Supporting Vertical Handover by Using a Pastry Peer-to-Peer Overlay Network

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***Abstract*— Vertical handovers (VHO) are expected to be a key feature in Beyond 3G (B3G) networks. This paper presents a Pastry-based P2P overlay network for supporting vertical handover in B3G networks. The P2P overlay is used to quickly locate attachment points (APs) for mobile entities and to rapidly retrieve the configuration and coverage information of these APs. The advantage of the P2P-based solution is its distributed nature, its scalability, and its self-organizing capability.**

I. Introduction

For mobile communications beyond 3G, heterogenous access systems are expected. A mobile terminal moving through a landscape and variety of access systems such as WLAN (802.11), WIMAX (802.16), 2.5G and 3G, and sometimes also fixed wireless access systems such as ISDN, DSL for fixed-mobile convergence, needs to perform *vertical handovers (VHO)* frequently, i.e. pass the ongoing connection from one access system to another, as well as from one operator to another. Access systems consist of numerous *attachment points (APs)*. An important task during a vertical handover is to locate quickly the appropriate access systems in range, respectively its APs.

In general, the execution of vertical handover can be accelerated if the involved entities are aware of the attachment points and their coverage areas. This approach saves considerable time which would otherwise be spent by the mobile or the attachment points by scanning the environment, e.g. channel frequencies or field strength, and to retrieve the configuration at the AP, e.g. used identification/authentication. The coverage areas of APs, however, might be not connected and highly volatile in their size due to radio wave propagation, interference, and system load. The identification of candidate APs is achieved by comparing the position, i.e. the geo-location, of the mobile device and the other attachment points. An entity controlling the execution of the VHO, e.g. a mobile or an AP, can query a *database* for AP candidates, their configurations, and their coverage areas.

Typically, such information will be stored in a central entity. Central databases, however, are vulnerable to system failures and to overload situation. In particular, a central database is restricted if time-limited coverage area information, e.g. measurements of mobiles, needs to be stored and retrieved quickly.

In order to avoid the disadvantages of centralized entities, a distributed and self-organizing *peer-to-peer (P2P)* based mechanism for vertical handover support is suggested. The solution employs a modified Pastry P2P overlay network to distribute the database containing the configuration and coverage information. Besides solving the overload problem, the application of a self-organizing P2P mechanism permits new ways of operating mobile communications systems. APs can be inserted easily with no or less manual interference, such as configuration tasks, due to the self-organization capability of the Pastry algorithm. Hence, access systems and APs of different technologies, and even of different operators, can easily be included into the system.

This paper presents the architecture of the proposed P2P concept. The paper is organized as follows. First, Section II discusses additional concepts for the support and the execution of vertical handovers. Section III describes how vertical handovers can be made more reliable by using radio coverage measurements. Section IV describes in detail the Pastry-based vertical handover support mechanism and Section V summarizes briefly the paper.

II. State of the Art

Vertical handover related issues address many different problems. However, the two main areas investigated by the scientific community are the one aimed at protocols to support the vertical handover phase and one addressing the resource management in order to fulfill the Quality of Service (QoS) requirements. Houyou et al. [3] suggests a roaming technique which considers locality-oriented self-awareness to allow the detection of wireless networks by mobiles. However, location information can only be found in the documents stored in a standard P2P network, hence, no performance improvements can be gained by exploiting location information.

Siebert, Lott et al. [1] describe a *Hybrid Information System* (HIS) that aids inter-system handover or vertical handover by creating a database where information gathered from the different radio access technologies is made available. This reduces scanning effort and provides information for a fast handover decision. However being a centralized component, the database used by HIS requires a high performance element resulting in high costs. Additionally, the signaling delay is dominated by the propagation delay from any entity in the network to the server. This means that a high load at the server is observed although the information is only required locally, since a mobile asks for measurements around its current position. The system must be redundant in order to cope with failure and replicas must be synchronized periodically. Lastly, a straightforward solution to cope with such limits is to let the involved mobile devices and access points scan the environment continuously, resulting in high overhead and statistically long handover times. These issues are altogether overcome by our solution, which distributes the database and creates a virtual entry point for the HIS functionality (i.e., an entity to request information from, even if the actual information gathering process is hidden).

III. Supporting Vertical Handover

The measurement information database system proposed by Siebert, Lott et al. saves much scanning effort. We want to support this approach by storing the information in a distributed database using a P2P overlay network.

