Supporting Mobility in Next Generation Internet with a Decentralized P2P LBS

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Abstract

The recent emergence of a whole plethora of new wireless technologies, such as IEEE802.11, IEEE802.16, and UMTS, etc, also offers mobile users more diversity and possibilities for cheaper and opportunistic access to the Internet. In next generation Internet, media independence such as that proposed in IEEE 802.21, requires vertical handover between co-located heterogeneous wireless networks. Handover is, however, triggered through costly beaconing mechanisms which allow both end-device and networks to discover each other, and to detect movement. If the mobile device is made location-aware (e.g. GPS-equipped mobile phones with navigation systems), mobility could be supported by the location-awareness, and a vertical handover could be triggered without relying on frequent beacons on multiple wireless interfaces. As a result, less energy is required by the mobile node to discover wireless diversity. Instead, the mobile user discovers the network coverage via a decentralized LBS, which is designed in this work. The LBS manages location-based meta-data describing network topologies and their functionality. The description templates are managed on an overlay system connecting distributed location servers. The overlay network, which connects distributed LBS systems, is structured in way to limit the overhead introduced by the query. The structure of the network is mapped to the data structure. A design methodology is developed to ensure the localized query overhead, while taking mobility into account.

1. Context-Aware Mobility Management

The research in the domain of mobility management is now facing the challenges of wireless diversity offered in next generation Internet or 4G scenarios. The way handover should be triggered between heterogeneous networks is a challenging and complex problem.

In recent years, context-aware vertical handover has been proposed [5]. For mobile scenarios, context has been modeled with the help of ontologies that divide context information for both user and network into dynamic and static components. In [8], a centralized architecture is used, where user context and network context are retrieved and collected for a given user, a handover selection process based on a context-aware algorithm is applied to trigger the handover decision.

In fact, three components to context aware mobility management type have been proposed.

1. Context modeling dealing with context ontology [8].
2. A suitable architecture for context sensing and context retrieval, dealing with context management, sensing, and storage [5,8].
3. Decision algorithms which have been centered around fuzzy logic, and multiple criteria optimization algorithms [9,1].

In [3,4] I propose to achieve context management with the help of a distributed mobile LBS. Mobile LBS require service provision which takes user movement into account. The service delivered changes with the movement and location of the user. Movement tracking is usually done with the help of a tracking hardware like GPS, which makes the user aware of its location. Assuming that the user can use the movement tracking capabilities context sensing is adapted to the user movement [3]. Based on the user's context, the network context could be queried. A query is started to search for available heterogeneous wireless cells belonging to various operators. The discovery of layout of wireless cells allows the mobile node to select a wireless node that most suits its context. This latter problem has been approached in [1] as multiple objective optimization decision process. Vertical handover is seen as the process of selecting the cell that suits the QoS needs of the user among several alternatives. Each alternative cell is evaluated according to several objectives like *(i)* minimizing interruption time, *(ii)* maximizing bandwidth, *(iii)* longest connectivity possible, *(iv)* minimizing price of communication, *(v)* minimizing jitter, etc. The score each prospective cell achieves is combined in a utility function, which is used to select the best handover alternative between overlapping cells or next in line cell.

In another simpler approach, the mobile node simply looks up nearest free of charge wireless LAN access point (similar to war driving) the user can move towards that place using a handheld navigation system.

2. Network Context Sensing and Meta Data Abstraction

The discovery of network context has to occur across heterogeneous system. Therefore, a middleware bridging between the different networks is needed. The middleware offers a common interface to represent the heterogeneous domains and their capabilities through a service description. The network context has to be discovered and retrieved while adapting to the discovery and retrieval process to the user context. Here both the discovery and retrieval effort of network context are of interest. An important characteristic of the network context is that it is scattered along autonomous domains.

The goal of the discovery effort is to gather the network context across the domains, while caring for the dynamic nature of this information. How a network context is generated depends on the explicit and implicit descriptive information of a given wireless domain. The characteristics of a domain can include:

- Each autonomous domain should reflect geographic proximity of wireless attachment points (i.e. a continued island of wireless coverage is guaranteed via a group of access elements).
- Given a set of link technology used within each domain, some mobility management capabilities are required to describe the connectivity and the intra domain mobility support offered. An example would be to describe a UMTS domain with maximum guaranteed bandwidth, maximum handover velocity, blocking probability, dependability (in terms of probability) of the connectivity and bandwidth guarantee). In comparison a WMN based on IEEE 802.11f might offer higher bandwidth, but support a lower handover velocity, but require a much lower cost per data flow.
- Some notion of load and available resources needs to be derived for each network organization. For instance, the network load could be a measurement of the number of admitted users connected to a given available resources. The network resources are those represented by the QoS parameters, such as available bandwidth average queuing delay, or loss rate. It could also include the number of users a given mobility protocol would still scale.
- In heterogeneous wireless networks, each domain should include only those base stations implementing the same link layer protocols.

