The Problem of Placing Mobility Anchor Points in Wireless Mesh Networks

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ABSTRACT
Hierarchical mobility management schemes such as HMIP and cellular-IP have been shown to be effective in providing low latency handoff in mobile networks. In this paper, we investigate the suitability of hierarchical mobility management schemes in Wireless Mesh Networks (WMN) and find that they are not directly suitable since MWNs have graph based topologies rather than tree based topologies. Because of this, there exist no natural locations for Mobility Anchor Points (MAP) sub that sub domains can be formed. In this paper, we present a scheme for finding the optimized placement of MAPs in WMNs, We validate our solution with experiments and argue that with optimized placement of MAPs, HMIP is applicable on WMNs and is able to give a close to optimal packet loss rate and handoff latency which is comparable to the performance of HMIP in fixed networks.

Categories and Subject Descriptors
C.2.1 **[Network Architecture and Design]** Wireless Communications

General Terms
Algorithms

Keywords
Wireless Mesh network, Approximation Algorithm, Mobility Management, HMIP

1. INTRODUCTION
In recent times, wireless mesh networks (WMNs) have emerged as a ubiquitous solution for providing flexible wireless access at a low cost [1]. WMN is also becoming an important technology for constructing beyond 3G high speed networks and several standards are in development contributing to its standards family[2], which includes IEEE802.11s [3], IEEE802.15.5[4] and IEEE802.16a[5].

The WMN (backhaul) comprises three kinds of mesh routers: *Mesh Point (MP), Mesh Portal Point (MPP),* and *Mesh Access Point (MeshAP).* MP is the basic entity of WMN that communicates with other MPs within its transmission range to deliver packets within WMNs; MPP is a MP collocated with a portal that acts as a gateway between WMN and the Internet; MeshAP is a MP collocated with an access point to provide network access to mobile stations (MS). An MPP can also be a MeshAP.

When a mobile station is stationary, WMN provides Internet access to it through a routing path generated by a WMN routing protocols such as RA-OLSR [2]. When the mobile station moves from one MeshAP to another, the old path to the MS becomes invalid and a new path to the current location of the MS has to be found. As we show later in this paper, this procedure usually causes high delay and losses of connections and is not acceptable for delay sensitive applications. To overcome this shortcoming, a mobility management protocol that supports seamless handover becomes necessary for WMNs.

Mobility management has been studied in depth in other network types including ad hoc [9,10,11], cellular [7] and mobile IP [8] based networks. Both the distributed [9] and hierarchical [10,11] mobility management schemes developed for ad hoc networks may perform suboptimally for WMNs since the MPs do not exhibit as high mobility as mobile nodes in ad hoc networks and therefore the wireless links between MPs are more stable. The mobility management protocols developed for cellular or mobile IP based networks could be used for WMNs. However, current centralized schemes such as cellular IP [7] and hierarchical Mobile IP [8] are designed for fixed networks with structured tree hierarchies that are not directly applicable for WMNs. These schemes assume that the fixed networking paths are stable and the hierarchies can be deterministically created following the network layout at deployment. In such networks, the mobility anchor points (MAP) can be placed at the root nodes in the tree hierarchy and sub-domains for the MAP are formed with the children under the root nodes. These assumptions do not hold true for WMNs which usually have an unplanned graph topology and where the wireless links are unstable and exhibit varying latencies. There exist no root nodes in a WMN topology for placing MAPs and there exists no easy way to form sub-domains.

In this paper, we adopt HMIP as the mobility management protocol for WMN by presenting a scheme for finding the optimized placement of MAPs in WMN and the optimized formation of sub-domains around these MAPs. We perform an experimental study and show that our scheme is capable of

MobiWac'08, October 30-31, 2008, Vancouver, BC, Canada.

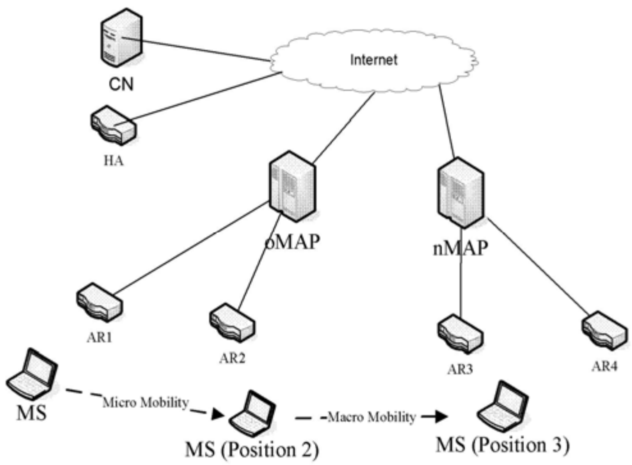

Figure 1. Local and global mobility in traditional hierarchical network

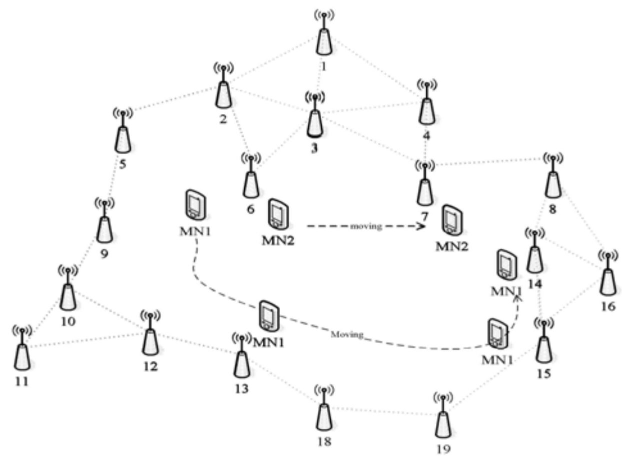

Figure 2. Mobility in a Wireless Mesh Network

finding locations of MAPs so that WMNs are able to deliver close to optimal packet loss rate and handoff latency.