The database is filled with content by the Attachment Points (AP) such as nodeBs and WLAN Access Points, which insert measurements like Received Signal Strength Indicator (RSSI), Block error rate (BLER) or Received Signal Code Power (RSCP). These measurements are associated with the locations that they correspond to, so that the database resembles a map of the covered area with measured values for points on this map.

When a handover decision has to be done for a mobile device, the database is queried with the location of that mobile. Then, an Intelligent Service Control (ISC) decides which measurement reports are of interest by computing a so-called Decision Area (DA) and merges all reports covered by that area. This processed information is then used by the entity deciding about the handover, which may be both network-initiated/device assisted or device initiated/network assisted.

The HIS system maps incoming measurement reports to locations, which can be enhanced observed time difference (E-OTD), satellite based global positioning system (GPS) or the new network assisted A-GPS. A specific uncertainty remains, which is modelled via a fuzzy function, assuming a Gaussian normal distribution for both the imprecision (the granularity of localization itself) and the reliability (probability of a mobile device actually being there).

While preserving this basic functionality, we propose to distribute this database, along with the functionality of the ISC, to the Attachment Points themselves, cf. Figure 1. The reason for this is that one mobile device only needs a limited amount of information gathered at locations near to it. If this information is stored locally near the potential requestors, we gain several advantages. We reduce response times to queries if we manage to route efficiently to the AP storing the requested information, since the distance between information requestor and provider is short. By segmenting the database we also put only a low load on each of the devices where pieces of this database are stored, keeping the single parts inexpensive. Moreover, the distribution of the database improves the resilience of the overall system, since the failure of one or several of the APs does not disable the whole

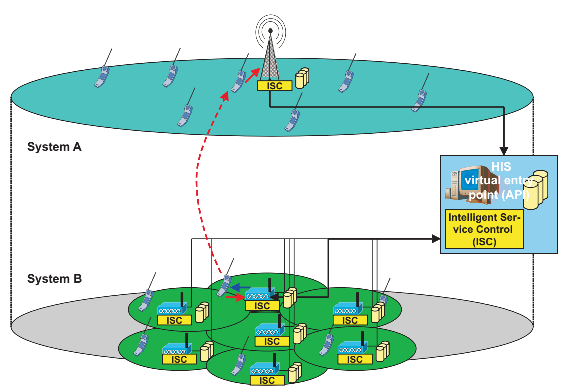


Fig. 1. Distributed information system: the database consisting of measurements is distributed among APs together with the ISC (enhanced figure from [1])

architecture, in contrast to a centralized system, where one component can bring the service down. The network is easily extended with new attachment points, since nodes configure themselves and only few pieces of information have to be redistributed to new peers. Due to the used algorithm, the whole system is scalable, i.e., performance does not degenerate for high load and a high number of nodes.

IV. Architecture Concept Using Pastry P2P Network

To achieve the characteristics described in the previous section, we introduce the basic constraint that each AP only stores measurements that were taken close to its position (we will later describe how we define 'close') and from its own access technology, e.g., a WLAN Access Point will only store WLAN measurements and no UMTS reports. In order to interconnect these local databases and to allow for search and storage of reports, we will use the basic overlay architecture of Pastry [2] and adapt it to our needs.

A Pastry network is based on a virtual address space. Each node in the network is assigned an ID which represents a location of the address space. Pieces of information ('documents') that are stored in the network also get an ID. For each document, the node with the numerically closest ID to the document's ID is considered responsible for it (i.e., it stores that document). Thus, the identifier space is divided in responsibility zones. In standard Pastry, the IDs consists of a sequence of L digits of base b. The ID is generated with a hash function, e.g. SHA1, which is applied on the IP address of the node.

Pastry uses prefix-matching for routing. Each node builds a routing table according to a shared algorithm. It chooses entries for this table selecting peers with different shared prefix lengths (Figure 2). When a peer receives a message, it is responsible for passing it to a peer whose ID has at least one more digit in common with the message's target, which just means looking up such an entry in the routing table. Figure 3(a) shows an example for the routing process.