- Separating domains, including within a single link technology, apply the following heuristic: handover latency between base stations within a given domain should be considerably smaller than that between two domains.

The storage and retrieval of the data description is done using a decentralized overlay system.

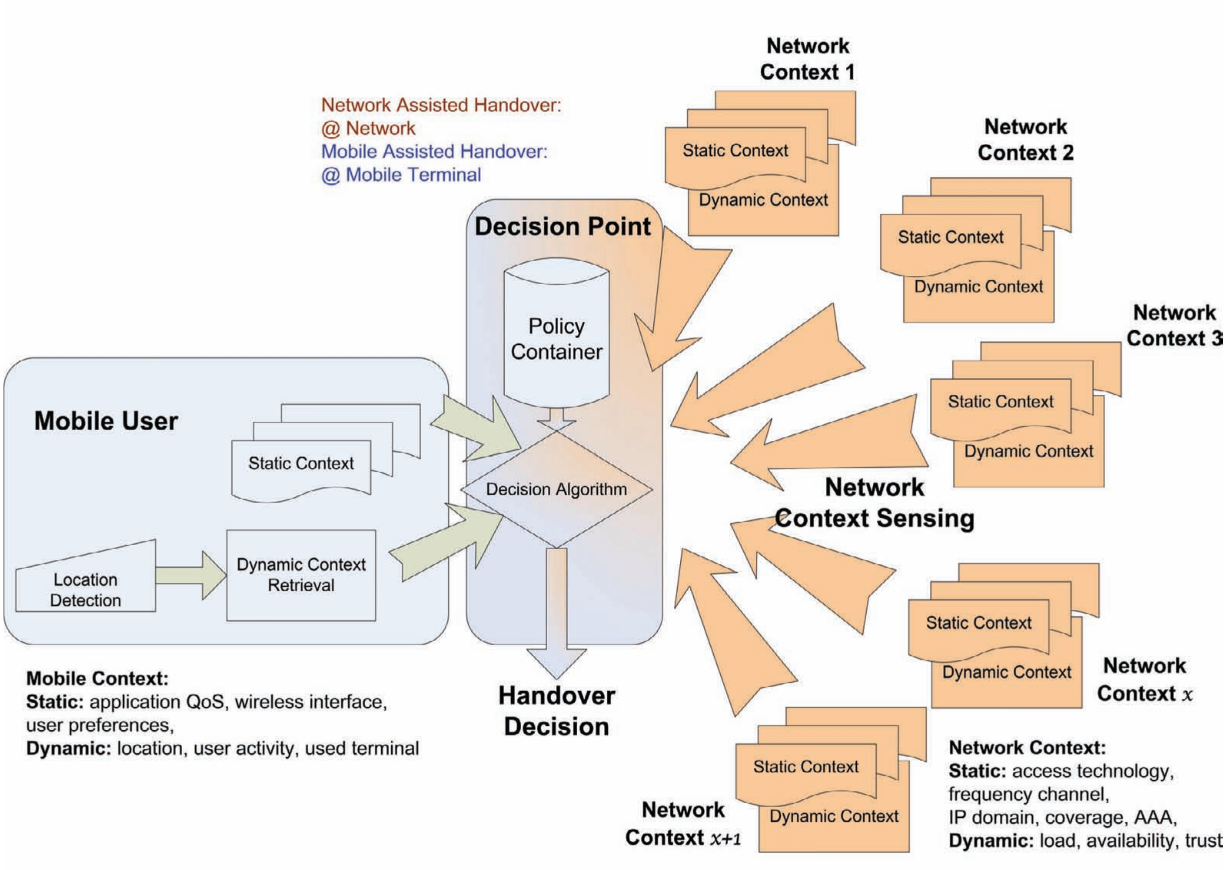

Figure 1. Context aware vertical handover – mobile and network context collection and sensing – decision point (either in network or in mobile terminal)

The architecture described in Figure 1 demonstrates the scalability and complexity problems faced by context aware mobility management. Whether a network assisted handover or mobile assisted handover is used, the decision process requires a retrieval of information from separate management domains, which has also to be adapted on one side to the user's static context (such as user network preferences, application QoS requirements, and wireless capabilities of end-terminal). An on the hand, there is also the problem of dealing with an ever changing location of the user, which requires network context adapted to the user's position and situation.