The rest of this paper is organized as follows. Section 2 describes the MAP placement problem in detail. Section 3 discusses some related work. Section 4 describes the proposed scheme. Simulation studies are carried out in Section 5. Finally, we conclude and discuss some future research directions.

2. PROBLEM DESCRIPTION

WMNs usually have a much smaller per cell coverage area compared to wide area access networks such as cellular networks. Thus handover is much more frequent in wireless mesh networks and handover performance becomes of highest importance. It is well known that Mobile IP (MIP) does not perform well with frequent handovers as a Binding Update (BU) is required to be sent to the Home Agent (HA) for every handover which introduces significant delay. Hierarchical mobility management protocols such as HMIP are therefore crucial to reduce the BU overhead in WMNs.

Hierarchical mobility management schemes developed for traditional fixed networks [7][8] separates mobility management into micro mobility and macro mobility management, otherwise known as intra-domain and inter-domain mobility management. The central element of these schemes is the creation of a special entity called Mobility Anchor Points (MAP). The MAP is placed above several access routers, which constitutes its network domain. It is usually a router or a set of routers and maintains a binding between itself and mobile stations (MSs) currently entering its domain. Figure 1 depicts such a network with hierarchical mobile IPv6 (HMIPv6). When the Mobile Station (MS) moves to position 2 (micro mobility), it acquires an on-link care-of address (LCoA) from AR2 and registers it to the current MAP (oMAP) by sending a regular MIPv6 Binding Update (BU). When MS moves to position 3 (macro mobility), it needs to acquire a new regional care-of address (RCoA) from the new MAP (nMAP), which is usually the address of nMAP, as well as a LCoA. After forming these addresses, the MS sends a BU to the MAP, which will bind the MS' RCoA to the LCoA. Further more, the MS must send a subsequent BU to its home agent that binds its home address to the new RCoA. Finally, the MS may also send BU to its corresponding nodes (CN) specifying the binding between the home address and the newly acquired RCoA.

Such hierarchical mobility management protocols are not directly applicable on WMNs which usually has an unplanned graph topology. As illustrated in Figure 2, there exist no obvious position to place MAPs and no easy ways to form sub-domains within the WMN. Further more, geographically close nodes in WMN can be very far from each other, such as MP6 and MP13 in Figure2 which makes it harder to determine the location of MAPs.

In order to apply HMIP to WMN, a scheme to find the correct locations in WMN for placing MAP(s) and forming network domains around these MAPs needs to be developed. Our problem can therefore be defined as finding the optimized placement of the MAP(s) and optimized formation of network domains to minimize the average handoff latency in WMN.

3. RELATED WORK

There have recently been a surge of interests in deploying wireless mesh access network to provide Internet access to home users. Examples of these networks includes MIT roofnet [13] and CUWIN[14]. Roofnet aims to provide broadband access to households using mesh technology and CUWIN intends to provide a meshed, ad-hoc, non-hierarchical network topology based on commodity infrastructure and technology. However, neither of them tries to address mobility management in their networks.

The problem of MAP placements in traditional networks is generally an easy problem and therefore this problem has been largely left untouched. However, numerous studies have been done on the performance of HMIP in wireless networks [12] and some of them [15] suggested that good placement of MAP can reduce the handover latency tremendously than bad placement.

There have also been a number of interesting studies on placing servers at optimized locations in different networks for better performances. For example, [16] examines the placement of Internet instrumentation; and [17] examines the placement problem of Gateways in wireless mesh networks. However, the previous works cannot be applied to the present problem as their focus are on maximizing the capacity of the network rather than minimizing the latency.

It is also worth mentioning that the MAP placement problem can be considered as a facility location like problem. Facility location problems are considered to be an important branch of operations research [18] and have also been extensively studied using approximation Algorithms [19]. Several approximation algorithms have been proposed for different variations of this problem. All previous proposals including the one proposed for Gateway placement in [17] might be useful for our problem. However, the complexity of the costing functions on both MAPs(facilities) and MPs (cities) makes our problem more challenging than the above-mentioned facility location type of problems in networking area.

