P2P-based Mobility Management for Heterogeneous Wireless Networks and Mesh Networks[1]

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Abstract. The recent emergence of a whole plethora of new wireless technologies, such as IEEE802.15, IEEE802.11, and UMTS, etc, has exposed the limitations of mobility solutions in the next generation Internet. Current mobility management systems are operator specific, centralized, and focused on single link technology. A rethink of how to exploit context awareness, lead by the emergence of sensor networks and pervasive computing, is explored. This paper suggests a roaming technique taking pervasiveness and self-awareness into consideration, by first, moving the intelligence to the mobile terminals. The mobile devices should look themselves for the most suitable wireless network. We also propose to organize the wireless mesh networks in a context-aware peer-to-peer network.

Keywords: Mobility management, heterogeneous wireless networks, context-awareness, peer-to-peer.

1 Introduction

Wireless Networks took the world by storm during the last two decades thanks to their universal coverage and the possibilities of roaming they offer. The success of GSM technology led the way to introducing UMTS standard, which promises more bandwidth for Internet applications. This evolution will continue towards the vision of *wireless mesh networks* (WMN) [1], where wireless networks could be categorized according to their coverage into: large area networks (e.g. Satellite), cellular macro-technologies (e.g. GSM, UMTS), and small area broadband (e.g. WLAN, WiMax). A variety of wireless mesh routers, running independently, are assumed to coexist in a dense urban environment. They connect mesh-clients, i.e. mobile nodes supporting those wireless technologies, to a backbone network. Already mobile devices are able to connect through several of these technologies; either simultaneously (using multi-

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homing), by selecting an alternative wireless radio or possibly dynamically following the promises of cognitive radios[15], or agile radios[16], and software radios [18].

Separately to how the mobile terminal is capable to support this heterogeneity, the assumption is that the mesh-client should be allowed to connect to the most suitable wireless mesh infrastructure. This choice of connectivity has brought up the term an Always-Best-Connected network [12], which is our ultimate goal in this study.

In this paper this problem is approached from the following viewpoints: The wireless infrastructure so far has been laid out by operators attempting to reach their customers through investing into well-organized and hierarchically structured cellular networks. The idea of random mesh networks might sound, at first glance, far-off and unmotivated economically. Nevertheless, similar trends are already happening with home users adopting WiFi in large scale. The end result is the emergence of hot-spots around our urban surroundings, which individuals are willing to pay for. In a way, operators reach their users through a new generation of wireless access islands that would well be used to allow a value return investment to home users. This would be possible if users were willing to offer parts of their wireless resources in a controlled manner to the outside world in return of a reduced rate for their subscriptions. Similar sharing examples could be found in other domains such as power grids, where individuals can feed their excess solar electric energy back into the power Grid. This idea of sharing would be an alternative to such uncontrolled pirating phenomena, namely war-driving [21]. Another point is the organization of WMN infrastructure, which cannot be envisaged through the existing 3G mobile systems location management[2] techniques [23]. The latter relies on pre-defined cell IDs stored in a database system. A mobile node only needs to report its current cell ID, for incoming calls to be directed to it. Some predictive measures could be also taken knowing the topology and direction of the movement of a mobile node [33]. A home location registry (HLR) can also store the location updates (LUs), sent from a communicating terminal, or use paging to indicate to dormant devices their current cell IDs [5].

In the mesh environment infrastructure has to be organized beyond a single technology or a single operator; it has to be light-weight compared to using the 2G/3G roaming agreements between network operators. It also has to cater for small providers offering much smaller networks of different technologies.

Using peer-to-peer (P2P) for location-aware queries has recently attracted increasing interest. Scholl et al. [26] suggest a P2P framework that locates geographically close peers and requests location-based information, such as local bookshops, etc. Their search takes into account the spacio-temporal movement and velocity of the mobile peer to indicate the validity of a response. Another promising approach using P2P for location management is named Palma (a P2P Architecture for Location Management) [27]. Palma concentrates on managing the mobile's current location or point of attachment similarly to virtual location registry (VLR) or HLR in GSM. The architecture uses the properties of Tapestry distributed hash tables protocol (DHT) to organize location servers (LS), which store the terminal's ID. Palma allows correspondent nodes (CNs) to efficiently retrieve the mobile node's current LS of attachment. It does not, however, aim at terminal mobility neither does it offer any handover man-

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[2] Location management consists of procedures that allow the network to identify the point of attachment of a mobile node.

agement mechanism. It also does not support existing communication between a CN and a MN.

In this paper, a P2P distributed and decentralized architecture is shown to organize wireless mesh networks in a location-based service[3] [25]. It is used to allow mobile terminals to stay always best connected, beyond a single technology or operator. This paper is a step forward towards our ultimate target of a full context-aware service [6]. In fact, the framework proposed here can easily be extended to integrate other contextual information along side the location of a mobile agent.

