3.3 Mobility

Mobility in IP networks technically is the act of a node changing its topological point of attachment. Koodli and Perkins distinguish the following two kinds of mobility

- **Roaming:** A process in which a mobile node moves from one network to another, typically with no existing packet streams.
- **Handover:** A process in which a mobile node disconnects from its existing point of attachment and attaches itself to a new point of attachment. Handover may include operations at specific link layers as well as at the IP layer in order for the mobile node to be able to communicate again. One or more application packet streams typically accompany the mobile node as it undergoes handover

Mobility can alternatively be described with the terms micro-mobility and macro-mobility. Micro-mobility refers to mobility that occurs within a network domain. In 6LoWPAN we can consider micro-mobility to refer to the mobility of a node within a LoWPAN where the IPv6 prefix does not change, which is the definition used here. Macro-mobility on the other hand refers to mobility between networks. In 6LoWPAN we consider macro-mobility to refer to mobility between LoWPANs, in which the IPv6 prefix changes. In relation to the previously defined terms, we can consider micro-mobility to require only handover, whereas macro-mobility is a process of roaming and handover

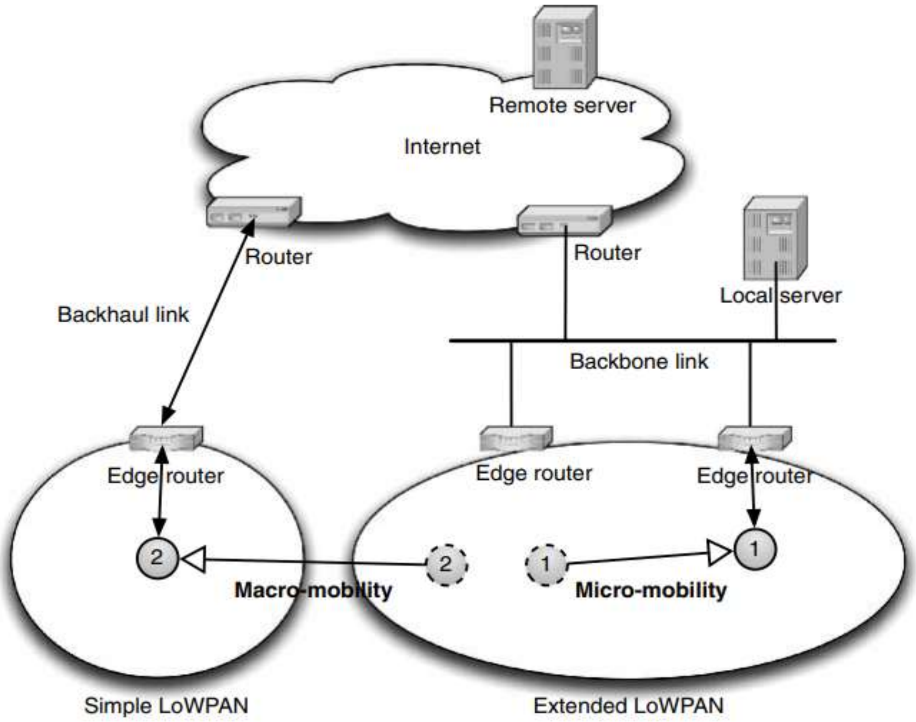

Figure 3.3.1 The difference between micro-mobility and macro-mobility.

Before looking at solutions for dealing with mobility, it helps to understand why mobility happens in the first place. In wireless networks there are a number of things that may cause a network to make a change in topology. The causes of topology change can be categorized simply as physical movement, radio channel changes, network performance, sleep schedules and node failure:

- **Physical movement**: The most evident reason for mobility is when nodes in a network physically move in relation to each other, which changes the wireless connectivity between pairs of nodes. This may cause nodes to change their point of attachment.
- **Radio channel:** Changes in the environment cause changes in radio propagation, called fading. These changes often require topology change even without physical movement, especially with simple radio technologies.
- **Network performance:** Packet loss and delay on wireless networks may be caused by poor signal strength, collisions, overloaded channel capacity or node congestion. High packet loss may cause a node to change its point of attachment.
- **Sleep schedules:** Especially battery powered nodes in wireless embedded networks use aggressive sleep schedules in order to save battery power. If a node finds itself attached to a sleeping router without a suitable duty cycle for the application, this may cause the node to move to a better point of attachment.
- **Node failure:** Autonomous wireless nodes tend to be prone to failure, for example due to battery depletion. The failure of a router causes a topology change for nodes using it as their default router.