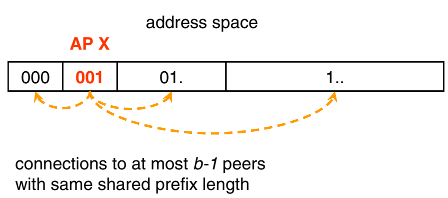
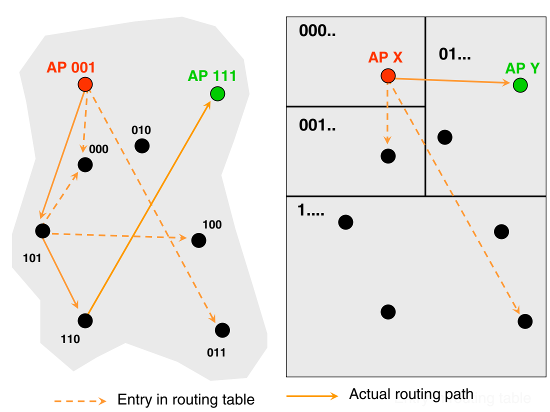


Fig. 2. Standard Pastry ID space

The most far-reaching change we apply to this basic algorithm is the modification of the hash function. In our approach, locations (i.e., coordinates) and access technologies are used to construct IDs and keys for the overlay network, cf. Figure 3(b). This is a big difference to the standard procedure, where a hash function, like SHA-1, takes IP addresses or similar unique identifiers and generates a pseudo-random hash value.

In general, a hash function of a P2P system is used for balancing the load in the overlay network. In our case, we can use the geolocation of the APs as hash value, since the network layouts of the different access systems are planned to cope with the load in the network. This means that the APs are arranged in such a way that for each pixel in the network layout the emerging traffic and occuring load can be handled by the access network. Load in the case of mobile networks means e.g. a large amount of required transmission power. This understanding of load can be translated into our overlay network:

- a high load (in the mobile network) results in a large number of measurements, which have to be put into the distributed database; this is reflected by a high load, i.e. number of transmitted messages per second, within the overlay network;
- a high load (in the mobile network) results in a large number of necessary handover information requests in order to reduce the load (in the mobile network); with respect to the overlay network, this means that a large number of search requests has to be answered which is realized by transmitting route messages between the APs until the requested information is found.



(a) Standard Pastry (b) Modified Pastry

Fig. 3. Routing example with SHA-1 and modified hash function which takes AP location and technology into account

Assume that a certain access point has the two-dimensional coordinates

$$(x, y) = (x_1x_2 \dots x_n, y_1y_2 \dots y_n)$$

and uses one access technology (e.g. UMTS, WLAN, etc) which is encoded according to a pre-defined scheme as $T = T_1T_2 \dots T_m$. The single digits of the coordinates and the technology are represented in the same base b as the digits for the Pastry IDs. The base b is a configuration parameter affecting the size of the routing tables. A typical value is $b = 4$, which means the x_i, y_i and T_i are quaternary digits.

In our concept, we use the Universal Transverse Mercator (UTM) projection system to identify locations. The UTM coordinate system is metrical and orthogoal, i.e. a Cartesian coordinate system, and has the advantage to easily project a position on a map and to correctly compute distances. Since the UTM coordinates are given in a decimal format, they have to be recomputed to the Pastry base b. Then we construct the ID of that peer in the overlay as $T_1 \dots T_mx_1y_1 \dots x_ny_n$. For future reference, we call the first part $T_1T_2 \dots T_m$ the *technology part* and the second part $x_1y_1 \dots x_ny_n$ the *location part* of the ID.

This identification scheme allows building a *name space*, which could be exploited also for organizing and rationalizing the network deployment and the administrative phase. For instance, rules could be established for deploying the entire system across different providers.

A. Storing information

The content that is stored in the network is the sum of the measurement reports done by base stations, mobiles etc. These documents also get a key that fulfils the same task for the routing procedure as a hash value. It is constructed in the same way as the IDs of the access points, with the location part being based on the coordinates where e.g. the signal strength was measured and the technology part reflecting the according access technology again. The actual information contained in the documents consists of the values measured in a suitable form (e.g. RSSI). Due to the routing mechanism of Pastry, this means that reports will be stored at the closest or at least one of the closest access points of the same technology (since the technology part of the IDs comprises the highest-value bits of the ID). For example UMTS measurement reports will normally be stored on the nodeB of the UMTS cell where the measurement was taken, while a WLAN measurement report in the same cell will be stored on a WLAN access point that covers the location of the measurement. We can assume that the positions of the mobile devices are always known due to the offered functionality of the HIS system, see Section III.

B. Searching for information

An entity interested in information of value for a handover decision (i.e., measurements that were taken near the mobile for which handover is considered) just needs to insert a query into the system (we use the term entity because this information can be of importance for different parties, depending for example on the handover model used). Inserting a query in our case means to directly send the query if the entity in question is a peer itself, or contacting a peer with the information that should be included in the query so that this peer can then create the message and forward it. This query just has to contain a key that is constructed in the same way as described above, with the technology part chosen according to the type of reports that are of interest and the location part coming from the coordinates of the mobile in question. Thus, the query will be routed to the access point that is closest to the mobile. This should be the peer storing the most important information for the mobile, or is at least only one hop away from an access point fulfilling this condition.