Our paper differs from [26] in that we do not need to consider spacio-temporal validity of queries neither do we care of the geographic closeness of a given peer. Our main aim consists in organizing the objects stored by the peers in a geographic-aware manner rather than trying to locate the peers themselves. Compared to Palma [27], our paper utilizes location-awareness to minimize interruption times of existing communication, reaching real-time demands. The work presented in this paper does not aim at redeveloping micro-mobility solutions at the link or network layer, like this is the case with hierarchical mobile IP, HAWAII, etc [2].

The proposed P2P architecture is described in Section 2. The design decisions are motivated, in that section too, while defining the object space. The architecture, designed in Section 2, makes use of DHTs. The choice and modifications to two candidate protocols are explained. Also the way they deal with the system requirements such as, mobility of peers, load-balancing, and flexible/rich querying, is discussed under the same section. The proposed architecture could be used depending on the location awareness capabilities at the end-device. It is assumed, in Section 3, that the end-device knows its movement pattern via an integrated navigation system (similar to [10]). The terminal should be able to detect its capabilities and location, and to query the P2P architecture. It also triggers its own handover process at both link and network layers, based on its location-awareness. A simulation comparison for the terminal handover is made in Section 4 between the location-aware triggers and the “blind” discovery mechanisms traditionally used in an IEEE 802.11b and IPv6 environment. Section 5 concludes the paper.

2 P2P Management of Location-Based Topology Organization

In this section, two different P2P protocols are presented, namely Chord [28] and CAN [22], to meet some design decisions. The aspects of organization, mobility, load-balancing, and querying are discussed. P2P technology has evolved, since the days of Napster as a file sharing technique between equal entities named peers, to become one of the fastest growing Internet technologies. The key aspect of interest in P2P is the decentralized location of objects queried through different types of P2P protocols. The latter protocols have evolved from an early server-based indexing of all existing file entries and their location, to the extremes of the chaotic Gnutella, and reaching the organized distributed hash tables (DHTs). Here, we concentrate on the potentials of DHTs, only, as a variation of the more general term of P2P paradigm.

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[3] Schiller defines Location-based services (LBS) as the recent concept that integrates the geographic location, i.e. special coordinates, with the general notion of a service [25]

The main advantage of using DHTs in P2P applications was to provide a scalable system capable of storing large numbers of items while minimizing the routing cost and offering a load-balanced indexing of entries among peers. Chord [28], for instance, requires each peer node to store routing information for *O(logN)* other peers, where *N* is the total number of participating peers. Similarly, it takes a maximum *O(logN)* routing messages to find any content in a Chord ring. Content addressable networks (CAN) [22], on the other hand, uses d-dimensional virtual address space for locating data. Each peer owns a given zone of the virtual space, and needs to store routing information to about *O(d)* other peers. The routing cost however is on average $O(dN^{1/N})$, which then depends on N, the number of peers in the system.
The main argument for using DHTs is that they provide a highly scalable, but self-organized distributed system. This section first motivates the use of DHTs and explains the exact design decisions taken to select the DHT protocol. An implementation with Chord is thoroughly explained, while listing the different design decisions that enable location based queries in Chord. For richer range type of queries an implementation of the proposed architecture is given with CAN. The two techniques rely, however, on similar roles for the participating nodes in the P2P system.

2.1 A Wireless Resource as a Shared Object in a DHT

In comparison with a P2P file-sharing application, the content shared in this DHT system are objects representing wireless resources accessible in a transparent way, and assigned a unique ID. The objects are described on two levels. First, an object description gathers a list of diverse attributes of a given wireless infrastructure. In Figure 1, a single "wireless resource" is identified as being geographically collocated access points (WLAN) or node Bs (UMTS) belonging to the same operator, while in the same IP-subnet. In other words, the mesh-routers in this case could be said to be the IP-gateways or GGSN nodes used to identify a single IP sub-domain.
To search for a given wireless resource, it is sufficient to look up access points that the mobile terminal is allowed to access in its vicinity. The attribute, out of this list of properties of the "wireless resource", used to address each single instance or object in the P2P object space is the location attribute. Global positioning system (GPS) coordinates are used to create a multi-dimensional space of keys representing a single object. Based on their latitude and longitude coordinates, the objects are distributed in a geographic manner among the peers.
In a file-sharing P2P application, a hash function such as SHA-1 is applied to the string representing the name of given file (e.g. SHA-1 [Mobi-play-track1] = key). The DHT protocol first indicates which peer should store the tuple (key,value) (where the value is the file itself) and the way to get to it. The application uses a get(key), at the DHT interface, to search for the file/resource.
In Figure 1, the peers are some entities connected through existing network topology in the form of an overlay formed of fixed AccessPeers and some mobile SearchPeers. The objects stored and shared on this overlay of peers can vary from a single AP to possibly a larger wireless domain as a single instance. An example would be to list network type roughly as either: a broadband micro-cell, a wide-area cell as in UMTS, or a macro-cell as in satellite (Figure 1 shows the two latter categories) [1]. Then for

