# Cell Coverage Area Information Service to Improve Cell Selection in HetNets

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***Abstract*—Information services providing diverse information about networks and their services have been widely cited as one of the key factors to better utilize the heterogeneous network environment. However, the current information services do not properly enable determining the base stations that reside within the range and close-by of a mobile device. The serving range of base stations can only be roughly estimated. Moreover, large variation in cell sizes bring additional challenges with respect to mobility management. In this study, a network information service allowing mobile devices to query for information about base station cells near their location is utilized in cell selection. A spatial database is used to store the coverage area geometries of base stations and the base station coverage area and distance information is utilized in cell selection. The paper presents a clustering method for grouping the cells found in the vicinity of a mobile terminal based on the coverage area and their distance to the terminal, which improves the handover target discovery in a dense cell environment. In pedestrian mobility, mobile network operators likely prefer the use of cells with short range for traffic load balancing purposes. Favoring large cells in the high-speed vehicular mobility, the results show that the number of handovers can be significantly decreased, even cut to half from that attained with the conventional cell selection scheme.**

***Keywords*—*Cell selection, coverage area, heterogeneous networks, information services.***

## I. Introduction

Heterogeneous networks (HetNets) have increasingly been utilized to better keep up with sufficient network resources for substantially increased mobile network usage. The strong growth of mobile data is widely anticipated to continue [1], [2]. One of the main solutions and, at the same time, challenges is to increase the access point density to improve network capacity. Areas that are densely populated are more and more equipped with small cell base stations (BSs) such as femtocell and microcell solutions and IEEE 802.11 access points, in addition to large macrocells. In a typical future HetNet topology, a macrocell coverage area includes several overlapping small cell BSs to support the traffic demand and service coverage. However, a large number of access points nearby and large variation of different types of cells bring additional challenges for efficient mobility management.

Not only academia but also standardization bodies and industry have paid much attention to heterogeneous handovers to better utilize the today's diverse network environment. IEEE 802.21 Media Independent Handover Services [3] and 3GPP Access Network Discovery Selection Function (ANDSF) [4] are specified to facilitate mobility in the heterogeneous multiple access technology based network environment. As the main service for the network discovery they both specify an information service to provide mobility management entities information about the network access points in range and close-by of the inquirer. Current mobile devices are equipped with a capability of knowing their precise geographic location, which can be related to the BS locations, if they are known. Despite that, wireless end systems need still listen to network announcements and beacons in different bands in order to ensure that the BSs proposed by the information services can be used in their current location. This scanning model is not efficient as the number of access points is constantly increasing, especially, when the mobile device supports several access technologies, densely deployed IEEE 802.11 access points are considered, and the mobile network operators (MNOs) share their BS infrastructures.

When designing a wireless network, the coverage area of each BS is often simulated for a consistent coverage and optimal spectrum usage. Once the network is deployed, the coverage areas are often verified with measurements. With all this information, the coverage area of each BS is well estimated. This information may often remain unused once the network is in commission, although it would allow improving, for example, user mobility if it was widely available. Making the BS deployment more dense brings challenges related to the limited radio spectrum, already restricting mobile network deployments. The coverage area information can also help dynamic spectrum access and spectrum sharing by providing timely information about the frequency occupancy in different areas, possibly with information about related licensing. The current information services are proposed to be expanded to provide such geospatial information. In addition to current information such as access technology, frequency band, and location, the coverage area of each BS is stored to a spatial database and made available for mobile devices and network mobility and configuration managers. Thus, for example, a mobile device can find a set of information about BSs of interest that are in range and vicinity through a single query.

In this study, we capitalize on the coverage area geometry enhanced network information service by improving cell selection. The BSs can be divided into different groups based on their operational range, each suiting for different mobility scenarios. Knowledge about BS coverage areas in range enable selecting the BS, which would likely provide the longest-term attachment point. Awareness of BSs residing nearby, outside the current range of a mobile device, allows making proactive mobility planning. The number of handovers can likely be decreased when only large cells are being selected in high-speed mobility. On the other hand, for stationary and pedestrian mobility usage from a load balancing point of view, the MNOs may prefer small cells. The goal of this paper is to show how cell area and BS distance based cell selection can be used to improve the efficiency of mobility management.