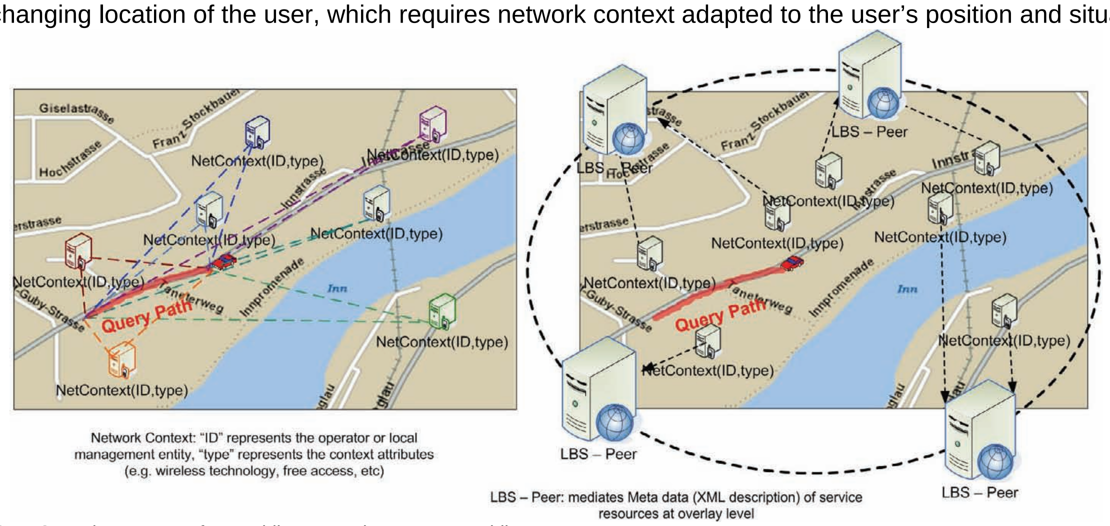

Figure 2. LBS overlay structure for providing network context to mobile users

Sensing and retrieving network context from scattered domains could be redefined as a context-rich location based service (LBS). Figure 2 shows on the left hand side a naïve approach which requires a separate query/or update process to each separate domain or context management entity. On the right hand side an overlay constructs a virtual network capable of routing to reach LBS peers (overlay nodes) as well as content. This architecture differs to classical LBS, in that a P2P relationship exists between backend severs. The overlay is used to restructure data, and route not only to pre-registered nodes, but also to scattered LBS content. The type network needed to offer efficient communication between LBS nodes is a semantic overlay.

3. Context Management in the Form of a P2P LBS

3.1. Semantic Overlays for Efficient Queries

Crespo et. al. define a semantic overlay as "a flexible network organization that improves query performance while maintaining a high degree of node autonomy" [2]. A semantic overlay aims at improving the querying process in decentralized systems while constructing overlay structures based on the semantics of the managed resources.

The type of queries that are supported by a semantic overlay are constrained by the following system requirements:

- Look up heterogeneous wireless cells among different operators.
- Look up only those wireless cells near the movement path of the user.
- Look up those wireless cells that the end device is capable to support.
- Limit the query path in the network for timeliness considerations (i.e. a result of a query is only relevant if it is sent back before the user has moved out of that cell).
- A wireless resource status could change which means that the query result is more likely to be invalid if the query occurred too long before the position has changed.

Selecting the right semantic attribute to cluster the nodes is also important. For network context, the chosen attribute has to satisfy several requirements:

- The common attribute might be described with the elements of a space S that could itself be split into subspaces $S_0 \cup S_1 \cup S_2 \cup \dots S_n = S$, where n is a large integer representing the partition of n subspaces between n possible overlay nodes.
- Each subspace is fully independent of other subspaces $S_0 \cap S_1 \cap S_2 \cap \dots S_n = \emptyset$, and therefore each overlay node from n nodes can be assigned a subspace that does not overlap with other spaces.
- The chosen attribute is common to all possible objects, but its value is assigned per object from the space S.

The choice of the semantic attribute could be for instance the wireless technology, so that each object representing a given technology is clustered together. Although this would satisfy the conditions above, the number of subspaces that result is quite limited. In addition to that, clustered objects representing the same technology would not scale, since this means a mobile user moving through the city of Berlin has to contact the same overlay node as a user from New York. Another possibility would be to achieve an aggregation along the lines of operator boundaries. However, the query with the same geographic scope has to be repeated per operator domain, similar to the naïve approach in Figure 2.