each cell an XML description template is filled up with as many attributes as possible (e.g. location, radio frequency/modulation scheme, network control information, router advertisement (look at Section 4), access restrictions, etc.). In our architecture we suggest to use geographic proximity combined to whether the access points/base-stations belong to the same IP-domain as way to aggregate a group of APs represented as a single object in our DHT object-space. The hash function in this case needs to represent the GPS latitude and longitude values of a single wireless resource as a unique ID that is storable and retrievable via an overlay. The DHT interface is then used to access those XML files describing the access network on demand. It is up to the query generating node to define priorities on the preferred technology to reduce the level of response. The found resources could also be aggregated per peer in a single response message to reduce the amount of generated messages. This kind of querying demands more than just a "get" function normally used by a file sharing application. Complex queries could include "if…then" requests. In addition, the load balancing also plays an important role in choosing the right DHT implementation. We need a system that takes into account the immensely different capabilities of the peers. A peer could be hosted on a user machine in a home network, while others could be larger servers used by cellular network operators. These server machines should store considerably more information.

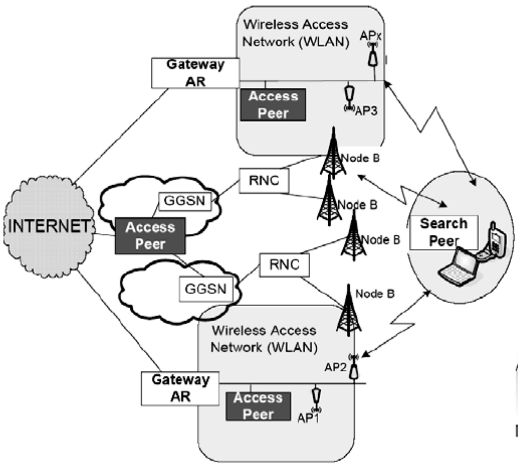

Figure 1. WMN Topology Organization Using a Peer-to-Peer System (e.g. UMTS-IEEE802.11)

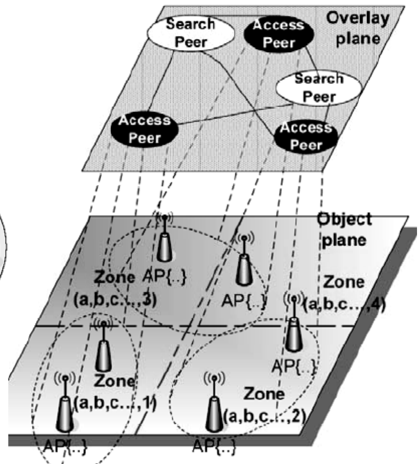

Figure 2. Roaming on Overlays: Zone Separation for a Chord-based Organization of the WMN

Furthermore, the mobility of the peer entity has to be taken into account. The mobile peer should not be burdened with managing shared resources in order to reduce the costly communication overhead. The mobility entities in a mobile peer use the DHT search to locate wireless resources. A clear separation is made between this role and that of what the processing of the obtained information.

2.2 Modifying Chord to Implement Location Aware Architecture

In this section we deal with the organization of the wireless mesh networks. For this purpose, we propose the following distinction in the roles taken by the different peers according to the Chord protocol [28]:

SearchPeer: is a member of the Chord ring as a leach node. It represents a moving node that both identifies the context of the mobile node and is meant to search and retrieve "nearby" wireless network resources. It translates the location-based query to a search to the DHT to retrieve all matching values.
This SearchPeer is hosted by a computer on board of the moving vehicle (in our studied scenario) and is connected via any active wireless interface providing connectivity to the large Internet. Since this peer is meant to change its point of attachment on micro-level, i.e. changing constantly its context, it is not required to store any context related information neither is it meant to take the role of a full Chord peer. The searchPeer ID is its hashed home IP address which should be within the IP subdomain of a router that can act as a home agent [20]. The hash function is applied to the global home IP address of the mobile node. Relying on the DHT routing mechanism all DHT-related messages from and to the SearchPeer will reach the home agent first. When using MIPv6 [20], the messages are then further forwarded to the care-of-address (CoA) identifying the position of the mobile node. The SearchPeer, despite its dynamic care-of-address, keeps a fixed ID. In the case of a micro-mobility scenario the mobile node may often change its IP address while attached to several IP domains. A further binding effect of the IP address adds to the DHT routing cost. However, the advantage of this added cost is keeping the consistency of the DHT finger tables and reducing the churn rate. This is the rate at which new peers usually join or leave the system.
Furthermore, the DHT needs to stay consistent keeping in mind the stochastic behaviour of "mobile peers" in the system. Once the mobile has left a given foreign network, in general, the home agent is informed. The home agent can be, first, explicitly informed by the old foreign network that the node has left the network. It could also be implicitly informed when receiving an association message carrying the new care-of-address [20]. In the case where the node leaves the network for good, the foreign network updates the reachability status [19] of the mobile node (to unreachable) and informs the home agent to stop forwarding incoming packets to the old CoA. If the home agent removes the home IP address from its known active addresses that would cause all routing messages sent to that address on the Chord ring getting dropped too. The SearchPeer node is eventually removed from the Chord ring.