The rest of this paper is organized as follows. In Section II this paper is related to previously published studies. Then, Section III introduces the information service and the cell selection method. Section IV presents the simulation results and Section V concludes this paper outlining also future work research items.

## II. Related Work

Overall, the apparent potential of information services are not thoroughly studied in the open literature for improving mobility. More emphasis has been put on event based signaling than use of relatively static information about networks and access points available through information services. However, Buiati et al. have studied the IEEE 802.21 Media Independent Information Service (MIIS) in [5] and present a hierarchical architecture for the MIIS. The geospatial information element addition proposed in this study is fully compatible also with the hierarchical service architecture. Experiments with IEEE 802.21 enhanced Proxy Mobile IP based handover scenarios presented in [6] show that most of the information exchanged during a handover procedure is related to information service queries. The clustering and the coverage area database solutions proposed in this study provide means for better directing the information queries only to the most potential target BSs, decreasing this overhead. The potential of MIIS to improve handover performance through a pre-authentication with the target access point is studied by Christakos et al. in [7]. In [8], MIIS is used to learn an IEEE 802.11 channel list about access points nearby a mobile device.

Frei et al. have compared the 3GPP ANDSF and IEEE 802.21 for heterogeneous handovers in [9]. The information services of both standards are observed as similar, but otherwise the standards have differences. The 3GPP ANDSF allows MNOs to deliver inter-system mobility policies for the mobile devices. These policies can be used to better select the BSs supported and recommended by the MNO to end-users. For example, MNOs could use the policies for controlling the use of different size cells for different mobility types and speeds. In addition to MIIS, the IEEE 802.21 standard specifies event and command services. They can be utilized to assist in the actual inter-technology handover procedures [10].

To the best of our knowledge, studies on cell clustering for improving mobility and cell selection are not publicly available. However, BS clustering for coordinated transmission in HetNet environment is studied, for example, in [11]. Cell selection algorithms have been proposed in a number of papers. Wang et al. [12] have proposed a handover algorithm considering the BS coverage area for different data rates. They estimate the high-speed range through signal power. Handover between femtocell and macrocell has been studied by Bai et al. in [13] and Chowdhury et al. in [14]. Both studies observe the challenge of optimizing mobility with short range femtocells, mostly caused by their short range and substantial number of cells close to each other compared to macrocells. This paper attempts to tackle this issue by means of an algorithm that advocates larger cells in high-speed mobility, not the ones with the highest received signal strength. In [15], Wang et al. have proposed an algorithm for LTE-Advanced heterogeneous networks, and observed that the conventional strongest signal cell selection scheme is not always the optimal cell selection scheme in terms of load balancing, especially, when there are smaller cells, such as picocells, available. This paper shows that basing mobility on BS coverage areas can be used to better control the load balancing in mobile networks.

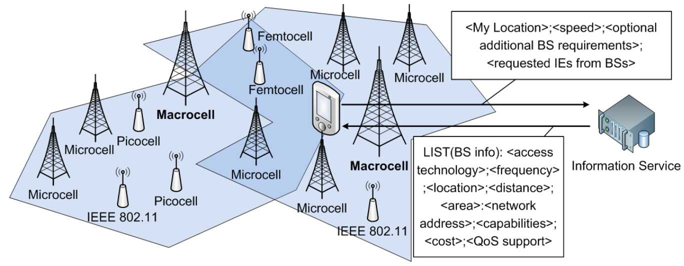


Fig. 1. Coverage area information service.

