Investigation of IEEE 802.11k-based Access Point Coverage Area and Neighbor Discovery

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***Abstract*— Possessing knowledge about access point coverage areas and neighbors is of essential need for the provisioning of, e.g., location based handovers or push services. A convenient method for their discovery is the usage of information obtained by the mobile devices which are currently associated with the access points. The time span being required for the discovery of coverage areas and neighbors is fundamental in order to assess the suitability of such a method in a dynamic environment.**

In this paper, exemplary numerical results of the required bootstrapping phase for the information determination are presented. Additionally, a relatively simple enhancement of the algorithm computing the coverage areas is introduced, reducing the number of vertices for the description of the areas.

Besides, the paper shows how the upcoming IEEE 802.11k standard enables APs to query mobile devices for location and neighbor information and hence presents for the first time an entirely standard compliant acquisition scheme.

I. Introduction

In the recent years, application scenarios such as new location based services [1] as well as fast and seamless handover support for highly mobile users [2], [3] employ information on a mobile's position as well as on the coverage area and neighborhood of access points. Generally speaking, the coverage area of an access point consists of all locations from which mobile devices can communicate with it, i.e. where the quality of the radio transmission exceeds a certain minimum. Because of the propagation phenomena, such a coverage areas has usually a pretty irregular shape, dependent on the environment, and is rather hard to predict.

The coverage area may even be variable. For instance, emerging projects standardize wireless networks operating in higher frequency bands [4], [5] which are vulnerable to environmental changes, e.g. rain, and thus experience pretty high dynamics. In addition, upcoming WLAN systems tend to move away form the paradigm of having static APs towards mobile relay stations: The most recent example is IEEE's 802.11s working group extending its scope towards mobile mesh access points/relay stations [6], [7].

Therefore, there is a need for measurement based coverage area estimation. One attractive option is just requesting mobile terminals connected to a given access point to report their location, and develop a coverage area estimate on the basis of these reports. In order to obtain some reasonable estimate, reports have to be collected at least over some period – which we will call the bootstrapping period. Unfortunately, the authors have not been able to find any research results giving some hints how long the bootstrapping phases could be, which is mandatory to gauge such a scheme's suitability considering the dynamics of a given environment. Hence, this work evaluates the bootstrapping phase of such a approach employing mobile devices to discover an AP's coverage area and neighborhood.

In this paper, we consider the coverage area estimation for IEEE 802.11 compliant wireless LANs. In particular, we propose for this purpose an entirely standard compliant report acquisition scheme based on the IEEE 802.11k amendment for radio resource measurement [8], and evaluate the length of the bootstrapping phase.

The remainder of this document is structured as follows: After summarizing related work, Section III introduces IEEE 802.11k and elaborates its possible usage for discovering an AP's neighbors and coverage area. Section IV details the coverage area estimation approach selected for the case of area based services which is evaluated using the simulation model introduced hereafter. Finally, Section VI presents simulation results of the bootstrapping phase length. The paper concludes with an outlook to the next steps of our ongoing work.

II. Related Work

Imielinski & Navas [9] and Stojmenovic et al. [10] identify the need to discover AP coverage area as well as neighborhood for geocast-based routing. The former employ information on the coverage area to determine to which AP – more precisely to which *GeoNode* being responsible for the dissemination of information in a certain area – messages are to be routed. The latter in turn utilize knowledge on each AP's neighborhood to forward messages towards their geographic destination area.

The authors of [11] elaborate such a coverage area based approach and present an architecture for the support of geocast services in cellular mobile networks. Even though the paper discusses problems like the mapping of geocast target regions to the boundaries of the wireless cells, routing and the required signaling procedure, the entire problem how to discover the coverage area is omitted.

In [12], a trial system for location aided handovers in heterogeneous wireless networks is described. In the approach, mobile devices report their current location to enable an entity in the backbone to decide on a handover based on this

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information. Even though the authors suggest the usage of field strength measurements of the mobiles for the generation of coverage information, they do not elaborate this acquisition but assume coverage information to be a priori available.

A general architecture for the acquisition and provisioning of wireless hotspot coverage information is presented in [13]. Field strength measurements of mobile devices are collected, processed and polygons describing the boundaries of the radio cells are generated. The approach is designed for the discovery of wireless hotspots close to current user positions but does not consider the dynamics of variable radio channel conditions thus affecting the size of the coverage area.

None of the presented papers considers the characteristics of the initial phase needed for the discovery of the coverage areas and neighbors. All assume this information to be available and valid over long time periods.