AccessPeer: is a full peer node capable of storing and managing content values and can be reached by other peers based on the Chord protocol. In other words, any peer can forward searches and requests for specific keys. It represents dedicated servers running the DHT roaming application. The AccessPeer also plays the role of forwarding search requests as well as filtering out the information sent back as a response.

The object space: the object space under Chord consists of an XML description file, retrievable by the roaming application. The content or object space is no longer randomized through the use of a hash function such as SHA-1, distributing the keys among the peers in load-balanced way [28]. In contrast, we rely for our system on Geocoding [25] to represent a geographic-aware distribution of (key,value) pairs among peers. This could be compared to an online map service that can generate a zip code from entered GPS coordinates. The problem with Chord is that its query language requires a precise known object ID that can generate a precise key value, making range queries difficult. For that reason we partition the ID of our wireless objects and use part of that ID to search for resources within a larger geographic area. Taking the zip example, one could imagine a global zip code dividing the earth in a grid of squares or zones, the size of Texas, with incrementing the integer ID per geographic square. Knowing the maximum number of squares, enough to cover the earth area, we form the first part of a given object with the ID of the square where it is located. This square is further divided into smaller zones, while giving a unique ID to each part of that square. This could be repeated depending on the area searched until reaching the size of a micro-cell, shown as a concatenation of IDs (a,b,d, ..,3) on Figure 2. The search needs only to look up all resources whose IDs lie in the range of a macro-cell. The search matching the most significant part of the macro-cell is processed further at the concerned peers. The search message will take the form of an XML file with different list of wishes that need to be matched at the AccessPeer (Figure 2) before a response is processed. This includes some attributes such as: the preferred wireless technologies at the mobile terminal, user credentials stating which services the user is allowed to access, etc. Another filter used is the rest of the location attribute, which could specify a "nearest neighbour query" [26], i.e. the shortest distanced resources from a given path or a given position point. These types of geographic queries assume a processing of the query request beyond a simple key matching as it is the case for file sharing applications. The wireless resource XML description could aggregate a list of APs depending on the priorities indicated by the user. More complex query processing could provide a kind of P2P data-base [13].

Load Balancing: For load-balancing purposes, we use the "virtual servers" extension to Chord, where a SearchPeer is clearly distinguished as being represented with a null number of virtual servers. The AccessPeer on the other hand depending on its storage and processing capabilities could be modelled as a number of virtual servers. Managing wireless resources includes deciding which resource should be managed by which group of virtual servers. This could take some attributes into account such as whether the AccessPeer has the right security attribute to find out about a given resource. The results to these changes of Chord are rather extensive and out of the scope of this paper.

2.3 Improved Range Querying under a CAN-Based Implementation

The more appropriate DHT protocol that best solves the aspects of range queries [24] is CAN. Next, a CAN-based solution is presented. To address content, a four-dimensional object space is chosen, which allows geographic range queries. Assuming R the set of objects representing instances of wireless resources with a geographic ID (x,y), where x is the longitude coordinate, and y latitude one. Each wireless resource can be assumed to cover at least a rectangular radio area. The object space, then, represents "geographic ranges", whose keys are distributed in a four dimensional Cartesian system. The first two dimensions represents the (low,high) range of the range x values, the two other dimensions represent the (low,high) range of y values. Now to generate a search, our roaming application defines a series of squares concatenated to cover a given path (i.e. a street and its surroundings). To define a search range is to first choose the path, draw squares along it, and find out the coordinate range of each square. Let us assume the first square on the path has x_1, x_2, y_1, y_2 coordinates, where $x_1 < x_2$ and $y_1 < y_2$. Looking closer at the DHT object space, but taking just the longitude coordinates, Figure 3 shows the range (x_1, x_2) indicating a single object (or point) on the two dimensions needed to describe longitudes. If we query that range then it is up to the peer owning the zone 1, to generate a response. Similar filtering capabilities at the AccessPeer are assumed in the CAN system as those in Chord. For load balancing, however, the zones are sized depending on the number of objects in it to match the peers' heterogeneous capabilities.