To reach peers of a different technology quickly, we enhance the Pastry routing table with *shortcut links* for each technology differing from the local node's technology. These entries contain the addresses of the physically closest nodes of the desired technologies. To understand the advantages of this modification, we will look at an example. Imagine a mobile that is currently connected via UMTS nodeB X. For this mobile, handover to WLAN is considered. Therefore, a request is spawned at X that contains a key constructed of the location of the mobile and the code for the WLAN technology. Without shortcut links, this request would be routed to a WLAN Access Point that is potentially physically far away, since in Pastry, the first routing step only matches the first bit of the target ID. By using the shortcut link, the request is forwarded to an AP that is in the coverage area of X, and thereby much closer to the target of the request Y (since Y should be near the mobile, which is also in the coverage area of X). The same applies to the storage mechanism, which is also sped up by the same links.

Since queries will enter the system near to the

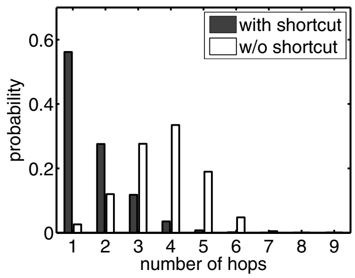


Fig. 4. Efficiency of shortcut links in terms of hops

storage location of the queried information (the peer originating the query is in contact with the mobile and thereby assumed to be at least in the same UMTS cell), and a low number of hops is achieved by the shortcut links, short response times should be ensured. In case the peer targeted by the search is not the one storing the relevant information, it should at least contain the responsible peer in its leaf set, meaning just one more hop is needed. The efficiency of shortcut links is indicated in Figure 4 which shows the simulation results of a scenario with realistic UMTS and WLAN layouts for Germany. We simulated about 18,000 nodeBs and 6,000 WLAN access points. It can be seen that the introduction of the shortcut link reduces the mean number of hops about a factor of 3. This means that the search time can be significantly reduced.

C. Node join and leave procedure

A node joining the proposed overlay follows nearly the same procedure as a node joining an unaltered Pastry system. It is necessary that the joining node knows of at least one peer already part of the network. Then, it constructs its ID as described above, and builds its routing table using the method of the Pastry architecture. Shortcut links are created easily by simply issuing a request at the new peer with the key consisting of its own location part and the technology part of the technology that the link shall point to (the key requested is therefore $T_1 \ldots T_m x_1 y_1 \ldots x_n y_n$, with $T_1 T_2 \ldots T_m$ being the technology wanted and $x_1 y_1 \ldots x_n y_n$ being the coordinate part of the searching peer). With this, the routing table is initialized and the peer is part of the network.

In general, no content replication, i.e., the copying of information already stored on other peers to the new peer, should be needed. Since each node stores the information relevant in its own coverage area, only minor discrepancies between the storage location of an information and the target of the query for that information should be expected.

In order to leave the system voluntarily, a node has to inform the peers that are affected by its leave. However, it cannot be guaranteed that all peers give notice of departure. For that reason, the Pastry protocol offers a resilience mechanism by perodically contacting the nodes of the neighborhood set. The modified hash function leads to rectangular responsibility areas for each peer, cf. Figure 3(b). If a peer has to store a measurement report for a location which does not fall within its responsiblity area, a node failure is detected. Thus, the knowledge about the overlay structure can be exploited to reduce overhead traffic,

V. Conclusion

Vertical handovers are expected to be a key feature in Beyond 3G networks. This paper has presented a Pastry-based P2P overlay network for supporting vertical handover in B3G networks. The P2P overlay is used to quickly locate attachment points for mobile entities and to retrieve rapidly the configuration and coverage information of these APs. The advantage of the P2P-based solution is its distributed nature, its scalability, and its self-organizing capability.

The goal of the architecture is to provide a *carrier grade* support mechanism for vertical handovers. This means in this case that the distributed architecture is capable to retrieve the measurements in minimal time while still guaranteeing search success. This requirement has been achieved by adapting the hash function in such a way that the geo-locations of the nodes and measurement reports are taken into account and by exploiting the locality of vertical handovers. As a result, only few hops are required to find the measurement reports. By introducing the concept of *shortcut links*, the number of hops could further be reduced significantly. The enhanced Pastry mechanism provides a reliable distributed service. Together with the knowledge of the structure of the overlay, node failures can be detected with the responsibility areas leading to reduced maintenance traffic.

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