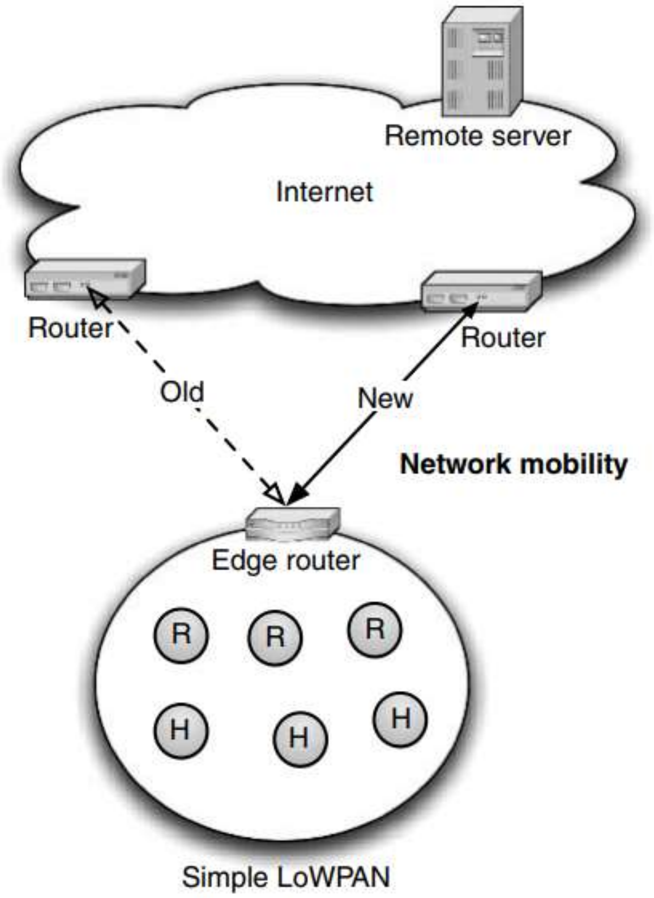

Fig 3.3.2 Network mobility example.

An example of network mobility is shown in Figure 3.3.2 When considering 6LoWPAN, network mobility occurs when an edge router changes its point of attachment while nodes in the LoWPAN remain attached to it. The kind of network mobility that affects 6LoWPAN is clearly macro-mobility, when the IPv6 address of the edge router changes, as this affects the addressing of all nodes in the LoWPAN.

Mobile IPv6

The mobility of nodes on the Internet can be dealt with at the network layer using a protocol called Mobile IP (MIP). The goal of MIP is to deal with the mobility roaming problem by allowing a host to be contacted using a well-known IP address, regardless of its location on the Internet. Mobile IP does this using the concept of a home address, which is associated with a host's home network. When a host is away from its home network, and attaches to another network domain (called the visited network), the new IP address it configured there is called its care-of address. A node communicating with a mobile node roaming in a visited network is called the correspondent node. Normally forwarding in IP networks is handled only by routers, whose route tables are maintained by routing protocols. Mobile IP works using a special kind of routing functionality, which is host controlled. This concept is called a binding, and is implemented.