III. IEEE 802.11k Based Information Determination

The IEEE 802.11k draft specifies a wide variety of mechanisms for the support of WLAN radio resource measurements but does neither directly address

- how to discover an AP's coverage area, nor
- how to construct a local database containing the AP's neighbor information.

The following subsections describe how the existing schemes specified in 802.11k can be intelligently combined in order to achieve these two goals in an entirely standard compliant way.

The proposed request/response based mechanism for the information retrieval enables a dynamic adoption to the capabilities of the access point, e.g. an enlargement of the request intervals if the received location reports exceed a certain amount. We believe this to be important, since the computation of coverage areas requires a non-negligible amount of computing power from the access points.

A. 802.11k Based Location Data Exchange

An access point periodically requests location reports from the terminals (mobile devices) which have currently connectivity with this access point.

IEEE 802.11k provides *location configuration information* (LCI) requests for the inquiry of station positions. These are broadcasted by the access points to the devices in their coverage areas. To avoid storms of reports, the access points add a measurement start interval to the requests. Terminals select a uniformly distributed random time from this interval as start time for the generation of the reports.

An LCI request is sent as a part of an *action* frame with frame type set to *radio measurement request*. The category field is set to *radio measurement*. The action frame with its content is carried by a legacy IEEE 802.11 *management frame*.

In an infrastructure *basic service set* (BSS), action frames belong to class 3 frames. Thus, terminals will only handle LCI requests from currently associated access points.

The associated terminals which possess the requested 802.11k capabilities to perform radio measurement actions will respond with LCI reports, containing their current locations. The positions are formated based on the IETF RFC 3825 standard [14], including 16 Bytes for Latitude, Longitude, Altitude and optionally 2 Bytes for Azimuth information. The acquisition of the position itself is not part of the amendment.

The transportation of the LCI reports from the terminals to the access points is performed similar to the one used for the sending of the requests. The reports will be inserted in action frames of type *radio measurement report*. The action frames will again be carried by management frames.

B. 802.11k Based Determination of Neighboring Access Points

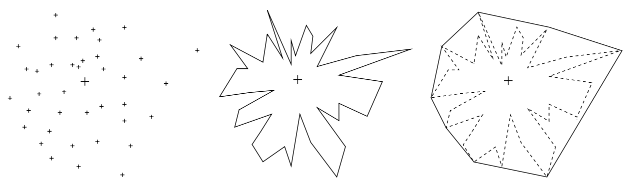
An access point is considered as a neighbor of another one if their coverage areas intersect. In the following paragraphs, two different IEEE 802.11k based mechanisms for the determination of the access point neighbors will be presented.

1) An access point learns about its neighbors from associated terminals which report the beacons being currently received from other access points to it. Afterwards, relevant information like the positions of the access points can be directly communicated between the access points, e.g. over the distribution network.
2) The terminals report not only the beacons, but also the position where these have been received. Such information enables an access point to estimate the coverage areas of its neighbors.

Both mechanisms rely on information being exchanged between the access points and the associated terminals. For the exchange of the location configuration information the same action frame based response and request scheme will be used that has been presented in the preceding subsection.

In the first mechanism, access points send *beacon requests* to the associated terminals, challenging these to report beacons received from other access points. The requests contain the regulatory class, channel numbers, BSSIDs and service set identifiers (SSIDs) for which a beacon report is requested. Since some information may not be available in advance, e.g. the BSSIDs, wildcard values can also be used in this context. A measurement mode indicates a method that has to be used for the beacon measurement, together with an appropriate duration. The mode can either be active via probe requests, passive or beacon table, whereas the latter one simply requests the recently received beacons from the mobile device without requiring additional measurements. Other parameters regulate the conditions under which a measurement should be reported, e.g. after each measurement or depending on a certain received channel power indicator (RCPI) or received signal to noise indicator (RSNI).

After a mobile device performed the measurement, it will generate a beacon report with the body of the latest received beacon or probe response for each different BSSID. Additionally, information about the physical channel like RCPI and RSNI, the actual regulatory class, channel number and BSSID as well as the measurement time and duration is transferred.