## III. Cell Area Based Mobility Improvement

The HetNet environment illustrated in Fig. 1 is typical of future network environment. Inside the coverage area of large macrocells there might be several micro, pico and femtocells deployed providing more extensive coverage and better overall network capacity. However, large numbers of various cells pose significant overhead to cell discovery procedure. Moreover, the small area cells are not ideal for high speed vehicular mobility as the number of handovers may substantially increase compared to favoring the use of macrocells. When the mobile device moves slowly (e.g. pedestrian or stationary use), the small cells likely provide the best connection point in terms of capacity as the number of users in their operational range is often smaller than in larger cells. The mobile device sends its information request with the current location, possibly along with other information describing the BS preferences, to the information service, which finds the BSs within range and nearby of the device and returns requested information elements (IEs) about them. The coverage areas stored in the database can comprise relatively strong signal strength areas, such as -80 dBm, or possibly several each with different signal strength level, in order to cope with different mobile devices with different radio sensitivities and sporadic changes in the environment affecting radio signal propagation.

The architecture of such an information service can be either centralized or distributed. For improving spectrum sharing and dynamic spectrum access, a centralized nationwide solution, preferably maintained by regulatory authorities, would likely provide the best solution. However, for mobility usage, the coverage area information services can very well be MNO operated. The operational geographical areas of MNOs are very large, often nationwide, or comprising also various countries. Hence, the database service can be distributed over different regions, like proposed in [5]. Different information services either know the area of responsibility of other information services or there is a centralized entity taking care of that. For example, when the mobile device connects to the network, it receives the network address of its local information service. If the local information service cannot support the location where the device currently resides, the server can forward the query to the information service responsible for the coverage areas in that particular region. To better cope with increasing capacity demand and lack of sufficient spectrum, MNOs should enable inter-MNO queries and roaming.

The number of BSs in the vicinity can be large, even tens of BSs, when factoring in access points from different MNOs and publicly open or MNO-operated IEEE 802.11 access points. Especially, the number of IEEE 802.11 hotspots, known as WLAN in short, is increasing fast, anticipated to grow by 350% from 2011 to 2015 [16]. For example, Japan's NTT DoCoMo is aiming to have 120,000-150,000 WLAN access points in 2013, from having only 8,400 a year back [17]. In Oulu, Finland, the free city-wide PanOulu network[1] has over 1,400 WLAN access points scattered around the city. Thus, in order to lower the processing overhead of going through all possible BSs in range, in this paper, it is proposed to use a clustering method to group BSs based on their distance and cell area. Clustering helps mobile devices find small cell BSs located near for pedestrian use and large cells nearby for high-speed vehicular mobility fast. Most of the clustering problems are NP-hard [18] and when the number of cells becomes large, the clustering is better to be performed on the network side. If the mobility decision entity resides on the mobile device, the clustering could be done on the information service server. In the case where handovers are initiated by networks, the clustering can also be done in the mobility management entity.

The coverage area database must be dynamic because all changes in the BS infrastructure must be reflected by it. The changes that affect the coverage area are, for example, adding/removing of cells, re-directing the antennae, changes in the surrounding environment (buildings, vegetation, etc.), sporadic obstacles, or use of spectrum sharing. To keep the database more actively updated, also end-users could be utilized through specific network measurement applications installed on their mobile devices and reporting signal strength results to the database, similarly to those already available to measure the speed of end-users' Internet connection[2].

Cell selection based on the mobility pace provides MNOs a possibility to enhance their network load balancing. Signaling overhead increases with the number of handovers in the network and in order to reduce that, the fast moving wireless devices can be kept affiliated with one BS longer when switching between large cell BSs. For end-users, handing over large number of cells of different capabilities and load situation may impact the quality of the current services. Knowledge about coverage areas enables also pre-planned and prepared handovers when the traveling route is known like, for example, from the road navigator. In future programmable networks, the route of the mobile user can be optimized in advance and the QoS level requirements guaranteed in each cell to be connected beforehand. For example, making load balancing operations in the BSs on the route of an emergency vehicle in advance would assure that the vehicle has a QoS level guaranteed high speed wireless connection available during the whole emergency situation, although it is moving.