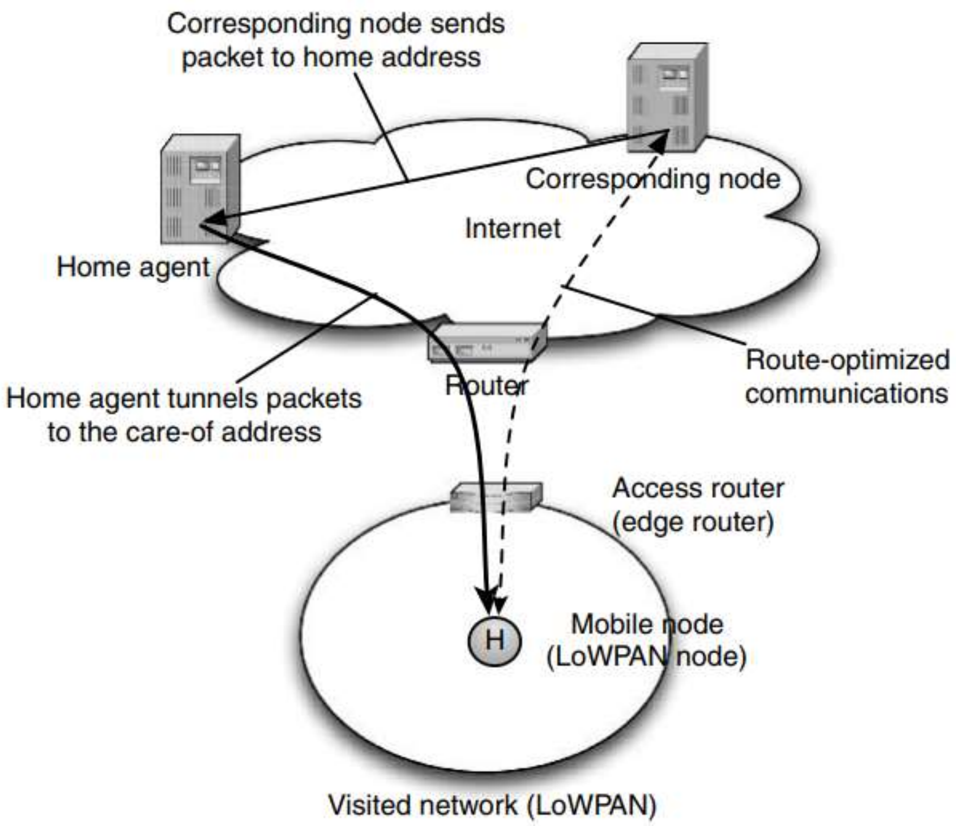

Figure 3.3.3 Example of Mobile IPv6 used with 6LoWPAN.

Figure 3.3.3 illustrates basic MIPv6 functionality. When a mobile node roams to a visited network, it uses MIPv6 in the following way to maintain global connectivity via its home address:

- After detecting that the subnet has changed, and that the node is no longer in its home network, it sends a MIPv6 binding update message to its HA. If the node doesn't know the location of its HA or its home prefix, there are methods to discover both. The binding update is acknowledged by the HA with a binding acknowledgment. These messages must be secured using e.g. IPsec methods.
- A bidirectional IPv6-in-IPv6 tunnel is then set up between the HA and mobile node for exchanging data packets. When an incoming packet arrives from a corresponding node to the home address of a mobile node at its home network, it is intercepted by the HA using an ND proxy technique. The packet is then encapsulated in another IPv6 header with the destination address set to the mobile node's care-of address.
- After receiving and decapsulating the packet, the mobile node can then respond through the IPv6-in-IPv6 tunnel through its HA back to the corresponding node. Alternatively, the mobile node can respond directly to the corresponding node using its care-of address.
- This is a case of triangular routing, where a more optimal path directly between the mobile node and corresponding node is possible. MIPv6 includes route optimization to avoid triangular routing. After executing a reverse routability test and possible security association between the correspondent node and mobile node, they can begin to communicate directly. First a binding update is sent to the corresponding node. Then data traffic is exchanged using IPv6 extension headers to properly indicate the actual home address of the mobile node.

In order for MIPv6 to be applied to 6LoWPAN Node mobility, it would have to be implemented on LoWPAN Nodes. The use of MIPv6 as defined in with 6LoWPAN has the following problems:

- IPv6-in-IPv6 tunneling between the HA and LoWPAN Node would incur large header overheads as the encapsulated IPv6 and transport headers cannot be compressed by the existing compression methods.
- The requirement of IPsec security associations between MIPv6 entities may be unreasonable for LoWPAN Nodes.
- The added complexity of implementing MIPv6 in terms of code size and RAM may be unjustifiable for LoWPAN Nodes.
- In domains with large LoWPANs and frequently mobile nodes, the traffic burden caused by MIPv6 may be too much for low-bandwidth wireless links.
- Route optimization adds an even greater burden on nodes, as state must be maintained for every active correspondent node.

