A STUDY ON WIRELESS MESH NETWORKS

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Abstract

After the great deployment and success of the Wireless Local Area Networks based on access points, which communicate by using wired links, the wireless world saw the birth of new technologies like Ad Hoc networks and Wireless Mesh Networks (WMN), which permit the flexibility, easy deployment and low cost. The first objective of these networks is to offer a seamless connectivity to mobile users. Nevertheless, wired mobility management protocols perform poorly with these new technologies.

In this paper, we investigate mobility problems in WMN and propose a new efficient solution with high performances. Specifically, we present a new mobility management scheme for WMNs, 3-layer mobility management scheme. It utilizes some WMN's features and uses IP Prefix in mobility management to reduce the signaling cost as well as to shorten the handoff latency.

We provide the following contributions. First, we talk about some routing protocols at layer 3. After that we propose a 3-layer mobility management scheme in order to reduce the signaling cost and shorten the handoff latency. We focus on our experiment in using IP Prefix in detecting client movement.

Keywords:
Mobility Management, 3-layer mobility management scheme, IP Prefix, Wireless Mesh Networks, Routing Protocols.

I. Introduction

Researches on Wireless Mesh Networks (WMNs) are being attracted much attention these days. A wireless mesh network, as a variant of Mobile Ad hoc Networks (MANET), is an IEEE 802.11-based infrastructure network in which Access Points (APs) and stations (STAs or hosts) can relay messages on behalf of other APs in ad hoc fashion to create a self-configuring system that extends the coverage range and increases the available bandwidth.

Accordingly, IEEE Task Group 802.11s has been proceeding with the standardization of a WMN. The basic concept of the WMN is that APs are inter-connected by an ad-hoc network and each AP and its terminals are connected to the AP in infrastructure mode. In a WMN, APs need to know somehow the mapping information indicating a list of correspondent terminals connected to an AP. A packet sent by a certain terminal is forwarded to a destination terminal via a number of APs referring to the mapping information in APs.

However, a WMN has several drawbacks compared with a wired network. For instance, communication by a WMN is not as stable as a wired network; suitable ad-hoc routing protocols are different depending on the user environment. Realization of a seamless handover is also an issue. The fact that stable communication cannot be ensured in a WMN that due to the connections among APs are made by an ad-hoc network, where flooding of a packet may not be carried out properly.

In the case of existing WMNs, routing protocols of ad-hoc networks and the administration of the AP/terminal mapping information are integrated, and as a result, it is not possible to replace routing protocols.

Mesh network is self-organizing and simple enough so that users are able to deploy, and maintain with limited technology experience. Mesh networking technology also provides numerous and unique capabilities that can facilitate the deployment of public access wireless networks, as it enables higher reliable Internet access services by providing a fault tolerant infrastructure and redundant access links with respect to traditional wired methods. Moreover, wireless mesh networks enable advanced applications/services through ubiquitous access and reliable connectivity.

Recently, an IEEE working group, named 802.11s, has been focusing on how to enhance current IEEE 802.11 standard with routing/forwarding functionality to achieve better efficiency and bandwidth utilization. IEEE 802.11s standard will be built upon the existing IEEE 802.11a/b/g technologies and it will use QoS features of IEEE 802.11e and security features of IEEE 802.11i. It will have extra forwarding functions to allow wireless APs to discover each other, authenticate and establish connections, and to work out the most efficient route for a particular task.

Each node of the network can be mobile, thus, the dynamic discovering and updating of routing information (including information about external networks, e.g. Internet), is unarguable one of the critical challenges for wireless mesh networks. The IEEE 802.11s working group is taking into account several MANET routing protocols. In particular they are evaluating different categories of routing performance, such as Ad Hoc On Demand Distance Vector (AODV) [1] and Optimized Link State Routing Protocol (OLSR) [4], which are based on on-demand and table-driven forwarding technique, respectively.