(a) Point cloud (b) Polygonal description (c) Convex Hull

Fig. 1. Computing the coverage area of an access point based on reported mobile device positions

For the second mechanism, the estimation of the neighbor coverage areas, a combination of beacon and LCI requests can be deployed. The IEEE 802.11k amendment allows multiple measurement elements to be included in one measurement request or report. Since the starts of both measurements are bounded to a random delay for the avoidance of report storms, the position determination and beacon measurement may not correlate with each other. This problem can be solved by a so-called parallel bit in the measurement request frames. Setting this bit in a measurement element indicates the mobile device that it has to perform this measurement in parallel to the one in the following element.

IV. Computation of Access Point Coverage Areas

There are numerous possibilities how the coverage area estimates could be derived from the terminal location reports. In fact, depending on the goal, such estimation might be done in a more conservative or more progressive way.

We claim that the following approach is useful for area based services, i.e. services which should be provided to all users available in some specific area. All associated terminals will be periodically requested to report their locations to the access points. Each access point stores the coordinates of all positions from its terminals, which leads to a certain cloud, e.g. as depicted in 1(a). For each direction from the access point we will determine the furthermost position reported by any terminal during the whole bootstrap phase. By connecting these positions via straight lines, a polygonal description of the coverage area can be generated (see Figure 1(b)).

The mechanism has the drawback that the polygonal description of the coverage area may consists of a large amount of vertices which steadily grows if new mobile device positions are to be added. This pertains to the computational complexity of the algorithm, and thus its overhead. In earlier work, the problem of a steadily increasing number of vertices has been identified [13]. With the number of vertices, the complexity of the decisions e.g. to forward messages via certain APs grows and reduces the efficiency of the mechanism.

Thus, suitable mechanisms for the reduction of the vertices are required. One of the mechanisms for the approximation of shapes leading to relatively good results regarding the compliance of the original and approximated shape and the reduction of vertices is the usage of convex hulls [15]. A convex hull is the smallest convex polygon enclosing all points of the actual coverage area (see Figure 1(c)). For a given number of points n, it can be computed in time $O(n \log(n))$.

Newly reported positions of the mobile devices become the vertices of the convex hull, if these are not laying within the boundaries of the existing polygon. Nevertheless, the problem of a steadily growing number of vertices still exists. To overcome this problem, we propose to only add vertices to the convex hull if the area of the new polygon is increased by $a_{\min}$ percent. Obviously, this approach will increase the deviation between the original and approximated area. Numerical results for different $a_{\min}$ will be presented in the remainder of this paper.

V. System Model

For the evaluation of our approach, we consider a large rectangular geographical territory $T = [0, a] \times [0, b]$, being covered by a wireless access network with N_{AP} IEEE 802.11 WLAN access points. A number of N_{U} users is moving in the territory. Every user owns an IEEE 802.11 compliant mobile device. The devices are aware of their current positions, for instance via GPS [16] or other appropriate schemes [17].

Wireless Channel – For the modeling of the wireless channel, we use a widely deployed, simplified model (see [18]). The pathloss, i.e. the attenuation of the received signal power P_{RX} during the transmission from an access point at position X_i to a mobile device at position U is computed via

$$P_{\mathrm{RX}} = P_{\mathrm{TX}} \cdot \frac{K}{|U - X_i|^{\alpha}} \tag{1}$$

where P_{TX} denotes the transmission power of the device. The constant K and distance power gradient α reflect the attenuation characteristics of the considered environment.

As long as the strength of the received signal and the ratio between the power of the signal and some interfering noise (*SNIR*) stays above a certain threshold, the mobile device can communicate with the access point. The *SNIR* is computed via

$$SNIR = \frac{P_{\mathrm{RX}}}{P_{\mathrm{N}} + P_{\mathrm{I}}} \tag{2}$$

with P_{N} denoting the equivalent power of the noise and P_{I} the interference of ongoing transmission of other devices.

Access Point Placement – For the investigation, access point positions are aligned deterministically in a hexagonal structure, which leads to constant distances d_{AP} between adjacent access points. Such an alignment has been recently used for the investigation of wireless networks and permits easier identification of the influence of, e.g., overlapping coverage areas on the analytical results.

User Mobility – In order to evaluate the effects of the resulting spatial user distributions, two different mobility models are used throughout this investigation. The first one is a slightly modified random waypoint model. At the beginning of each investigation, the users choose random starting positions in the geographical territory. Then, each user individually selects a uniformly distributed destination for his movement, together with a certain speed $|v_0|$ from a given distribution. Afterwards, each user moves to his destination via the shortest path. As soon as he arrives, a new destination is chosen.