[1] www.panoulu.net

[2] e.g. Netradar (www.netradar.org) and Portolan (portolan.iet.unipi.it)

### A. *Improving the BS Selection*

The number of potential target cells can first be cut by eliminating cells that do not satisfy the basic requirements such as sufficient bitrate for, e.g. video streaming or are detected as congested. However, as the networks are widely evolving, the basic capabilities between different BSs can be perceived as fairly similar for most of the network applications. Thus, we propose a clustering method to be used to facilitate the process of discovering the most suitable target BS. The chosen clustering features used for grouping the cells are the BS distance and the coverage area. However, for the clustering, other features than those can also be considered, such as a guaranteed or expected bitrate in the BSs. The clustering of cells decreases the number of the potential BSs taken, for example, for a more detailed analysis of the BS capabilities to meet the on-going network service requirements. The use cases evaluated in this study are related to high-speed mobility and low-speed or stationary use of wireless networks.

In this study, the cells found as possible target accesses for a wireless device are clustered by using the k-means algorithm. The expectation-maximization (EM) algorithm [19] is used to find the partitioning into $k$ groups. In the EM algorithm, $k$ clusters are created and the items are randomly assigned to them. After that, the centroid of each cluster is calculated as the mean data vector averaged over all items, and for each item the closest cluster centroid is determined where the item is reassigned to [20]. This process is iterated until no further item reassignments occur or the user-defined maximum number the EM algorithm will be run is exceeded. The cluster centroid is defined as the mean data vector averaged over all items in the cluster. In order not to give the cell area too much weighting, taking a square root of it before passing to the k-means clustering algorithm was observed to be helpful.

Once the BSs are clustered, the mobility management algorithm selects the cluster whose centroid describes the optimal target access point solution best. Fig. 2 illustrates a simulated example of network environment with different cell sizes, where the BSs in range and nearby (the distance to the cell coverage area is at maximum 500 meters) of a mobile device are clustered in four groups. The markers filled in light gray indicate the BSs within the range of the mobile device. If only those BSs are being clustered, the division is naturally different than shown in Fig. 2 due to the difference in number of items. Knowing the point of attachments currently in range facilitates the assessment of the all cell candidates. For high speed mobility, the cluster items shown as cross are the most potential target cells as the distance of the BSs are relatively short and the cell areas are large. This cluster, considered as vehicular cell cluster in this study, is found by comparing the centroids with two largest areas and selecting the one with shorter distance. However, as the example shows also the BSs in the vicinity, outside the range of mobile device, the BSs shown as triangle markers are of possible interest in the future, as well. Diamond items depict the potential cells for pedestrian mobility and stationary usage.

## IV. Results

The proposed solution to optimize mobility has been studied through simulations. In the simulations, different size cells

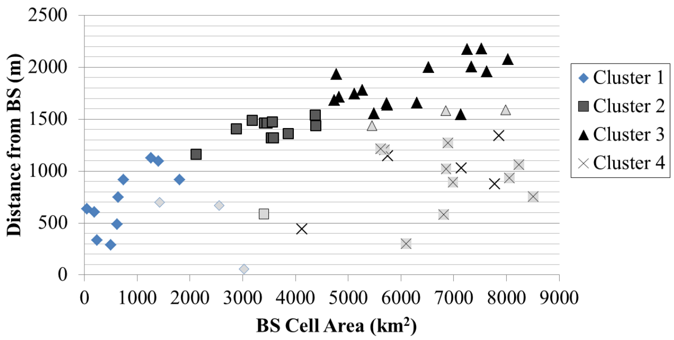


Fig. 2. Clustered BSs found in vicinity.

TABLE I. CELL COVERAGE DISTANCE RANGES

| | Femto | Pico | Micro | Macro |
|---|---|---|---|---|
| $R^c_{min}$ (m) | 10 | 20 | 100 | 600 |
| $R^c_{max}$ (m) | 20 | 100 | 600 | 2000 |

are randomly located across a square area, with sides of 10 kilometers long. The cells are represented by a polygon geometry model. The polygon vertices are given as geographical coordinates that are stored in a spatial database, PostgreSQL (version 9.1.5) with the PostGIS extender (version 2.0.1). The coordinates are handled in a Universal Transverse Mercator (UTM) format, which allows easy meter based locationing for the simulations. The cells are shaped as heptagons, but the beam direction for each cell is randomly selected. The cell sizes are meant to roughly represent realistic femto, pico, micro and macrocells. However, the polygons used in the simulations do not include coverage holes typical of coverage areas in practice caused by different kind of signal propagation obstructions. The BS range ($R$) for each cell is uniformly distributed random value