Proxy Home Agent

A proxy Home Agent (PHA) is an entity which performs MIPv6 functions on behalf of a local mobile node, interacts with the actual Home Agent of the node, and handles route optimization on its behalf. This greatly simplifies the functions that a mobile node needs to perform to participate in MIPv6. In 6LoWPAN this is an especially critical optimization as seen from the previous section. A global architecture for PHA is described in [ID-global-haha], where PHA functionality is described.

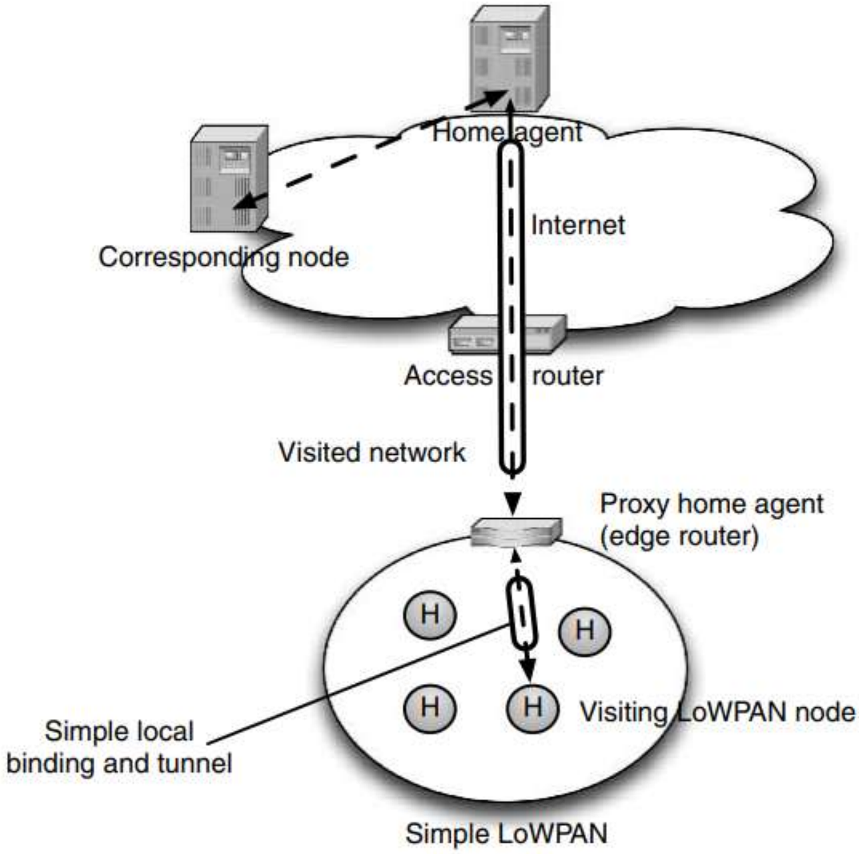

Fig 3.3.4 Example of a proxy Home Agent located on an edge router.

The PHA is located in the visited network where a mobile node is roaming, in 6LoWPAN this would logically be the LoWPAN Edge Router. A PHA acts like a normal MIPv6 host, but additionally performs binding updates, HA tunneling and route optimization on behalf of other nodes. In order for a mobile node to use a PHA, it simply needs to perform a local binding update with (possibly much simpler) credentials, and to create a single tunnel to the PHA. The PHA architecture is show in Figure 3.3.4. This provides huge improvements in efficiency with regards to security associations and for route optimization which requires tunnels and other state for every correspondent node. In order to use the PHA concept with 6LoWPAN, a mechanism for registering with the PHA would need to be defined for use inside the LoWPAN. The logical place to do this would be as an option for the 6LoWPAN-ND Node Registration message. Such an option would need to include the Home Agent's address or home prefix, the node's home address and some credentials (if L2 credentials are not sufficient). As the tunnel is local between the LoWPAN Edge Router and the LoWPAN Node, it could be realized as a simple IPv6 extension header option with very low overhead.