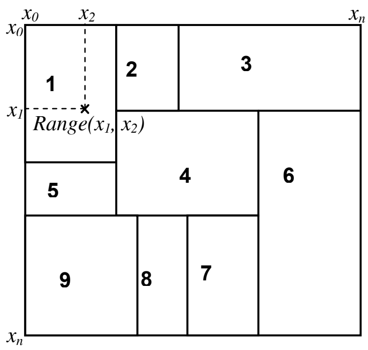

Figure 3. Location Range Queries Based on CAN: A Single Dimension for Longitude Ranges

3 Location Aware Terminal Handover

Having explained the P2P architecture for storing location-based wireless resources, we move on to the mobile terminal side, where location awareness is first used to define the queries, but also to select technology for a handover. The actual way the handover occurs still relies on the mechanisms used for each technology, but we aim at dealing at least with an all-IP-world relying, here, on Mobile IPv6 [20]. A thorough analysis of mobile IP variations has been carried out recently [2], [29], and [14]. In our studied scenario we use a small mobile network[4], which should be distinguished from using a mobile router that supports the network mobility protocol (NEMO) [8]. Furthermore, any of the IP micro-mobility protocols could apply in this case.

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[4] We define a small mobile network to be a network of mobile terminal sharing the same mobility context, e.g. a group of portable devices (phone, PDA, laptops, a vehicle's computer system) attempting to access the Internet during a Bus ride.

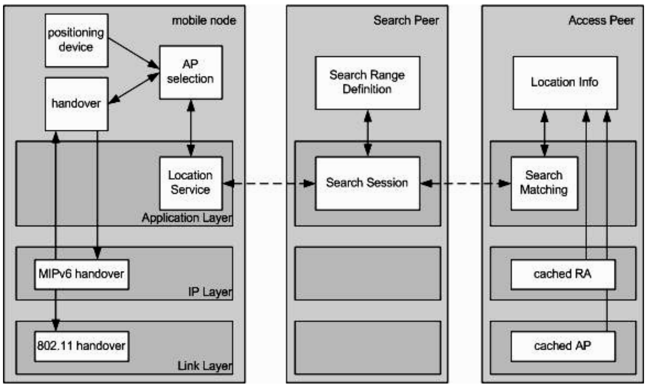

Figure 4. Terminal Handover Management

A movement-aware handover application is implemented. The application is able to track the movement of a vehicle, generates a search for appropriate resources, and manages the handover based on the approaching access point. Figure 4 depicts how the application modules are designed to interact with each other and with the underlying protocols. Due to lack of space, a summarized implementation of the proposed architecture is presented. A proof of concept is aimed here via the development of a prototype system that uses a navigation-based system to generate both search requests and also to decide on the terminal handover procedure.

The simulation model generates some simple searches and retrievals, while focusing on implementing in details the handover procedure adapted to the chosen link and network layers. After the driver of the vehicle entered the desired destination into the navigation system it will start calculating a route accordingly. Then, the navigation tracks the movement of the vehicle and correlates it with the calculated route. The MN can foresee the future movement making it possible to choose the next AP.

The positioning module resembles that of a navigation system, the movement is tracked along a path on a map (e.g. a unidirectional movement along a concatenation of few streets) based on a current location, speed and direction of the MN. This module also detects path changes. The search is emulated using a ***Search Peer*** module**.** Matching our range query with its multiple attributes, a list of APs is returned with two key pieces of information: AP related location and technology (frequency used at the AP), and IP-layer related information based on a router advertisement (RA) of the access router (AR) to which the AP is attached to. This RA is cached automatically as part of the stored description of a given AP. Further processing at the peers could reduce the number of possible answers by only providing aggregated APs matching more complex preferences or priorities. This is however out of the scope of this work. The current implementation in the simulation model places the returned APs on a map and makes a location-only based handover, since the APs are of the same technology. A sequence of neighboring APs are selected using Voronoi graphs.This decision is being extended to take into account the application class and its requirements. Based on this information, a handover decision among heterogeneous WMN is made depending on several objectives that need to be optimized [4], including the minimum interruption time, QoS utility function, price, etc.

4 Simulation Results

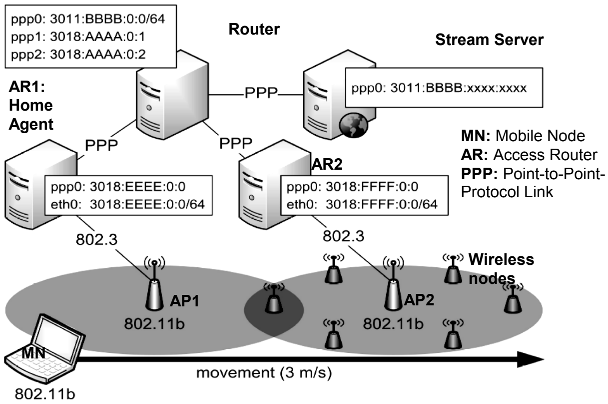

Figure 5 Simulation Topology Layout

To analyze how a location aided handover performs under OMNeT++ [30] in comparison to standard MIPv6, different test-beds have been setup implementing the application interactions discussed in Section 3. This implemented model demonstrates the effect of improved movement detection on the overall terminal delay handover. Some simplifications are made to extract that specific effect from the whole handover procedure at both the link and network layers.