$$R \sim U(R^c_{min}, R^c_{max}),$$

where $R^c_{min}$ and $R^c_{max}$ are listed in Table I for different cell types. In the evaluation, three different distributions of different types of cells are used. The proportional distributions of different cells in the measurement area for each scenario are given in Table II. Scenario 1 (S1) includes mostly macrocells while Scenario 2 (S2) and Scenario 3 (S3) increase the number of smaller cells. The coverage area of WLAN access points are, in general, comparable with the femtocells and picocells.

The measurement area does not emulate any specific environment (e.g. terrain, buildungs, etc.), but the BS cells are randomly located within the measurement area. The simulations were performed with different number of cells in the area; 500, 1000, 2000, and 3000 cells. The first simulation setup was to randomly select different locations in the area and querying for BSs within the range of mobile device and in vicinity. These simulation runs were repeated 1000 times for each number of cells in the area by using different random locations each time. Another setup was to simulate high speed vehicular mobility in the area. The whole area was gone through from left to right 100 times using a different random route in each run. The results show how the number of handovers can be decreased when the target BS is selected from the optimal cluster with respect to the distance and area, for example, shown as Cluster 4 in Fig. 2. The target BS is randomly selected from the cluster considered as the most potential one. For the optimal selection, all BSs in the cluster should be gone through regarding their capabilities. The non-optimized method chooses the nearest BS, which attempts to represent the traditional cell selection scheme where the BS with the highest signal strength is selected. The simulations do no take radio channel into account. The operational ranges of BSs are based on the coverage area polygons stored in the database.

TABLE II. CELL TYPE DISTRIBUTION SCENARIOS

| Scenario | Femto | Pico | Micro | Macro |
|---|---|---|---|---|
| 1 | 0.15 | 0.35 | 0.2 | 0.3 |
| 2 | 0.2 | 0.4 | 0.2 | 0.2 |
| 3 | 0.3 | 0.3 | 0.3 | 0.1 |

The simulation setup is implemented in Perl. First, a different number of cell polygons according to the measurement scenario are generated and stored in the database. Another Perl script was implemented for querying the database in different locations for cell availability. For the database operations the DBI module is used and the C Clustering Library [20] is used to divide the BSs into $k$ k-means clusters. If $k$ is too large, finding the most appropriate cluster becomes difficult and the most potential target BSs may easily be divided into different clusters. On the other hand, making $k$ very small diminishes the gain of reducing the number of potential future handover targets from all discovered. Thus, in this study $k = 4$ to provide cluster diversity, however, without adding too much complexity for the cluster selection. The used limit for the EM algorithm iterations is set to 100.

## A. *Querying for Base Stations*

Fig. 3 presents the division of cells found to cover the mobile device's current location into categories of pedestrian cells, vehicular cells, and other cells. The use of other cells are not considered in this study, but they are left for the future development of the cell selection algorithm. They should be included in normal mobility management scenarios, possibly based on clustering with different features than area and distance and different mobility speeds than considered in this paper. It can be observed that the number of overlapping cells is the higher the more large cells are incorporated into the measurement area. However, the number of cells found in the different scenarios are not comparable, but the goal is to study the advantages of the clustering with the different cell type distribution models. For example, S1 includes mostly macrocells and the observed overlapping between cells in different locations is the highest. As the wireless network design aims to optimize the coverage and spectrum usage, the number of overlapping macrocells should be minimized. Thus, this scenario is mostly representative of the case where multiple MNOs share their network infrastructure for inter-MNO roaming purposes. S3, on the other hand, contains more femtocells and picocells, which causes significantly lower cumulative coverage area with the same number of BSs than in S1 and S2. Due to the largest number of small cells in S3, it most likely reflects the future BS infrastructure best.