The more intuitive aggregating attribute is location. Those objects belonging to any operator and using any type of technology are clustered together if they are geographically close to each other or co-located together. For range queries, further DHT routing is required to efficiently structure the overlay network and query objects.

3.2. Distributed Hash Table for Location-based Range Queries

Chord [7] is the most efficient DHT protocol when looking at routing effort. In order to route to any object or peer, a $O(log(N))$ effort is required. Each node has to store pointers to $O(log(N))$ other nodes (where N is the total number of peers). The problem with Chord is that its query language requires a precise known object ID that can generate a precise *(key, value)* pair, making range queries difficult. Semantic clustering dependent of location, replaces the Chord hash addressing scheme, so clusters the $O(log(N))$ search effort is repeated for each cluster instead of each object. For instance for W the number of objects, $O(W \cdot log(N))$ search effort is required with classical Chord. With a range gathering w objects, the search effort is reduced to $O((W/w) \cdot log(N))$ messages. If a range is split among several direct neighbouring peers M, then the overhead becomes $O((W/w) \cdot [log(N)+M])$. The next problem with Chord is how to address geographically different types of information with a one-dimensional key system.

3.3. Hilbert Space Filling Curve for Addressing Geographic Information

In [3,4] space filling curve based addressing is shown to achieve the geocoding [6] required for addressing. The Hilbert based transformation of 2-D geographic IDs into 1-D integer space allows for instance to model the earth surface as a closed integer space $S \subset N$, with elements starting at 0 and finishing with 2^m (represented by a ring of modulo 2^m), where *m* the number of bits used in the Chord ID space.

The continuous ring representing the ID space is mapped to a Hilbert curve filled grid covering the earth surface. The clustering property of the Hilbert curve is taken into account so that neighbourhoods are preserved by the addressing scheme. In other words, two objects geographically close to each other are also close in their 1-D Hilbert address.

3.4. Fractal Design Optimization of Space Model

The problem with the Hilbert curve is the need for a large amount of keys to describe the same geographic content, which is depends on the granularity of the space filling curve. The more granular the Hilbert curve is, the larger the overhead becomes. This is partly due to the fact that each object (in our case a wireless cell) of let say *500m × 500m* size requires *2500* Chord keys when using *38*-bit keys to model the earth, and only *one* Chord key when using 20-bit keys [4]. The problem with *20*-bit though, is that a smaller cell of let say *50m × 50m* must be encoded as well in as *500m × 500m* cell reflecting a significant loss of information about the stored data. The added complexity of using a higher granularity can be reduced by introducing a hierarchy in addressing both nodes and objects (example shown in Figure 3 (left)).

The compromise between the accuracy of geographic data is for instance a major reason for increased communication complexity. The way to compensate this is to take advantage of the fractal nature of the space filling curve used in addressing. Nodes are then addressed with a lower resolution than objects.

Each peer is assumed to manage a considerable number of keys, and the objects corresponding to those keys. This translates into assigning several subspaces ($S_i \cup S_{i+1} \cup S_{i+2} \cup \dots$) to a single peer. Assuming a $2^k \times 2^k$ mapping of a 2D space is filled by the k^{th}-approximation of a Hilbert curve (resulting in *2k*-bit long IDs). If a given cell in that grid is divided into 4 subsquares, each resulting cell requires 2-bit longer ID, while sharing the same 2^{2k}-bit long prefix. The fractal nature of the Hilbert curve can be utilized to distribute the 2^{2k} possible keys in a k^{th}-approximation of a *2D* space to $N=2^p$ peers (and *p* is a binary index reflecting the number of peers). Therefore, each peer is responsible for 2^{2k-p} keys, where all objects managed by the same peer share the prefix which is 2^{2k-p} long (see Figure 3 (left)). The addressing scheme does not rely on a centralized name service neither does it require an external negotiation process. The given the geographic data items offered by a GIS are addressed locally. The bootstrapping stage allows the content of the GIS servers to be placed along the Chord ring.

Based on the number of nodes that discover each other due to predecessor and successor rules (as defined in Chord [7]), it could be said that some clusters with closely stacked data items will emerge. These clusters are quasi continuous, since they are allocating objects to keys which are separated by small or no gaps in the object Chord ring. Based on this, some further optimization of constructing the overlay could be achieved.