Proxy MIPv6

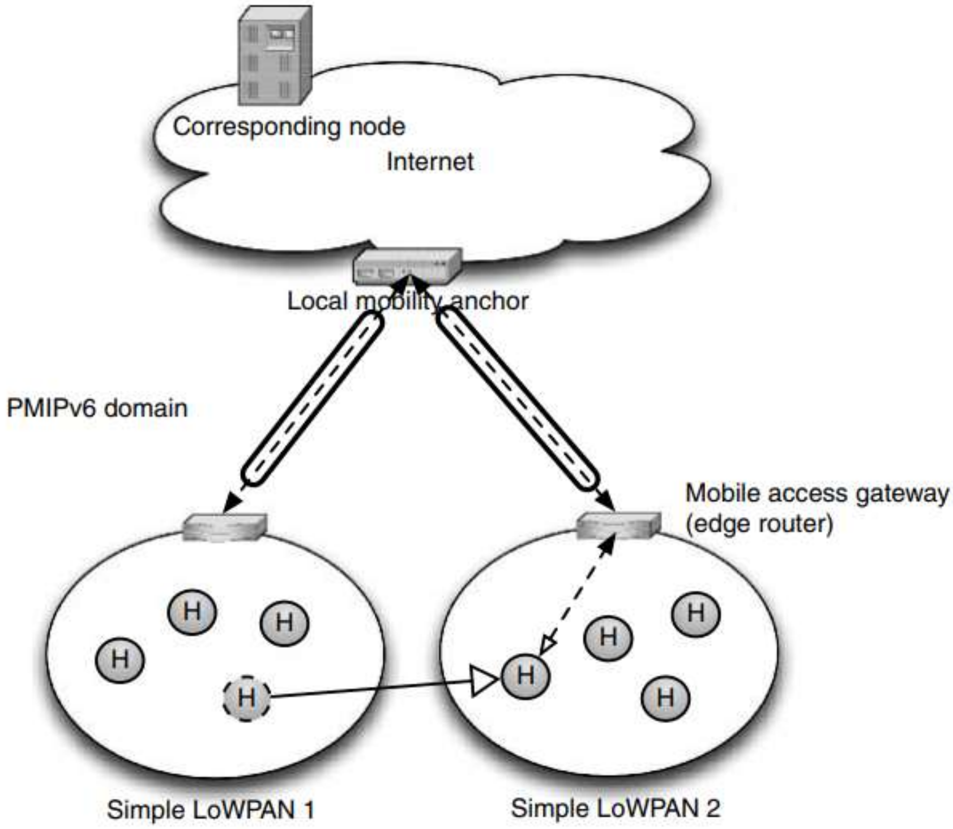

Fig 3.3.5 Example of PMIPv6 with 6LoWPAN.

The architecture of PMIPv6 is illustrated in Figure 3.3.4. The concept of a PMIPv6 domain is introduced, which is controlled by a local mobility anchor (LMA). The LMA function is usually combined with HA functionality. The LMA handles the local mobility of nodes with the help of mobile access gateways (MAGs), which are points of attachment supporting PMIPv6. MAGs send proxy binding updates to the LMA on behalf of mobile nodes attached to them. Using bidirectional tunnels built between each MAG and the LMA, the LMA is then able to forward traffic to the mobile node always using its static address (known as a mobile node home address). A binding in the LMA is made between this address and the temporary address from the visited MAG (the proxy care-of address). PMIPv6 makes use of RS/RA exchanges directly between the mobile node and MAG in order to detect when the mobile node has changed its point of attachment.

Although the PMIPv6 model would seem to fit well with 6LoWPAN, there are some problems that would still need to be solved:

- The RS/RA exchange defined in is not compatible with a multihop Route-Over LoWPAN, and would require each LoWPAN Router to act as a MAG.
- PMIPv6 is meant to provide a separate 64-bit prefix for each mobile node.
- PMIPv6 only enables a node to talk with its point of attachment (default router), and requires NS/NA exchanges which are not required by LoWPAN Nodes otherwise using 6LoWPAN-ND.

NEMO

Network mobility (NEMO) is a solution for dealing with network mobility problems, when a router and the nodes attached to it, move their point of attachment all together. The philosophy behind NEMO is to extend Mobile IP so that each node does not need to run Mobile IP, instead only the router they are attached to runs Mobile IP. This philosophy fits the 6LoWPAN model perfectly as LoWPAN Nodes are not capable of dealing with MIPv6. Edge routers or other router entities run full IPv6 stacks, and have the capability of dealing with MIPv6.