4. MATHEMATICAL ANALYSIS

To solve the MAP placement problem, we first formulate it as a directed graphs. Let $T=(V,E)$ be the topology graph of a fully connected WMN where M is the set of MPs and E is the set of links between any connected MPs. Let P_{ij} be the shortest path from MP *i* to MP *j*. We create a complete bipartite graph from the topology graph with bipartition (F,M) where $F=V$ is the set of potential locations for MAPs and $M=V$ is the set of MPs. Let $c_{ij}=|P_{ij}|+|P_{ji}|$ be the cost on the edge from MP *j* to MAP *i* (average latency between MP and MAP) and f_i be the cost on MAP *i* (average latency between MAP and HA). Also let p_j/p_i be the possibility that an arrival at *j/i* is macro mobility and w_j/w_i be the (average) number of arrivals at *j/i*. Then we can formulate the cost of selecting MAP *i* as $p_i w_i f_i$ (cost for binding update to the HA) and the cost of assigning MP *j* to MAP *i* as $(p_j+1)w_j c_{ij}$ (cost for local binding update). The problem is then to find a subset $I \subseteq F$ of MAPs and a function $\alpha : M \rightarrow I$ assigning MPs to MAPs where the total cost of selecting MAPs and assigning MPs to MAPs is minimized.

We come up with the following integer program:

$$\begin{array}{lll} \textit{Minimize} & \sum_{i\in F, j\in M}(p_j+1)w_j c_{ij} x_{ij} + \sum_{i\in F} p_i w_i f_i y_i & (1) \\ \textit{subject to} & \sum_{i\in F} x_{ij} \geq 1 & j\in M \\ & y_i - x_{ij} \geq 0 & i\in F,\ j\in M \\ & x_{ij}\in\{0,1\} & i\in F,\ j\in M \\ & y_i\in\{0,1\} & i\in F \end{array}$$

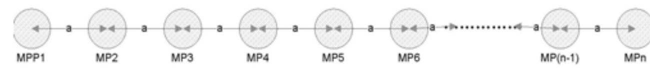

Figure 3. A chain of MPs with MP1 acting as a portal

In this program, y_i is an indicator variable denoting whether MAP *i* is selected, and x_{ij} is an indicator variable denoting whether MP *j* is assigned (connected) to MAP *i*. The first set of constraints ensures that each MP is assigned to at least one MAP, and the second ensures that this MAP must be active (has been selected). If we assume $p_i w_i f_i$ and $(p_j+1)w_j c_{ij}$ are constants which are pre-measurable, then equation (1) can be understood as a standard facility location type of problem. It is NP-hard to find the optimized answer for such problems in general although an approximation algorithm with factor within 2.408 has been proposed [20]. We will study the problem in several topologies to validate the correctness of it. For simplicity, in the following sections, *i* and *j* will also be used as integers that represents the number on particular MPs.

4.1 Chain Topology

We will first study the placement problem in a simple chain topology. As mesh points can be placed on traffic light poles for road and traffic networks [24], it is possible to have a mesh network with a chain topology along a main road. Figure 3 shows a chain of *n* mesh points (MPs) where MP1 is also a portal point. Assume the average latencies on all wireless links between any two adjacent MPs are the same and equals to *a*, thus $c_{ij}=|i-j|a$. Also assume that the number of clients' arrivals at MP1 and MPn is *b* ($w_{1,n}=b$), and is *2b* at all other MPs (symmetric traffic from both ends). We first consider the case where only one MAP will be selected. In this case, there is no macro mobility so $p_i = p_j = 0$. Subject all the assumptions to program 1, we get program 2:

$$\begin{array}{lll} \textit{Minimize} & \sum_{i\in F, j\in M}|i-j| a w_j x_{ij} y_i & (2) \\ \textit{subject to} & \sum_{i\in F} x_{ij} \geq 1 & j\in M \\ & y_i - x_{ij} \geq 0 & i\in F,\ j\in M \\ & x_{ij}\in\{0,1\} & i\in F,\ j\in M \\ & y_i\in\{0,1\} & i\in F \end{array}$$

By calculating the absolute $\sum_{j\in M}|i-j| w_j x_{ij}$, program 2 can be transformed into the following program.

$$\begin{aligned} &\textit{Minimize} \quad && \sum_{i\in F}(2i^2 - 2(n+1)i + (n^2+1))aby_i && (3) \\ &\textit{subject to} \quad && \sum_{i\in F} y_i = 1 && \\ & && y_i \in \{0,1\} && i \in F \end{aligned}$$

Because *n, a* and *b* are all constants, this program can be solved in polynomial time by solving the polynomial coefficient equation. When MAP $i=(n+1)/2$ when n is odd (or $i=(n+2)/2$ when n is even) is chosen and all MPs are assigned to it, the above program gives the minimal value. Not surprisingly, this represents the central MP in the chain.

We then study the case where two MAPs will be selected. Assume the average latency from the gateway MPP1 to the home agent is *d*. It is also safe to assume that each MAP domain is continuous and the number of global handover is *b* to each domain based on the mobility pattern assumed before. Subject these assumptions to program (1), we get

$$\begin{aligned} &\textit{Minimize} \quad && \sum_{i,k\in F} \begin{array}{l} ((2i^2 - 2(n_i+1)i + (n_i+1)^2)aby_i + 2db + \\ (2(k-n_i)^2 - 2n_k(k-n_i) + (n^2{}_k - 2))aby_k \end{array} && (4) \\ &\textit{subject to} \quad && \sum_{i\in F} y_i = 1 \qquad \sum_{k\in F} y_k = 1 && \\ & && y_i, y_k \in \{0,1\} && i,k \in F \end{aligned}$$