The fractal property of the Hilbert curve could be further applied to tree structure node scope as follows:

- Geographic urban groups require well meshed peers, whereas far away nodes are less important in a finger table.
- Transition between large geographic zones need to be supported, to allow ubiquity of the system and support moving between cities or in rural subspaces

Figure 3 (right) demonstrates the addressing principles and scope of each node in the overlay. Objects or data items can described with a higher granularity which suits the geographic information. During bootstrapping iterations, zones could be identified in the sense that those nodes sharing the longest prefix can be grouped to form a subspace representing an urban agglomeration. This subspace is a single Hilbert cluster starting from a min ID and finishing at a max ID.. In the urban subspace, a fully meshed Chord ring is built. The participating peers within that zone can elect a single node which is used as a gateway to access another ring at a higher hierarchical level. This selected node takes as an address with the longest common prefix shared by all the nodes and objects at a lower level and can be part of a smaller sized Chord ring (at a higher level). Each hierarchy is addressed by a different resolution depending on its geographic scope. The efficiency of the multiple Chord hierarchy is proved in [4].

4. Conclusion

A context management architecture has been proposed in this paper in order to build decentralized mobile LBS between context containers. The geographic-centered semantic structure of the information and data is used to address a semantic overlay network. A summary of the requirements for geographic information coding which cares for efficient communication has been listed. The overlay is also structured to limit the scope seen by each node is a global network. The routing aspect is therefore optimized thanks to the self-similarity and fractal addressing scheme offered by the Hilbert space filling curve. The curve can address geographically dense environments with higher granularity, while keeping a less granular knowledge about less dense areas.

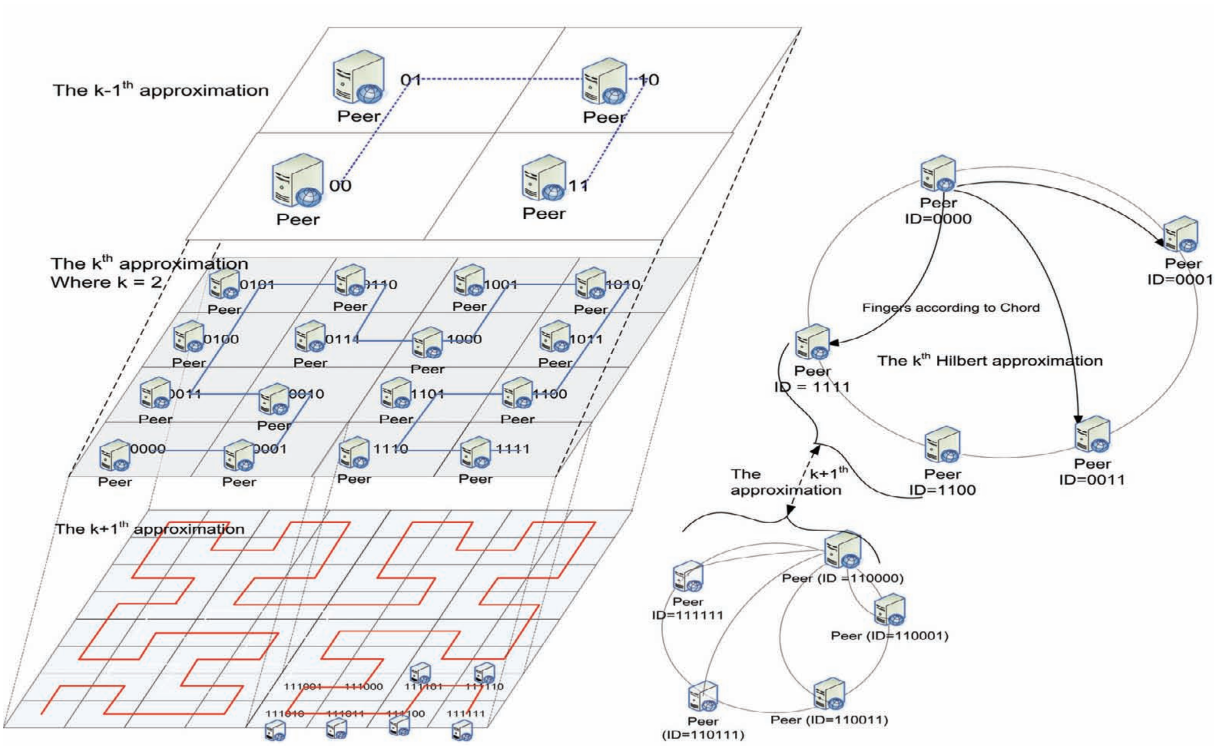

Figure 3. Left: Hierarchical partition of peer IDs following the Hilbert 1st, 2nd, and 3rd approximations; Right: Hierarchical Approach to Partition of Geographically dense spaces to more granular Chord rings

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