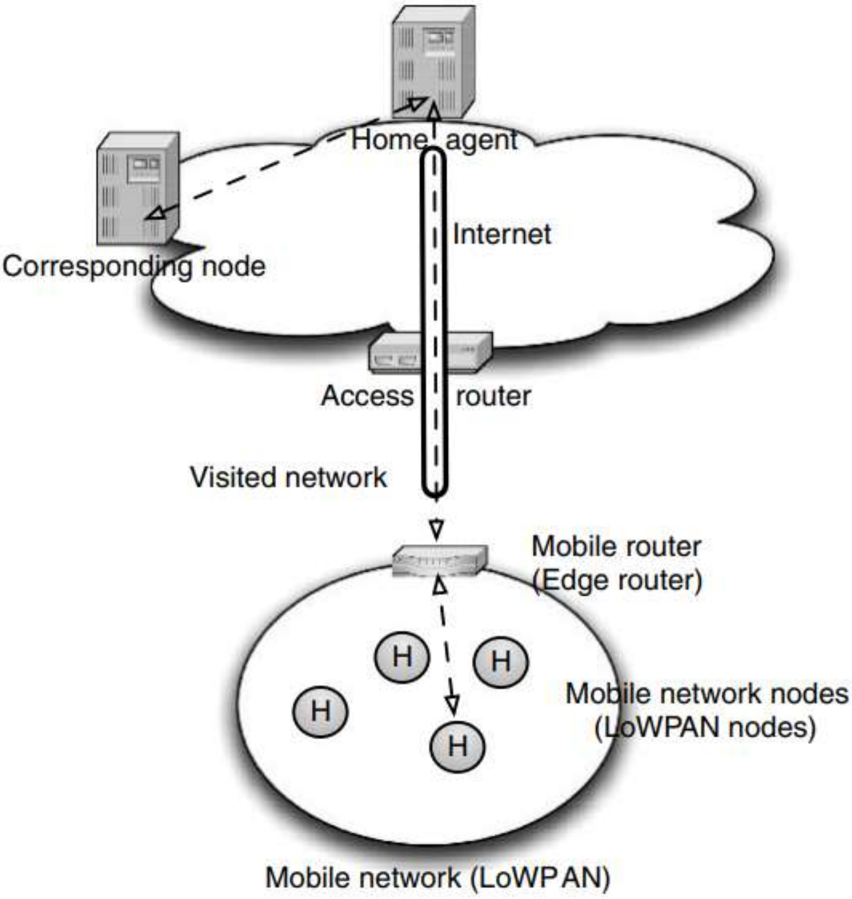

Figure 3.3.6 Example of the basic NEMO protocol working with 6LoWPAN.

The NEMO protocol works by introducing a new logical entity called the mobile router, which is responsible for handling MIPv6 functions for the entire mobile network. Mobile nodes which are part of the mobile network are called mobile network nodes (MNNs). These entities can be seen from Figure 4.7. MIPv6 normally only handles forwarding for the home addresses bound by mobile nodes. NEMO extends the functionality of the Home Agent to be able to deal with prefixes in addition to home addresses of mobile nodes. A mobile router functions like a normal MIPv6 host setting up a bidirectional tunnel with its Home Agent, but in addition it negotiates prefixes to be forwarded to it by the Home Agent. The Home Agent then forwards all packets matching the bound prefix (therefore packets for the MNNs) to the mobile router. A special flag in the binding update allows the mobile router to indicate it wants prefix forwarding, and a prefix option lets it configure prefixes with the HA. Alternatively, prefix delegation can be done using e.g. DHCPv6

NEMO is clearly beneficial when applied to mobile LoWPANs, where the entire LoWPAN including the edge router and associated nodes move together to a new point of attachment. When this happens the edge router acts as a NEMO mobile router. Using MIPv6, it binds its new care-of address in the visited network, and in addition the home LoWPAN prefix. Thus inside the LoWPAN no change can be noticed due to network mobility, as the LoWPAN continues to use the same prefix as in its home network. The HA takes care of forwarding all traffic destined for the LoWPAN prefix through the tunnel to the edge router and vice versa.

The drawback of NEMO is that it can not deal with individual node mobility on behalf of the LoWPAN Nodes. Thus a mobile LoWPAN Node would still have to implement MIPv6, unless it would use a proxy Home Agent or be moving within a PMIPv6 domain as discussed in the previous sections. Furthermore, NEMO starts to become complicated when mixing different kinds of node mobility along with PMIPv6.