Where *i,k* are the two MAPs and n_i , n_k represent the number of MPs assigned to MAP *i* and MAP *k*. This program can also be solved in polynomial time and we get the results

$$n_i = (n-1)/2 \qquad n_k = (n+1)/2$$
$$i = (n+1)/4 \qquad k = (3n-1)/4$$

It is also interesting to calculate when two MAPs over performs one MAP. We can do this by subtracting program (3) from program (4) with their optimal solutions. It's only worth placing two MAPs when the result is larger than 0, thus we get

$$n^2 - 6n + 9 - 8d/a > 0 \qquad (5)$$

Simplify (5), we get

$$n > 2\sqrt{2d/a} + 3 \qquad (6)$$

(6) states that when the number of MPs is larger than $2\sqrt{2d/a}+3$, two MAPs should selected instead of one. This analysis also gives us some hints on the appropriate number of MPs that should be in each MAP domain. For example, when the average latency from MPP to the home agent is twice the average latency on wireless links between MPs, the number of MPs in each MAP domain should be less than or equal to 7.

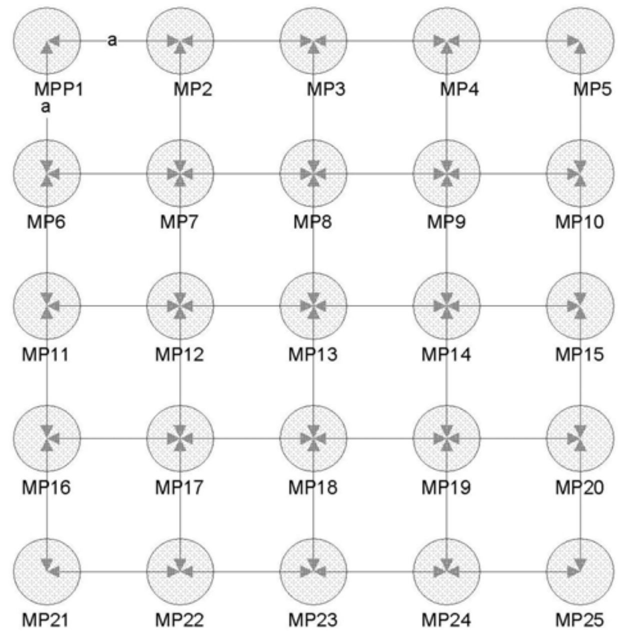

Figure 4. A Grid of 25 MPs with latency=a on each link

4.2 Grid Topology

We will then study the placement problem in a grid topology. We only consider the case when only one MAP will be selected. Figure 4 depicts a grid of 25 MPs where MP1 is also an MPP. Assume the number of arrivals is *b* for MPP1 and MP25, and *2b* for all other MPs. Also assume the average latency on each link is *a*. Let $i=5(m-1)\times n$ where *m* represents the row of the MP and *n* represents the column, we get the following program:

$$\begin{aligned} &\textit{Minimize} && \\ &\sum_{i\in F}(10m^2 - 10(5+1)m + 10n^2 - 10(5+1)n + 10(5^2+5) - 8)aby_i && \\ &\textit{subject to} \quad \sum_{i\in F} y_i = 1 && \\ &\qquad\qquad y_i \in \{0,1\} && i \in F \end{aligned}$$

As *m* and *n* are independent, when *m*=*n*=(5+1)/2=3 and *i*=13, the program gives the smallest value. Note the solution can also be extended to a $d_1 \times d_2$ grid by replacing 5 with d_1 and d_2.

4.3 Arbitrary Topology

The MAP placement problem becomes significantly more complex in an arbitrary topology when an arbitrary number of MAPs will be selected. In this case, w_i and p_i , p_j are not constant anymore which makes program (1) non-linear.

If we assume w_{mj} is the (average) number of arrivals from MP *m* to *j* (constant and pre-measurable), then the non constant factors can be formulated as:

$$w_j = \sum_{m \in M} w_{mj} \qquad w_i = \sum_{j \in M} x_{ij} w_j \qquad (7)$$

$$p_i = 1 - \frac{1}{w_i}\left(\sum_{j,m \in M} w_{mj} x_{ij} x_{im}\right)$$

$$p_j = 1 - \frac{1}{w_j}\left(\sum_{m \in M, i \in F} w_{mj} x_{ij} x_{im}\right)$$

Apply (7) to (1), we get the following general program for the MAP placement problem.

$$\begin{aligned} \textit{Minimize} \quad & \sum_{i \in F, j \in M} (2c_{ij} + f_i) w_j x_{ij} - \sum_{i \in F, j, m \in M} (c_{ij} + f_i) w_{mj} x_{ij} x_{im} \qquad (8) \\ \textit{subject to} \quad & \sum_{i \in F} x_{ij} \geq 1 \qquad j \in M \\ & y_i - x_{ij} \geq 0, \qquad i \in F, j \in C \\ & x_{ij}, x_{im} \in \{0,1\} \qquad i \in F, j \in C \\ & y_i \in \{0,1\} \qquad i \in F \end{aligned}$$

As has been discussed before, it is computationally costly to optimally solve the MAP placement problem. As shown in Table 1, we design a greedy placement scheme by iteratively connects MPs to MAP in a way that minimizes average cost when selected in conjunction with MPs chosen in previous iterations.

