODV Routing Agent
- Gateway Discovery
- Mobile IP RegAgent

The implementation of the AODV Routing Agent supports AODV routing features such as routing request and reply and the entries within the routing tables. Gateway discovery is needed to find the route to the default gateway. The Mobile IP RegAgent supports the registration process of the mobile node to discover agent advertisements of the visited Foreign Agent.

IX. SIMULATION RESULTS

Fig. 8 presents a screenshot of the ns-2 simulation based on a multi-level hierarchy. This simulation is a 3-2-5 hierarchy which means that there are 3 different levels which consist of a GFA level, an RFA level, and an FA level. All GFAs are connected via one router. It is also possible to simulate more than one router that can be used for investigations of Internet backbone capabilities. Furthermore, every RFA supports two FAs in this simulation.

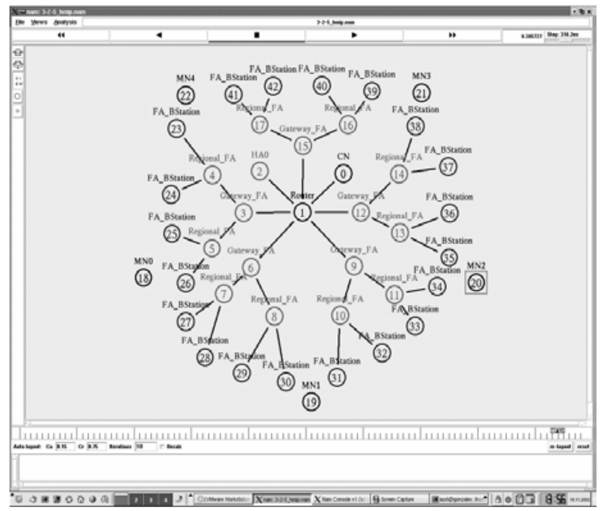

Figure 8: NAM scrrenshot of a hierarchical 3-2-5 Mobile IP simulation

This simulation contains 5 different mobile nodes which are connected via wireless access to the wired Hierarchical Mobile IP infrastructure. The gateways between the wired and wireless infrastructure are presented by the Foreign Agents. The mobile nodes use the Foreign Agents to exchange the bindings to the Home Agent which is also connected to the infrastructure (i.e., router). The Correspondent Node is the source for the Internet traffic to the mobile nodes and is linked to the router.

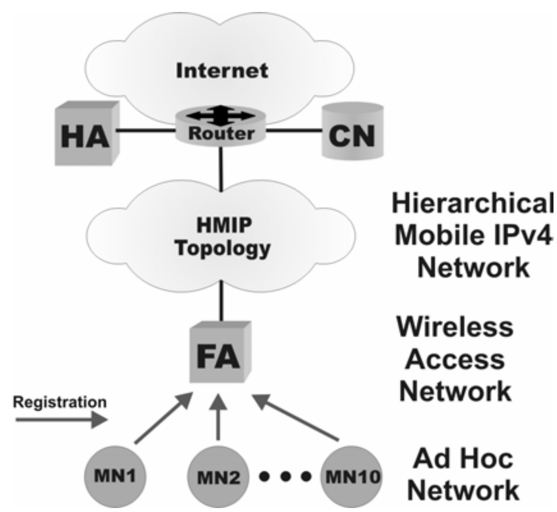

Figure 9: HMIP and AODV topology

To show the effectiveness and results of this HMIP extension the topology in Fig. 9 is defined for a simulation of HMIP in combination with AODV (10 mobile nodes). The topology consists of one Home Agent (HA) and one Correspondent Node (CN). For the