In this paper, in order to reduce signaling cost and handoff latency in wireless mesh network, we analyze an OLSR routing protocol, then compare OLSR with AODV in terms of packet delivery ratio, throughput, routing overhead and packet end-to-end delay. We choose to compare this two algorithms since these are the ones currently interested by the IEEE 802.11s working group.

When the mobile clients are stationary, with the support of backbone routing, the wireless access for them can be accomplished within a few hops. However, difficulty arises when there are needs for the mesh clients to move across the coverage area of different APs. How to maintain the ongoing connection and how to forward the downstream and upstream packets are not solved by the current standards. IEEE 802.16e adds amendments to the original standard to support mobility, but only specifies MAC and PHY layer. IEEE 802.11s attempts to extend the WiFi to support the mesh mode and provide mobility support, which is still under development. Mobility management is not a new topic in other existing networks. In cellular systems, this part has already been a critical part to the continuous service of the mobile clients. Handoff quality is one of the most indispensable testing items in each field trial test. However, wireless mesh networks, which lack of infrastructure such as HLR and VLR, face more challenges in mobility management. Mobile IP is an approach which provides mobility support to mobile clients with IP identity.

The main idea is very similar to the HLR/VLR mechanism in cellular systems. Home Agent (HA) and Foreign Agent (FA) play the roles of home database and visiting database in the IP networks, respectively. Home address is used as the ID of a mobile client and the Care-of-Address (CoA) is used to locate the current position of the moving mobile clients. Mobile IP can provide a solution to the inter-domain movement in WMNs. However, it is not suitable for the intra-domain movement, which is much more frequent than the inter-domain movement. The reason is that if FA is implemented in every AP, signaling cost and handoff latency become the major problems to the mobility support. Therefore, the solution to cope with the local movement is required. Protocols for IP micro-mobility have been proposed above to solve the mobility dilemma in small-scale networks.

Though these protocols can be applied to WMNs, heavier signaling cost and longer handoff latency due to more frequent local movement in WMNs still impede the practical mobility support.

In this paper, we propose a mobility management scheme in WMN, termed **Mesh Mobility Management.** Some features of WMNs, such as multi-hop, mesh topology and continuous coverage, have been taken into consideration to better support the IP micro-mobility in WMNs.

The rest of this paper is organized as follows. Section I is introduction, Section II discusses some related works including some routing protocols and our proposed scheme. Conclusion is given at the end.

II. Related works:

1. Routing Protocols:

First we briefly review the most popular ad hoc routing protocols those are the direct candidates for the routing protocol in wireless mesh networks, and then analyze their characteristics and propose a routing protocol suitable for small/normal-scale wireless mesh networks.

Traditional ad hoc routings can be divided into two categories: on-demand (or reactive) and table-driven (or proactive) protocols. In reactive protocols, a route path is established only when a node has data packets to send. Some of the best known on-demand protocols are Ad-hoc On-demand Distance Vector routing (AODV), Dynamic Source Routing (DSR) and Temporary Ordered Routing Algorithm (TORA). In contrast to the on-demand routings, proactive routing protocols continuously update regardless the traffic activity in the network. Normally, each node generates control messages periodically and/or in response topology changes. Some popular proactive routings include Optimized Link State Routing Protocol (OLSR), Destination Sequence Distance Vector routing protocol (DSDV), Wireless Routing Protocol (WRP) and Cluster-head Gateway Switch Routing (CGSR) are the most popular table-driven protocols for mobile ad hoc networks. However, all these routing protocols do not scale well because they periodically propagate routing information of all nodes throughout the whole network. Further the traditional routing schemes, geographic Routing. With this scheme, packets are forwarded by only using the position information of nodes in the vicinity and the destination node. Thus, topology change has less impact on the geographic routing than other routing protocols. It is more scalable since it only demands local states for communication without end-to-end path setup. However, geographic routing relies on the existence of GPS or similar positioning technologies, which increase cost and complexity of wireless mesh networks. Meanwhile, it needs the Geo-location service for the destination. All these issues increase the complexity of devices and routing protocol. Therefore, we do not consider the geographic routing in the paper.