Table 1. Greedy Placement algorithm for MAP placement problem

```
Sort all the MPs in V by f_i
For(MP i in V)
    Remove i from V and put in I
    Sort M by c_ij
    L=0
    For( j ∈ M )
        L' = avg cost based on equation (8)
        If(L' <L or L==0)
            Remove j from V and M , assign j to i, L=L'
        Resort w
        For( m ∈ M with w > 0 )
            Recalculate avg cost L'
            If(L' < L)
                Remove m from V and M, assign m to i
            Resort w
        Done
    Remove i from M
Done
```

5. SIMULATION VALIDATION

The goal of our simulations was to examine the effectiveness of the proposed solution for selecting MAPs in WMNs. OMNeT++[21] was chosen for conducting our simulation studies. The base OMNeT++ was installed together with the INET Framework [22] and IPv6Suite, which provides basic IPv6 operation including wireless and mobile support. The simulation environment was further extended with our implementation of mesh management layer, MeshAP entity and MPP entity to support mesh networking. We studied the performance of different MAP placements in a simple chain topology and an arbitrary topology and compare the results with the theoretical analysis in the last section.

5.1 Chain Topology

We firstly conduct a simulation study on a simple chain topology. A chain of 9 MeshAPs was created where MeshAP1 was also an MPP. The MPP is connected to a Home Agent (HA) and a correspondent node (CN) over wired links. Each MeshAP was equipped with two wireless interfaces for Mesh and Access Point communications. The channels of the two interfaces were set to 1 and 11 respectively in order not to interfere with each other. The transmission ranges are set to 150 and 75 on MP and AP interfaces. All MPs were then placed 100 meters apart. One mobile station travelled from MeshAP1 to MeshAP9 and then back to MeshAP1 at a speed of 5m/s. All results represent the average of at least 100 independent simulations.

Figure 5 demonstrates the average latencies when one MAP was placed at different MPs. As can be observed from the figure, the average latency decreased as the MAP moved to the central of the chain and was at its lowest when MAP was placed at MeshAP5. The result follows our mathematical analysis in the previous section. Because there is no macro handoff, the central MeshAP usually have the smallest average distance to all other MeshAPs and thus gives the lowest micro handoff delays.

Figure 6 presents a performance comparison of one and two MAPs placed in the WMN with different round trip time (RTT) to the HA. The placement of MAPs and selection of MAP domains were based on theoretical analysis conducted in the previous section. The RTT from the MPP to the HA was configured with explicit values. When only one MAP was placed (at MeshAP5) in the WMN, there was no macro handoff and the average handoff latency always remains the same. When two MAPs were placed, the WMN was divided into two domains, where the first domain ranged from MeshAP1 to MeshAP4 and the second domain ranged from MeshAP5 to MeshAP9. The two MAPs were placed at MeshAP2 and MeshAP7 respectively. It can be observed from the figure that 2 MAPs gives a smaller average latency until the

RTT reaches 25ms. As the RTT to the HA increases, the macro handoff latency increases and the average handoff latency with two MAPs increases.

This scenario validates the correctness of our mathematical analysis and suggests the potential locations of MAPs and the relationship between the delay to the HA and the number of MAPs.

5.2 Arbitrary Network

To validate the performance of our scheme in an arbitrary topology, we compare it to the performance of random placement, gateway placement, WMN default and fixed network performance. .

The random placement algorithm randomly places an MAP at an MP and assigns MPs to the MAP iteratively until all MPs are managed by MAPs. To avoid wasting resources, one MP has at most one MAP and MPs connects to MAPs at most 2 hops away. This approximates un-coordinated deployment of MAPs in WMN, and gives a baseline to evaluate the benefits of our proposed algorithm.

The gateway placement algorithm places MAPs at MPPs and iteratively assigns other MPs to MAPs based on hop count until all MPs are managed.

It is interesting to see how WMN performs without a mobility management protocol. This gives us a good sense of how well HMIP with a reasonable MAP placement algorithm can increase the handoff performance.

We also want to compare the result to the performance of HMIP in fixed networks, which gives a good benchmark to evaluate the performance of all other solutions. .

An arbitrary topology with 22 MeshAPs and 2 MPPs was generated randomly to avoid bias. Each MPP was also a MeshAP. Each MPP was connected to a server which acted as a correspondent node (CN) from the Internet and the MPPs were connected to each other with a wired link. A Home Agent (HA) was also generated and connected to both MPPs over wired links. Same as before, each MeshAP was equipped with two wireless interfaces on Channel 1 and 11 respectively to avoid interference. The transmission ranges of both wireless interfaces were set to 100 meters and the bandwidth were set to 11Mbps. The wired link between MPPs was modelled as a 100Mbps duplex link with 2ms delay and the links to the CNs and the HA are modelled as a 100Mbps duplex link with 10ms delay representing the Internet in a metropolitan area setting. The mobility pattern used for mobile stations was generated from Dartmouth [6] traces using algorithms from Minkyong Kim etc. [23]. This mobility pattern simulates the movement pattern of real users in a university and enables a reasonably accurate analysis. A number of mobile stations (MS) were generated using the real user traces and connected to a random CN. The CNs generated background traffic at 64kbps to each of these MS. *One* MS with a *deterministic* movement pattern were generated. The MS moved at a speed of 10m/s through all the MeshAPs. It was connected to both CNs with UDP traffic of 500 bytes transmitted at an interval of 10ms. In this simulation, we only analysed the handoff latency and packet loss rate of this deterministic MS.