4.1 Simulation Assumptions

In order to isolate the effect of movement detection, the simulation model is based on a simple topology - shown in Figure 5-. This simple topology should optimize the triangulation effects and routing of mobile IPv6. It also minimizes the binding phase of MIPv6. Terminal mobility is of most interest here rather than route switching. IPv6 modifications that focused on improving binding updates delays, concentrated mostly on reducing the number of hops to the home agent. Some approaches introduced hierarchical proxies to the home agent closer to the access networks. These proxies only update the remote corresponding nodes and home agent once the MN changes such an attachment point. This is in fact a summary of how HMIPv6 presents a solution to micro-mobility at the IP layer [2].
In this simulation model, OMNeT++ implementation of MIPv6 is first used unchanged [30]. Although the authors of IPv6Suite [31] claim to have a complete implementation of the MIPv6 RFC, it turned out that layer2 triggers, defined theoretically to trigger movement, were not running well enough to conduct constructive measurements, under OMNeT++. The other way to detect movement defined by MIPv6 [20] is a special router interval option (RIO) that is part of every RA. With the RIO the MN awaits the next RA and detects movement through the missing of an expected RA. Each IPv6 neighbors (nodes and routers) keep a reachability state of

each other. Once movement is detected, this state is turned to zero, removing nodes from the routing tables for instance.
Also part of the simulation model [31] is a rather realistic implementation of the IEEE802.11b standard, except its theoretical association phase (or AAA). This is kept very simple. However one could argue that this can easily be handled by the DHT framework [9]. The users of the framework would have priorly signed in to the wireless management services in order to search for wireless resources, therefore obtaining the ESS ID and AAA details in advance.
In fact, the theoretical analysis of handover delay in 802.11 is carried out to a certain extent in several other papers [17],[7],[3],[29],[32]. It is well-known result that the movement detection and the search phases at the link layer take up to 90 % of the handover delay [7], compared to a short AAA phase. The movement detection delays, however, vary depending on the hardware implementation. In the simulation model movement is detected whenever the signal to noise ratio (SNR), measured at the physical layer of the MN's WLAN interface card, decreases below a given threshold. Right then, a long probing phase of each of the 13 channels follows, searching for a new AP.
New proposals such as IEEE 802.11i use the historic build-up of neighbor cells and caching that information in a similar manner to ARP cache. This information is first gathered from MNs that successfully completed a handover from a cell to the next, building a map of neighboring cells. A MN attaching to the network could receive this cell map and therefore restrict the probing to those expected cells. This approach may work perfectly within a single distribution system (DS) managing an extended service set (ESS), but it cannot solve the problem of multiple IP domains or frequent network changes. In this paper, the used approach aims at a more heterogeneous environment, where the mobile node could select one of many "access points" that belong to different technologies. The movement detection is done independently of the underlying technology, making the choice of the next AP a matter of application and movement context.
In the simulation model, the movement-aware trigger at the link layer specifies the frequency channel which the expected AP uses. This information is entered in the XML template describing the AP. Movement awareness is also used to indicate when to start the probing phase. On the routing side, the movement aware software entities, at the terminal, gather enough information about their "expected network" during the querying of the DHT framework. The handover trigger takes the form of a router advertisement fed directly into the neighbor reachability state machine. This avoids a normally lengthy movement detection mechanism, while reducing the complexity of the neighbor reachibility state machine. The terminal sends a RA of the old AR with a lifetime set to zero to its own Neighbor Discovery (ND) module [19] to clear the entry in the neighbor cache. Right after, the MN sends the new AR's cached advertisement to its own ND module to complete handover.

4.2 Chosen Scenario Description

As shown in Figure 5, three Ethernet-based subnets are connected using three routers. One access router is assumed to be the home agent (AR1), while the second is a vis-