In this paper, we investigate the impact of reactive routing protocol AODV and proactive routing protocol OLSR in wireless mesh networks. We choose the two algorithms, due to the fact that these two routing schemes have the dominant role in the ad hoc networks, and the working group IEEE 802.11s is currently focusing on these two protocols, or variation of them, to understand the advantages of both the strategies in the mesh environments. In the following we review the two protocols.

As reactive routing protocol, AODV reacts relatively quickly to the topological changes in a network and updates only hosts that may be affected by the change. However, AODV tends to cause heavy overhead due to the flood search triggered by link failures. As a result, AODV does not perform well in heavy load or mobile networks.

Optimized Link State Protocol (OLSR) is a proactive routing protocol that is an optimized version of a pure link state protocol by applying Multipoint Relays (MPR) concept. The idea of MPR is to reduce flooding of broadcast packets by shrinking the number of nodes that retransmit the packets.

In wireless mesh networks, Mesh Points (MPs) usually have minimal mobility, while STAs can be stationary or mobile. If a STA moves into another Mesh AP and AODV is used as the routing protocol, the STA needs to flood the network again to discover a new path. Therefore, AODV will incur excessive routing overhead. In contrast, with proactive routing protocols, the host can find the path immediately without finding a new route after moving into another mesh router's coverage. Thus, in the paper we propose to adopt the OLSR. In addition, to overcome the drawback of the scalability problem of OLSR, we enhance OLSR protocol with Fisheye (FSR) concept.

The OLSR operates as a table driven and proactive protocol regularly exchanging topology information with other nodes of the network. The key concept used in the protocol is that of multipoint relays (MPRs). MPRs are selected nodes which forward broadcast messages during the flooding process. The idea of MPR is to minimize the overhead of flooding messages in the network by reducing duplicate retransmissions in the same region. Each node in the network selects a set of nodes in its symmetric neighborhood which may retransmit its messages. Each node selects its MPR set among its one hop symmetric neighbors. This set is selected such that it covers (in terms of radio range) all nodes that are two hops away.

The nodes selected as a MPR by some of the neighbor nodes, announce periodically in their control messages their condition of MPR to their neighborhood. Thereby, a node announces to the network, that it has reachability to the nodes, which have selected it as MPR. In route calculation, the MPRs are used to form the route from a given node to any destination in the network. The protocol uses the MPRs to facilitate the efficient flooding of control messages in the network. A node selects its MPR among its one-hop neighbors with symmetric link. Therefore, selecting the route through MPRs automatically avoids the problems associated with data packet transfer over unidirectional links. Each node maintains information about the neighbors that have selected it as MPR. A node obtains such information from periodic control messages received from the neighbors.

OLSR protocol is proactive or table driven in nature, hence it favors the networking context where this all-time-kept information is used more and more, and where route requests for new destination frequently. The protocol also goes in favor of the applications which do not allow long delay in transmitting data packets. OLSR protocol is adapted to the network which is dense, and where the communication is assumed to occur frequently between a large number of nodes.

A.Simulation

We conduct simulation experiments using the network simulator ns2 [8]. In our experiments, the maximum speed is varied from 0m/s to 100m/s. There are two source-destination pairs which are selected among all nodes in the network (figure 1).

H1 node communicates with **H4** and **H3** node communicates with **H5** node. Traffic source is FTP. For each FTP session, packet size is 1460 bytes. The transmission range is 250m and channel rate is 2 Mbps. We place 4 static MPs nodes at 250 meters interval to form a connected partial mesh, and 6 mobile hosts moves in the grid area as show in Fig.1.