A fixed network had also been set up with the same APs locations and link properties to get the HMIP performance in fixed network for benchmarking all other results.

All simulations had duration of 200 seconds with 20 seconds warm up time. Greedy placement approach was given 500 seconds MAP set up time with 200 mobile users. All results represent the average of at least 50 simulations.

Figure 7 shows the handoff latency over the total number of Mobile Stations (MSs). As can be observed from the figure, when the number of MSs is small, e.g. 10 or below, the handoff latency of Gateway placement is better than the greedy approach. This is because when the traffic on the WMN is light, the dominant factor for the handoff latency is the wired link delay for BU to the HA and the gateway placement approach only generates two macro motility events. However, for Gateway placement, every micro-mobility event generates a BU to the gateway from the MS's new point of attachment (PoA) which is usually far away from the gateway. As the number of stations increases, the latency increases faster than the other approaches due to the higher delays over the wireless channels. This can be observed in the figure where the greedy approach starts to give lower latency at a point between 10 and 15 MSs. It can also be observed that the greedy placement performs closest to the fixed network until the long access time on the wireless channel begins to dominant the handoff latency. We also simulated the handoff latency of the WMN without any mobility management scheme; the latency is 5 times to 1 magnitude higher than all other schemes and therefore is not shown in this figure.

Figure 8 shows the packet loss rate over the number of mobile stations. Similar to the handoff latency, the gateway placement approach gives a better performance when the number of MSs is low and the dominant contributing factor to the handoff delay is the BU to the HA. The greedy approach starts to give better performance when the number of mobile stations increases and the latency over the wireless links increases. Until the saturation level of the packet transmission has been reached in the WMN, the greedy approach gives a close to benchmark result. Figure 8 also shows the packet loss rate of WMN when no mobility management scheme is used which, not surprisingly, is significantly higher than the other approaches.

This scenario suggests that Gateway placement could be an efficient solution to the MAP placement providing enough MPPs are placed at strategic locations and the number of users is small. However, the Gateway placement approach has several limitations. First, the cost of MPPs is much higher than other MPs. Second, the locations of the MPPs are limited as a wired link to the Internet is required. For these reasons, the greedy approach is the most feasible solution for MAP placement in WMNs.

6. CONCLUSION

Mobility management to allow seamless roaming represents a key element of mesh based wireless access networks. In this paper we proposed a scheme to enable efficient hierarchical mobility management to WMN by solving the problem of efficient MAP placement. First, we formulate the MAP placement problem as a facility location type of problem, and design a greedy placement scheme. We also study the correctness of our theoretical analysis with a simple chain topology and compare the performance of our greedy placement approach to several other MAPs placement approaches in an arbitrary network. We demonstrates that our approach is the most feasible approach for the WMNs which can give close to optimal handoff latency and packet loss rate comparable to the performance of HMIP in fixed networks.

7. FUTURE WORK

Although significant performance gain can be observed from the greedy placement approach of MAPs for mobility management in WMN, there are a number of avenues for future works.

First, we have made several simplistic assumptions on the wireless link models and interference models. One necessary future work is to take wireless link models and interference models into consideration when investigating our solution.

Second, a dynamic load balancing scheme would be necessary to reduce the saturation over MAPs. In WMN, a MAP is also an important routing agent for general traffic and its links do not usually have a higher capacity. If all tunnelled traffic to mobile stations goes through one MAP, a saturation level of packet transmission on its wireless channels will easily be reached while the number of MSs entering its domain increases. A potential solution is to have multiple MAPs covering one MP and dynamically balance the traffic load through these MAPs. Our proposed scheme has the capability of assigning multiple MAPs to MPs but a dynamic MAP selection algorithm needs to be developed for optimized load balancing.

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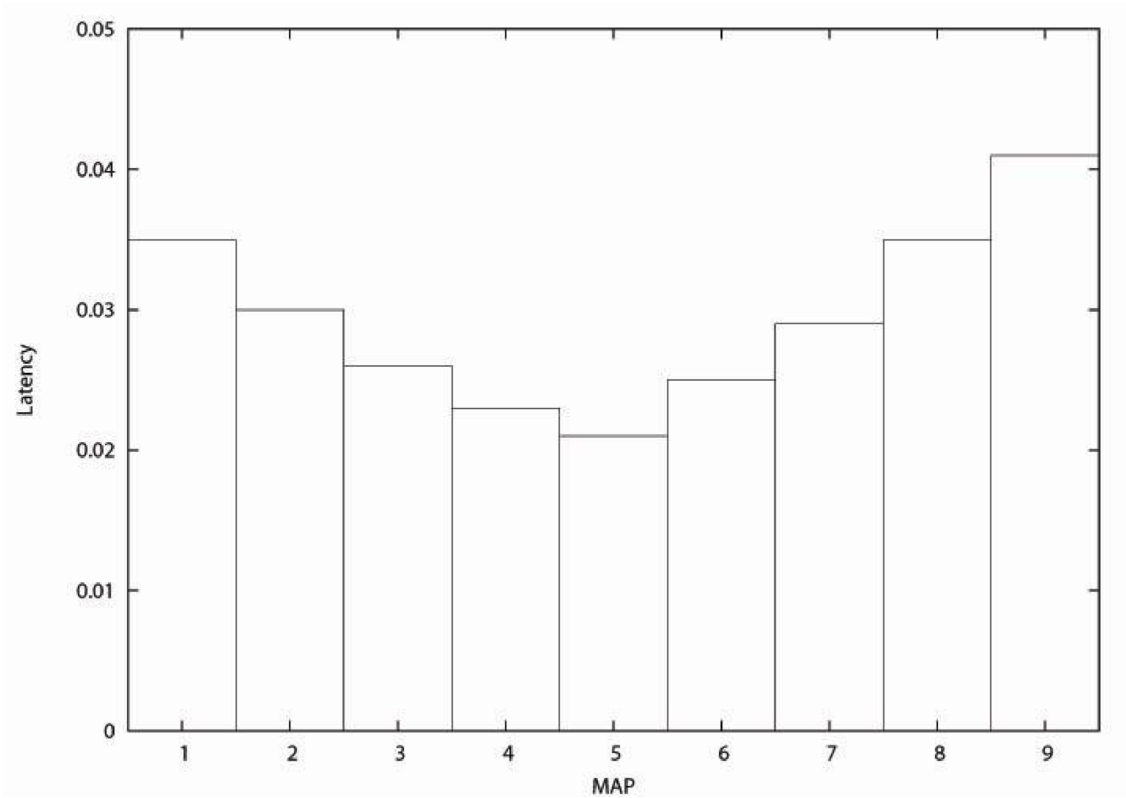