By using clustering for the cell features, namely BS distance and cell area, the number of cells discovered to well suit high-speed vehicular mobility can be significantly decreased,

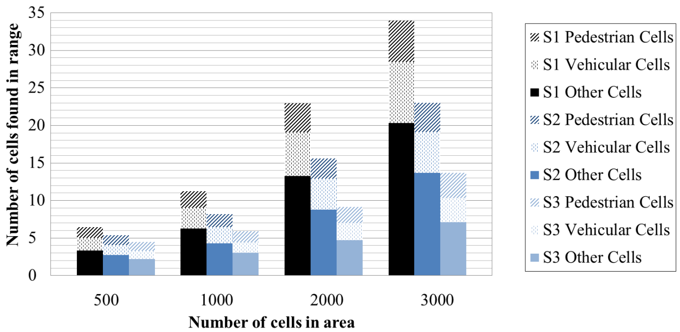


Fig. 3. Distribution of cells in range.

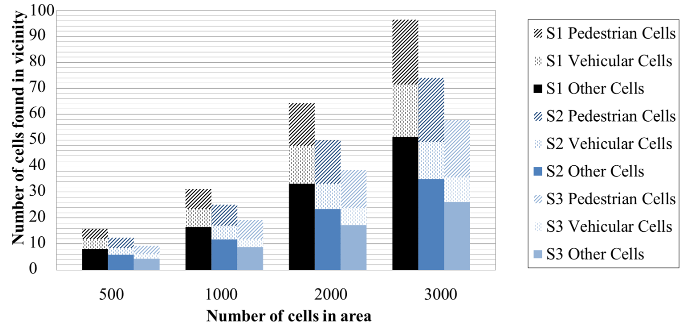


Fig. 4. Distribution of cells in vicinity.

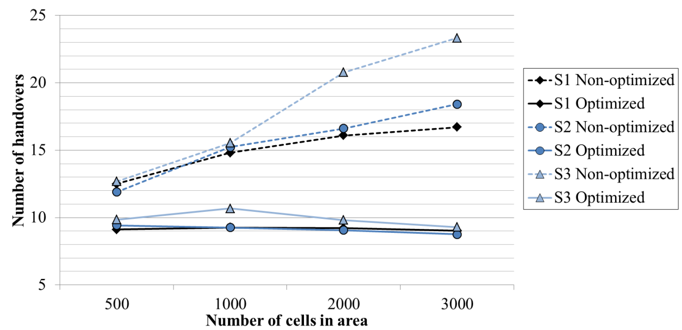


Fig. 5. Cell size improved mobility.

on average by over 75% in all measured cell distribution scenarios. When the measurement area is equipped with 500 cells, the average number of overlapping cells in different locations is observed to range only from four to six. The clustering method does not bring much advantage to the cell selection in this case, but the optimal target BS can be selected by going through all the BSs. However, the gain is more pronounced the more cells the area includes. For example, in S1 with 2000 cells, the average number of overlapping cells is 23. Taking only the cells from the selected cluster for high-speed mobility into closer consideration decreases the number of candidate target cells down to six, 17 cells less than found in total. In S1, where the number of macrocells is the biggest, the cells classified as pedestrian cells by the algorithm account for only 16% of all discovered cells in range when the area is deployed with 2000 and 3000 cells. Similar results are observed in S2, but in S3 the pedestrian cell ratio increases to 24%, due to the larger proportional amount of small cells. Although the attained gain in S3 is observed to be less significant than in S1 and S2 with respect to the small cell discovery processing, the importance of coverage area based cell selection is expected to be more evident when the amount of femtocells and picocells is high.

For making the cell selection procedure more proactive and reducing the frequency of inquiries, knowledge of BSs in the vicinity, considering also cells nearby but whose operational range does not yet cover the inquirer's current location, allows planning the required handovers in advance. For example, if there is a very good potential BS nearby, possibly providing a long-term attachment point, the next access point to reach it may not necessarily be that important to be assessed in detail if the distance to it is relatively short. Also, if the mobility route is known, for example, from a road navigator, a next few target access points can be evaluated beforehand. Fig. 4 shows the number of BSs found within range of and close-by a mobile device. A cell is factored in the results if the distance between the cell area border and the mobile device is at maximum 500 meters. Naturally, the number of found cells increases when the area the BSs are queried from grows, which improves the gain of the clustering method. With 3000 cells, the average number of cells found in vicinity is 57 in S3 and grows up to 96 when considering S1. From these cells, only about 20% are classified as large cells with relatively short distance from the BS to the mobile device. However, when the cells close-by are taken into consideration, the ratio of femtocells and picocells increases in all considered scenarios. In S1, about 25% of cells belong to the pedestrian cell cluster with each measured number of cells in the measurement area. In S2, the proportion of small cells is about 33% and in S3, even a ratio of 39% is reached. When the perceived proportion of small cells becomes high, the cell selection in high-speed mobility needs more attention.