*** Wireless Mesh Network**

To simulate routing protocols for wireless mesh networks, only MPs are allowed to exchange routing update messages with each other, and a host information is embedded in the routing message sent from its associated AP. The aggregate delivered throughput results in Fig.2 and Fig.3 confirm again the resilience of OLSR to increasing load. In fact, they show that OLSR clearly outperforms AODV when traffic load (number of traffic pairs) is large. When traffic load further increases, AODV generates much more routing overhead for finding routes and repairing link breakages. In contrast, the throughput consistently increases over OLSR. All the simulation results consistently proved that when compared with AODV, OLSR exhibits a much better scalability of traffic loads.

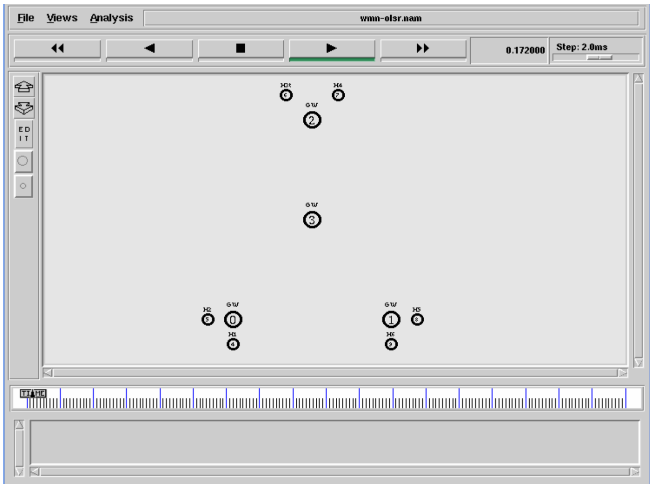

Fig.1 Simulation Topology

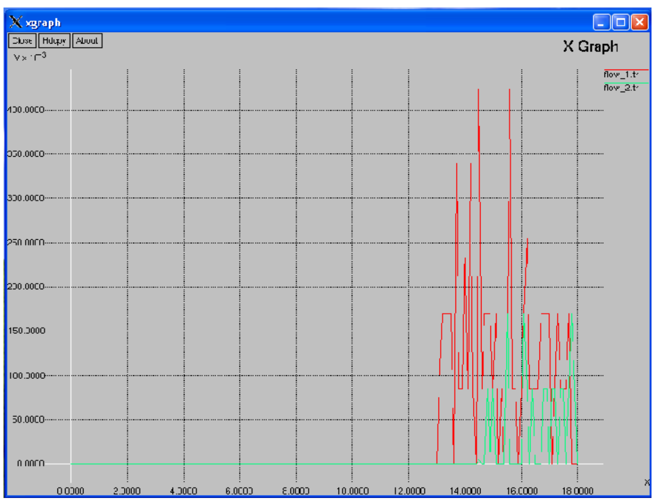

Fig.2 Aggregate FTP Throughput vs. Host Mobility over AODV

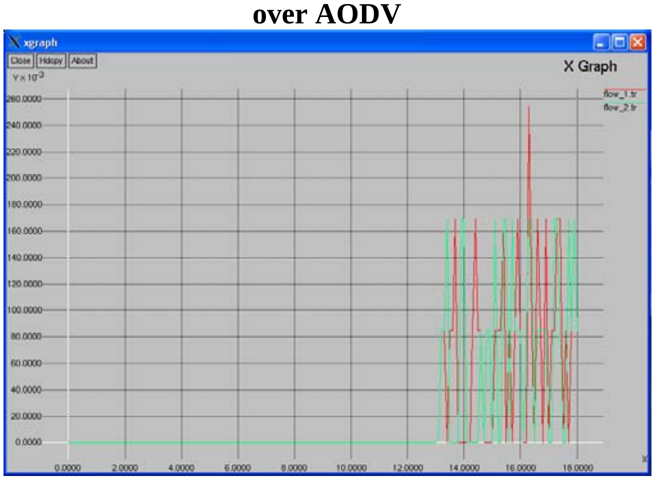

Fig.3 Aggregate FTP Throughput vs. Host Mobility over OLSR

2. 3-layer mobility management scheme

In this paper, we focus on the mobility management within one WMN. Proposed model is a 3-level one including 1 gateway that connects to the Internet, some superior routers which connect to that gateway, all the rest APs are in peer-to-peer status.