Figure 5. Average handoff latency with MAP placed at each MP.

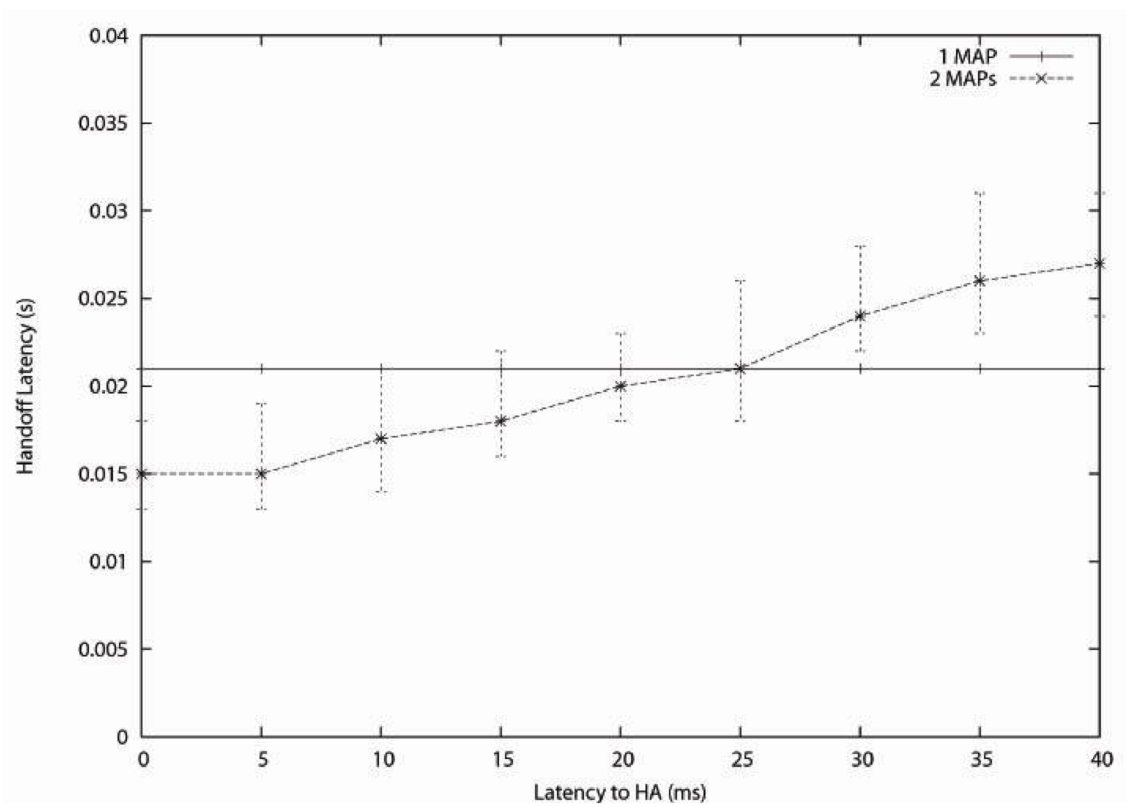

Figure 6. Handoff latency comparison with different RTT between the HA and the MPP with 90% confidence interval