ited one (AR2). The two subnets include, each, an IEEE 802.11b access point. The third router connects the two access routers and a server via point-to-point protocol links (PPP). The PPP links offer a data rate of 10 MBits/sec, Ethernet 100 MBits/sec, and 802.11b with 11 MBits/sec. The MN, initially attached to AP1, is assigned an IP address (by AR1) using Automatic IP; the server on the other hand has a static address assigned. The average RA interval of all routers is set to 1.25sec (MinRAIntervall = 1sec, MaxRAIntervall = 1.5sec).
The server has two applications running: a ping6 and a UDP server. The ping6 application is configured to auto reply to any incoming ping requests. On the other hand the UDP server is streaming one 600bytes UDP datagram every 0.005sec up to 0.01sec. This results into an average data rate of 640kBits/sec, which could be a comparable rate to receiving a live video on a PDA screen for instance.
The experiment is conducted with a mobile node (MN) traveling at a speed of 3m/sec (about 10 km/hr for longer measurement time)[5] starting from an initial position with coordinates [88,247]. The two APs were positioned at [147,247][6] and [194,247], respectively. Both APs have a radio propagation radius of about 85m. The MN, at the start-up conditions, is connected exclusively to the first AP. Every setup was simulated 200 times with different random seeds to gather statistically significant data. In the Location-aided case, the MN triggers handover based on its movement and position knowledge at the position [150,247], whereas in the standard handover the MN would loose connectivity to the old AP at a position near [234,247].
In order to allow fine grained measurements of delays while handing over some measurement points (shown in Table 1) are used.

Threshold too low	**802.11:** time of loss of connection to old AP
Restart active scan	**802.11:** time of restarting scan
Probe channel	**802.11:** time to probe one channel
Star of Authentication	**802.11:** start of AAA
Layer2 Trigger	**802.11:** end of 802.11 handover
New RA	**MIPv6:** time to receive new RA from new AR
movement detected	**MIPv6:** time of movement detection
start BU	**MIPv6:** beginning of binding update
handover complete	**MIPv6:** first ping after handover completion

Table 1. Overview of the measuring points

The simulation returns the instance in time at which each event occurred during each run.

4.3 Obtained Simulation Results

Figure 6 records the sequence of the measured event instances for the two types of handover as they both progress in time (from Table 1). The graphs in Figure 6 is

[5] The topology was too small for standard triggers to deal with speeds higher than 100km/hr
[6] OMNET++ coordinates are in meters. The movement coordinates and speed are defined in the model.

taken from one of the simulation runs plotting on two parallel lines the event instance for the two scenarios, i.e., location-aided (shown as *"**improved**"* on the upper timeline), and standard IEEE 802.11 handover followed by MIPv6 handover according [31] (shown as *"standard"* on the lower timeline).

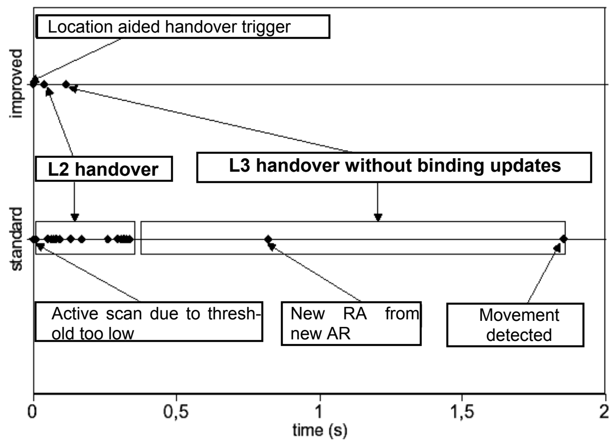

Figure 6 Time line of events for standard MIPv6 and location aided handover - L2 stands for handover event sequence at the link layer. L3 handover refers to the measured MIPv6 events required during the handover procedure.

It can clearly be seen in Figure 6 that the handover latency is brought down from 1850msec to only 125msec using the location triggers at both layers. In the standard case, probing all 802.11 channels, then inserting a new router advertisement, and detecting movement engulf a considerable portion of the overall delay, as expected. Another important result is considerably reduced number of handshakes and probing events, in the improved handover case.

The next graphics looks closer again into the standard handovers to evaluate the level of accuracy of the chosen model. Taking the results of the 200 simulation runs, distributions of the separate event relating to movement detection are given in Figure 7. These events are given in Table 1.

As expected, the search phase for a new AP based on the blind triggers used in the model lead to the largest part of delay with an average 350msec required for that phase. The Authentication, Authorization and Accounting (AAA) delay is far below the real values [7]. This can be traced back to the rather rudimentary AAA implementation in the IPv6Suite [31]. Assuming the AAA was still needed, it could be shown through practical measurements [7] that the dominant factor during the handover procedure would still be the search for a new AP.

Now taking a look at the MIPv6 delays, the first thing that comes to one's eye is a rather large delay to detect movement and receiving a new RA from the new AR and a rather small delay for completing binding update (remembering the simple topology chosen for this purpose). This confirms our expectations, but it is worth noting that having used the model's 1.25sec RA interval, the movement is detected quite slowly. If the MN receives a RA right after completing the handover at the link layer, the IPv6 could complete right away. This effect is seen in scenario 3 in Figure 8.