The three APs connecting have superior status than their downstream nodes. They are required to collect the location information of the mobile clients in the cells of the subordinate APs. We named these APs “superior router (SR)”. SRs act as the delegates of the gateway and share the signaling traffic. In small-scale network, if bottom neck doesn't happen at the gateway, we can converse the above structure into 2-level structure.

The gateway is required to assign a unique IP address in its domain to a mobile client when it is powered up. This unique IP address of a mobile client can be the CoA when mobile IP is provided for the inter-domain roaming. The foreign agent (FA) and home agent can be resided in the gateway.

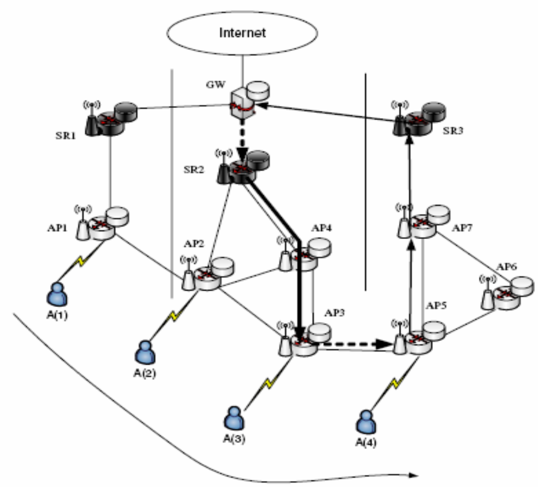

Fig.4 3-layer mobility management scheme

A WMN can be constructed in a tree-like structure. Each router has its only parent node and may have some children nodes. Tree-like structure shows its limitation in routing process. So, this new structure will allow the routing process between APs which are not in the same branch to get the optimal result.

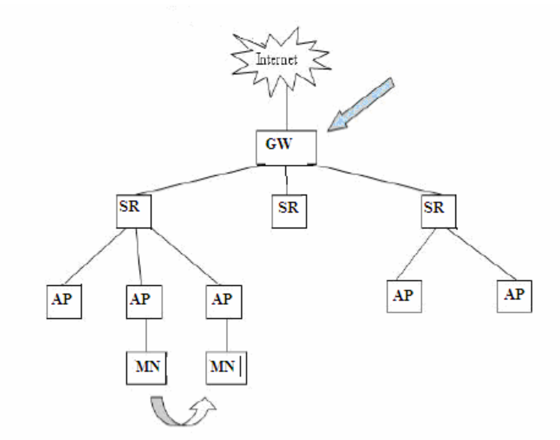

Fig.5 A tree-like structure

We assume that the routing in the backbone (APs, SRs and the gateway) has been set up. Since the backbone nodes in WMNs are mostly stationary, this assumption is reasonable. The remaining problem is on ensuring a mobile client to move around in this area without incurring high packet loss, long latency and high signaling cost to the system.

In this paper we suggest a new solution for this problem. Before talking about our solution, it is interesting to briefly introduce the NDP protocol.

Neighbor Discovery Protocol

Neighbor Discovery Protocol for IPv6 determines the relations between the neighbors. It replaces the Address Resolution Protocol (ARP) used with IPv4. Clients use this protocol to find neighbor routers, to discover addresses and configuration parameters. Generally, nodes use it to detect changed Ethernet addresses and to maintain a track of reachabe neighbors.

They are five different Neighbor Discovery packet types, and all are ICMP packets:

_ Router Solicitation: This packet type is rarely used; it permits hosts to force routers to generate Router Advertisements,

_ Router Advertisement: Generated periodically, this kind of packets is sent by the routers to advertise their presence with various link and Internet parameters.