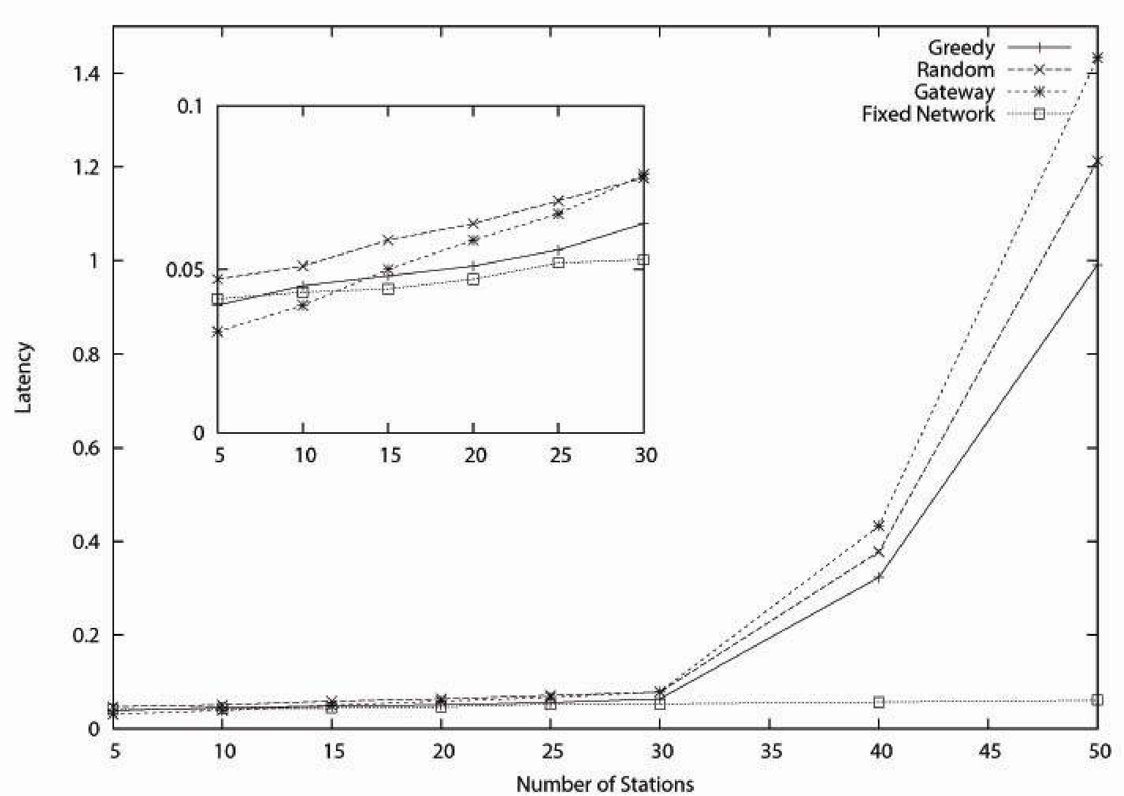

Figure 7. Impact of number of stations on handoff latency

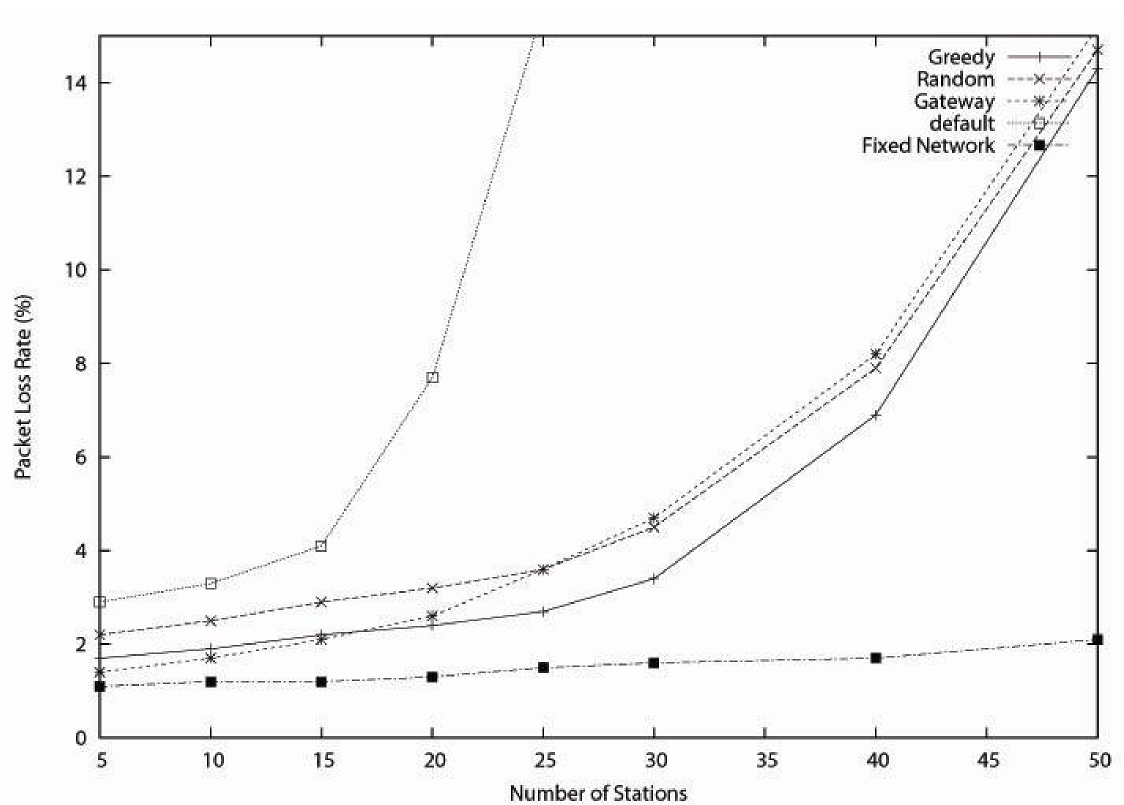

Figure 8. Impact of number of stations on packet loss rate