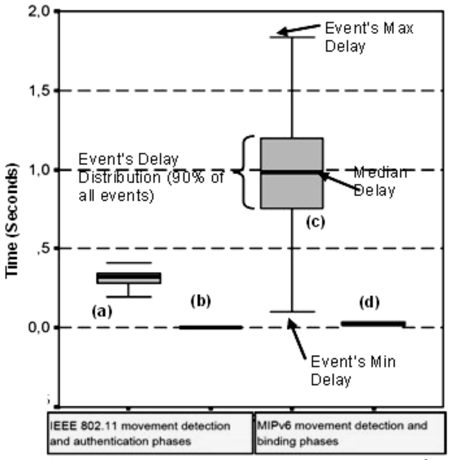

Figure 7. Delay distributions of major handover events at link and network layer with no location-aware triggers: (a): Access point (AP) search phase, (b): AAA phase at link layer, (c): MIPv6 movement detection phase from reception of new RA till terminal mobility completion, (d): Routing update and mobility binding phase

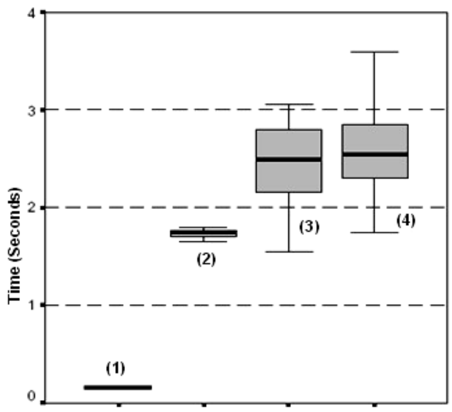

Figure 8. Comparison of the cumulative handover latencies for the different scenarios: *"on"* refers to the enabled location aware triggers at the Link or Network layers: *"off"* refers to disabling the triggers: **(1)** 802.11 *on* - MIPv6 *on*: **(2)** 802.11 *off* - MIPv6 *on*: **(3)** 802.11 on - MIPv6 *off*: **(4)** 802.11 *off* - MIPv6 *off*

This figure shows the impact of 802.11 location-aided handover and the improvements of MIPv6 handover separately. It compares four scenarios, where each of the link and network layer triggers are switched "on" and "off" interchangeably.

The final delay distribution plotted in Figure 8, adds up all intermediate latencies. It is taken to be the moment at which the communication with the CN is resumed. This moment occurs at the "handover complete" event given in Table 1. For this purpose frequent Ping messages were sent from the MN to the CN (server) to simulate a highly interactive application.

Analyzing the obtained delay distributions, first, it can be seen that only the combination of both location-aware triggers can improve the handover significantly. The second observable deficiency of the chosen model is shown when "***MIPv6 off***". The delay and variance increase dramatically. This could be all attributed to the rather infrequent router advertisements applied for those scenarios (a RA every 1.25 sec as specified in [31]). This effect is nonetheless totally removed once looking at scenarios (1) and (2), where the ***"MIPv6 on"*** trigger is used. A more detailed analysis of the different effects such as increasing the RA frequency to 0.05sec is given in [11]. It is however worth noting that the power cost of receiving very frequent RAs at the MN is quite high. Some other aspects of the scenarios are further discussed in [11] such as the effect of using multiple mobile nodes in the visited network, or the final effect of speed of the mobile nodes. This is done with speeds reaching more than 100Km/hr, where the movement-aware triggers immensely improved the connectivity and interruption delays.

5 Conclusions and Future Work

This paper advocates using a novel P2P location-based service to organize heterogeneous wireless mesh networks topology organization and discovery. The decision to use DHTs, however, requires that the object space identification and distribution be fitted, accordingly, to the DHT interface used. The design decision was made to organize objects as geographically collocated access networks of the same technology and belonging to the same operator. In Chord some extensive modifications are needed to cater for location-centric storage of resources. A less randomizing "hash" function is used, while the object space is organized geographically. Mobility of part of the peers and the disparity of the peers' storage capabilities have also been catered for by the modified Chord implementation. CAN, on the other hand, requires less efforts or modifications, while being more suitable, in its original version, than Chord to deal with range queries. Furthermore it was seen that the way to make use of the location-based stored resources, depends greatly on the terminal's pervasive capabilities. A scenario demonstrating the feasibility of such a system has been presented. It allows mobile devices to use navigation facilities on board of a transportation vehicle to learn about their location-context. An application running on the mobile terminals accesses the P2P system, locates the wireless resources along a planned itinerary, and triggers handover at the lower layers. The simulated improvements in an IPv6 and IEEE 802.11b environment have cut the interruption time of communication, due to handover, by more than 10 times to a mere 170msec (suitable for real-time applications). Using other methods to learn about the location of a terminal is planned for further research. Currently adding other context information, besides location, is seen as an essential extension to the system. A multitude of goals need to be optimized while deciding on the next wireless access point in heterogeneous conditions.

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