### B. *Vehicular Cell Selection*

The previous results indicated how the cell discovery processing can be mitigated by using the clustering method. Fig. 5 depicts how the number of handovers decreases when the target cell is selected from the cluster considered as most suitable for the high-speed mobility. Already with 500 cells in the measurement area, an improvement of over 20% with respect to the number of handovers can be observed with all cell distribution scenarios. In overall, the performance can be perceived the better the more small cells are deployed in the measurement area. For example, with S3, including least macro cells, the number of handovers is more than half of that in the non-optimized case. The standard deviation in the number of handovers is also smaller in the optimized case, the deviation gain ranging between 0.4 and 2.5 from 500 cells to 3000 cells in the area, respectively. However, not much variation between the cell distribution scenarios is observed.

The cell selection aims to affiliate with BSs residing nearby and serving a large area. Already with 500 cells, the average area of the selected cells is 62% larger than in the non-optimized case. In S3, the algorithm results in 25% larger cells, on average. Going to 2000 and 3000 cells, in S1 the average area of the selected cells is more than twice as much as in the non-optimized case. Over three times larger cells are selected in S3 due to the optimization of cell selection, on average.

Selecting the target BS from the cluster, which includes large cells but is close to the mobile device does not necessarily result in the optimal solution. In the case of large cells, a cell that is far but within range could still provide the longest-term continuous connection. However, the route the wireless device is traveling needs to be known beforehand to make the optimal decisions. Selecting the target from the cluster including also large cells, but whose centroid is further than in the results shown in Fig. 5 causes, on average, more handovers. With 2000 cells in the measurement area, by selecting the target BS from the nearer cluster results in 10% and 14% better handover rates in S1 and S2, respectively. With 3000 cells, in S1 the improvement is 6% and in S3 10%. Thus, selecting a large target cell that is also relatively near provides a good trade-off when the upcoming traveling direction is not known.

## V. Conclusion and Future Work

For mobility, network information services can help mobility managers select the most optimal target BS in case of handover. Enhancing the current information services with BS coverage area geometries, many mobility decisions can be made more accurate by basing the decisions only to that information. Through a single query, a mobile station can receive information about BSs in range without need for scanning wide frequency bands, possibly occupied by different access technologies. The number of discovered BSs at and near the wireless device will substantially increase in the future as the increasing capacity demand compels MNOs to increasingly deploy small-cell BSs. Moreover, better utilization of the wireless networks and more efficient use of the very limited spectrum indicates need for sharing of MNOs' BS infrastructure and considering national roaming agreements, providing mobile devices more BS options to connect to. In the proposed clustering method, either the information service or the handover decision entity groups the potential target BSs in terms of cell coverage area and BS distance in order to take only the most suitable BSs into closer consideration. The clustering method proposed decreases the processing overhead of going through all possible handover target candidates. For example, when the proportion of macrocells in range is small, clustering the BSs into four groups in high-speed mobility decreases the potential handover targets by even more than 80%. The results also showed that selecting only the large cells located near for the high-speed mobility use, the number of handovers can be reduced even by half compared to the cell selection scheme choosing the nearest BS.

The cell selection algorithm presented in this paper is not fully optimized, but the main goal was to show the benefits of using coverage area information as an additional information element of current information services to improve mobility management in HetNets. High in the future work agenda is to improve the algorithm and to incorporate the coverage area information into an IEEE 802.21 information service implementation for hands-on tests. The practical implementation is planned for conducting signaling scalability evaluation and finding the best practices for the clustering method.

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