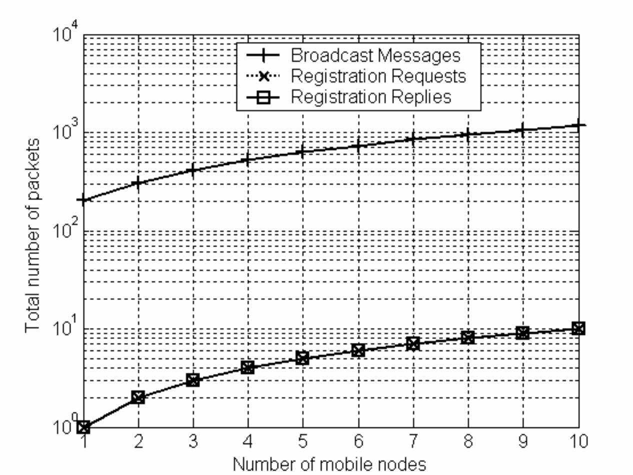

Figure 10: Broadcast and Registration Overhead during 100 simulation seconds

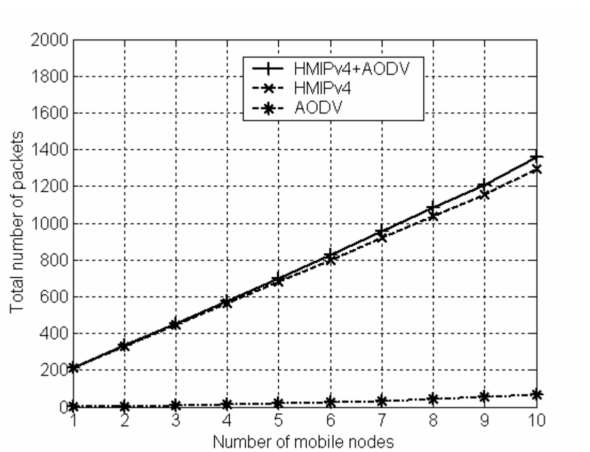

Figure 11: HMIPv4/AODV Routing Overhead during 100 simulation seconds

examination of HMIP extensions a simple hierarchical structure is chosen (one GFA and RFA) to evaluate the routing functionality of HMIP, the registration process and the interworking of HMIP and AODV.

Fig. 10 presents the relation between the number of nodes and the registration requests and replies. It can be shown that one mobile node forces one registration request and reply, two mobile nodes force two registration requests and replies, and so forth. At last ten mobile nodes force the same number of registration request (10) and replies (10). This presents that the extension of HMIP is reliable and is suitable for further investigation of HMIP structures.

In Fig. 11 the HMIP and AODV routing overhead of the topology is shown for the number of mobile nodes during 100 simulation seconds. The overhead increases constantly with the number of mobile nodes in the network topology. The HMIP routing overhead that includes advertisements, solicitations and registration messages which are transmitted during simulation increases proportional with the number of mobile nodes in the ad hoc network. AODV routing overhead increases slowly with the number of mobile nodes since all mobile nodes are always on hop away from the FA base station. No route changes occur that leads to a minimum of AODV routing packets. The sum of HMIP and AODV routing overhead shows the expected routing overhead of transmitted packets.

X. Conclusions and Future Work

The extension of the current Hierarchical Mobile IP implementation is needed to investigate complex communication infrastructures for cellular and IP based wireless networks. Therefore, Hierarchical Mobile IP is a most appropriate micro-mobility protocol which can be used and simulated with the network simulator (ns-2). The extensions of the Columbia IP Micro-mobility Suite (CIMS) described in this paper are the source for complex Hierarchical Mobile IP investigations. They contain the extension of the hierarchical address schemes and present a solution for multi-level hierarchies. Moreover, simulation results are described which shows the scalability of Hierarchical Mobile IP structures.0

Furthermore, the interworking of Hierarchical Mobile IP and ad hoc protocols is essential for the coverage extension in cellular networks. Coverage extension allows the integration of ad hoc users in cellular networks and reduces the number of base stations based on multihop ad hoc communication. The evaluation of the number of base stations which will be needed for coverage extension will be part of the future work.

References

[1] C. E. Perkins, "Mobile IP – Design Principles and Practices," Addison-Wesley Wireless Communications Series, 1998.

[2] J. C. E. Perkins, "IP Mobility Support," Request for Comments (Proposed Standard) 3344, Internet Engineering Task Force, August 2002.

[3] E. Gustaffson, A. Jonsson, C. E. Perkins, "Mobile IPv4 Regional Registration," draft-ietf-mobileip-reg-tunnel-07.txt, work in progress.

[4] The Network Simulator (ns-2), http://www.isi.edu/nsnam/ns/, release 2.1b9a, July 2002.

[5] The Network Simulator: Contributed Code, http://www.isi.edu/nsnam/ns/ns-contributed.html ,

[6] The Columbia IP Micro-Mobility Suite (CIMS), http://www.comet.columbia.edu/micromobility, March 2001.

[7] S. Corson, J. Macker, "Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations". RFC 2501, January 1999.

[8] C. E. Perkins, E. Belding-Royer, S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing". RFC 3561, July 2003.

[9] T. Clausen, P. Jacquet, "Optimized Link State Routing Protocol (OLSR)". RFC 3626, October 2003.The Network Simulator (ns-2), http://www.isi.edu/nsnam/ns/, current release 2.1b9a, July 2002.

[10] The Mobile IP.org website; http://www.mobileip.org