_ Neighbor Solicitation: This packet is very important and often used, it is sent by a node to determine the Ethernet address of a neighbor and to check if a neighbor is still reachable.

_ Neighbor Advertisement: As its name indicates, it is a response to a Neighbor Solicitation message. This packet type is interesting because it can be sent without solicitation, what we call (Unsolicited Neighbor Advertisement) in order to announce an Ethernet address change.

_ Redirect: It is used for the routing, which do not concern our approach. In addition to maintain all information about theirs neighbors and theirs communications, four different cache types are used:

_ Neighbor cache: Associates IPv6 addresses to the corresponding neighbor's MAC address.

_ Destination cache: Associates the destination IPv6 address to the corresponding address of the next-hop neighbor.

_ Prefix List: Contains the list of on-link prefixes obtained by Router Advertisement messages.

_ Default Router List: Contains the IPv6 addresses of routers, which have recently sent Router Advertisement messages.

Here we talk about our solution:

_ For each client, the subscriber information includes authentication, authorization, accounting (AAA) information and QoS profiles. If every AP in a domain maintains a copy of all the mobile clients' subscriber information from the gateway, we will meet some difficulties in network management and expansion. For this reason, in our scheme, when a mobile client is powered up, the authentication procedure should be fulfilled before an IP address is allocated to this client according to the subscriber information in the gateway.

_ If the authentication is successful, the gateway then activates the record of this mobile client and records the location information hereafter. The APs also keeps a copy of the subscriber information to avoid frequent visiting the database in the gateway. The database of each AP only contains information about the current clients which are being active in their domain. The database of each superior additionally contains location information of all the mobile clients residing in the subordinate APs' cells. All these AP are administered by the SR.

_ We assume that routing in the backbone (AP, SR and gateway) is established. We also consider that all backbone nodes in WMN are almost fixed.

_ Each AP will administer mobile clients by using an IP Prefix which is already assigned to that AP. When mobile client moves to a new domain of another AP, new AP will check the client's IP address to know which AP administers that client. Then, the new AP will contact with the old one to forward all the information about that client to the new AP.

_ To reduce packet loss, the old AP will create a temporary entry whose destination IP is client's. Hence, when the routing packets move to the old AP whose destination IP is client's, the old AP will forward all data to the new AP.

_ By using different IP Prefix, all the APs will identify clients quickly and minimize the handoff latency.

_ The clients have to send the update messages about their current location to the other mobile client which is communicating with them. The APs have to update their database and gateway's database.

_ Handling Downstream Packets: The downstream packets, in which the destination address is not the AP's address, cannot be routed by the intermediate superior router and APs without routing entries. In this scheme, tunneling technique is used to forward the downstream packets. These packets are attached with extra IP headers in which the destination address is the destination AP's address. Upon receiving these tunneled packets, the destination APs decapsulate and forward them to the addressed mobile clients in the cells. In Fig. 1, the bold lines illustrate the downstream process, with the dashed lines and solid lines indicating the routing part and the tunneling part, respectively. From the gateway (GW) to the SRs, the packets are routed according to the location information.

_ Handling Upstream Packets: For the upstream packets, the tunneling is not needed. The APs can use the default routes to forward packets to the gateway.

When a mobile client moves to a new domain, we should know how it gets the CoA for the AP to administer that client. The detailed solution is given below:

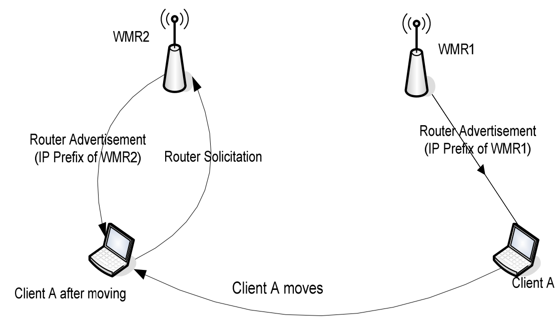

Fig.6 How to get CoA when the mobile client move to a new domain

1. When client A connects to WMR1 for the first time, it may send out a Router Solicitation that requests WMR1 to generate Router Advertisement immediately rather than at their next scheduled time.
2. WMR1 advertises its presence together with various link and Internet parameters either periodically, or in response to a Router Solicitation message. Router Advertisement contains prefix that are used for on-link determination and/or address configuration, a suggested hop limit value, etc. Suppose that the client is on the home network, it will combine IP Prefix of WMR1 with its MAC address to get a Home Address (HoA).
3. When the client moves from WMR1 to WMR2, it will receive a Router Advertisement which is generated periodically. If no RA is generated, the client will then send out a RS to request WMR2 to send RA. When the client receives RA, it will check the IP Prefix immediately to find out whether it is on the home network or foreign network. If it is on the foreign network, it will register a CoA with WMR2. There are 2 ways to get a CoA: stateless (it combines IP Prefix of

AP with its MAC address to make a new address) or stateful (use DHCPv6 to get a dynamic address).

The detection of client can be done in two ways: either the old WMR detects its client movement (self-detection) or the new WMR detects a new client and notifies it to the old WMR. In this subsection, we present the main idea of our proposal, where the detection is done by the new WMR. We assume that each WMR add an IPv6 address called CommonIPv6 to its client interface. This address is equal in all network WMRs, which means all WMRs in the network have this IP address on its client interface.

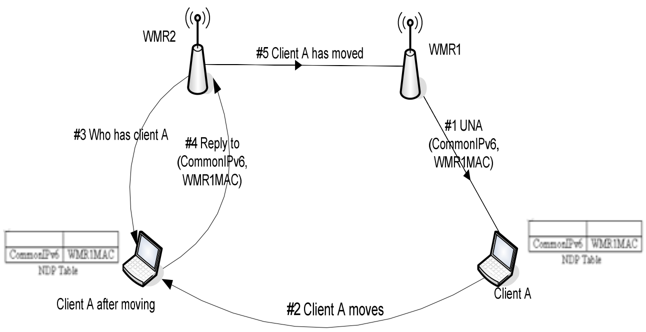

Fig.7 Solution Process

Let's consider the scenario of Fig. 4 and show how client movement is detected. We assumed that the Client A connects for the first time to the network through WMR1. We present our solution in the following steps:

1. When the Client A connects for the first time to WMR1, it receives from WMR1 an UNA message "associate the Common address to WMR1 MAC address in your cache". Therefore, the Client A updates its neighbor cache.
2. The Client A keeps in its Neighbor cache the Common address and WMR1 MAC address association during its displacement.
3. When the Client A moves from WMR1 to WMR2, it sends an authentication frame to WMR2 containing its identity. If the later responds with an authentication frame indicating acceptance, the client A sends an association request frame to WMR2 which reserves memory space and establishes an association. After the layer 2 connection, WMR2 sends a neighbor solicitation packet to the Client A with IPv6 address source equal to the Common address and MAC address source equal to WMR2 MAC address "Who has the Client A?".
4. The neighbor solicitation packet sent by WMR2 is not used to obtain the MAC address of the Client A but to know where the Client A was connected. When the Client A receives this solicitation, it checks its Neighbor cache and finds the Common address associated to WMR1 MAC address. Thus, it replies, using WMR1 MAC address.
5. Receiving the reply, WMR2 extracts WMR1 MAC address and derives the IP address of WMR1. It sends a Unicast packet to WMR1 in order to notify the Client A displacement. In the same time, WMR2 sends an UNA message to the Client A "associate the Common address to WMR2 MAC address in your cache", in order to update the Client A cache.

III. <u>Conlusion:</u>

3-layer mobility management scheme is proposed to meet the requirement of lower signaling cost and shorter handoff latency. Moreover, by using different IP Prefix, all the APs will identify clients quickly and minimize the handoff latency. Consequently, this scheme mitigates the shortcomings and achieves the advantages of both.

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