The speed $|v_0|$ is left constant during the investigation in order to prevent slower users from traveling longer through the territory and thus making the stationary speed distribution differ from the initial one (see [19]). The stationary spatial distribution of the mobile devices is not uniform regarding the geographical territory, since users tend to reside in the middle of the territory with a higher probability.

The second model is derived from the Gauss-Markov model which has been presented in [20]. Users choose uniformly distributed starting positions in the territory and directions for their movement, together with a speed $|v_0|$ from a certain distribution, resulting in an initial velocity vector v_0.

After moving for a fixed duration t_{travel}, a new velocity and direction is selected. The new movement in a time interval n is computed via

$$v_n^* = \alpha_{\text{m}} v_{n-1} + (1-\alpha_{\text{m}})\mu + \sigma\sqrt{(1-\alpha_{\text{m}}^2)}w_{n-1} \quad (3)$$

where v_{n-1} is the movement in the previous time interval $n-1$. The w_{n-1} denotes an uncorrelated two-dimensional Gaussian process with zero mean and unit variance. The memory level $\alpha_{\text{m}} \in [0,1]$ affects the principle mobility behavior of the users. For small α_{m}, the Gaussian component outweighs the influence of the previous movement, leading to a random walk mobility pattern with mean μ and standard deviation σ.

For a more deterministic behavior, we compute the unit vector of Equation 3 and multiply it with the norm of the initial velocity v_0, i.e.

$$v_n = \frac{v_n^*}{|v_n^*|} \cdot |v_0| \quad (4)$$

in order to determine the velocity vector v_n. If a mobile users reaches the boundary of the territory, his movement direction will be reflected. The model leads to a uniform spatial user distribution.

Metrics – The accuracy of the decision e.g. to choose a particular AP for the transmission of geocast information depends on the availability of the coverage regions and neighbor information. Thus, the investigations will focus on two primary metrics. The first one is the ratio of the areas of the discovered and original coverage regions of an AP. Here, the original region is defined by the circular region resulting from the maximum transmission range. The second metric is the ratio of the number of already discovered neighbors and those which can be theoretically determined, again under the assumption of the maximum ranges. Access points are considered as neighbors if their coverage areas intersect.

VI. Investigation of Bootstrapping Behavior

The determination of the coverage areas and neighboring access points that has been presented introduces a certain bootstrapping phase, where the access point has to obtain the information from the reports of the mobile devices. In this section, the duration of this phase is investigated under varying radio transmission ranges and thus number of neighbors and coverage area sizes.

For the numerical investigation, the required mechanisms have been implemented and integrated it in the discrete event simulation tool *OMNeT++* [21].

For the discovery of the coverage areas, the access points send LCI requests at a rate being uniformly distributed in between 3 and 4 seconds. The interim of beacon requests for the discovery of the neighbors is drawn from a uniform distribution in between 5 and 6 seconds. The scanning for beacons is performed for a duration of 1 second. The measurement start interval being used for the avoidance of reply storms has a length of 0.1 seconds.

The considered IEEE 802.11 devices use 5 different channels being randomly assigned to the access points. Each access point emits beacons with a period of 0.1 seconds. Mobile devices use passive scanning for their detection. If a mobile device is associated with an access point and does not receive one of its beacons in an interval of length 0.35 seconds, the connection is assumed to be lost. The device will then scan the 5 used channels and try to establish a connection with the access point whose beacons are received with the largest power. The parameters of the models being presented in Section V are summarized in Table I. Regarding the mobile users, a mixture of three different categories (pedestrians, vehicular and others) with different speeds will be investigated.

TABLE I
Simulation Parameters

Parameter		Value
Territory	T	$1\,\text{km} \times 1\,\text{km}$
Number of APs	N_{AP}	30
AP distance	d_{AP}	$200\,\text{m}$
Number of Users	N_{U}	50
User speed	$\lvert v_0\rvert$	50%: 1.5 m/s, 20%: 5.5 m/s & 30%: 15 m/s
Travel duration	t_{travel}	30 s
Mean	μ	0
Standard deviation	σ	1.5, 5.5 & 15 m/s
Memory level	α_{m}	0.9
Transmission power	P_{TX}	12, 30 & 100 mW
Attenuation	K	-40 dB
Power gradient	α	2.8
Bandwidth	B	20 MHz
Data rate	R_{bit}	2 Mbps
SNIR threshold	$SNIR_{\text{treshold}}$	14 dB
Equiv. noise power	P_{N}	-100 dBm
Min. signal strength	$Sensitivity$	-86 dBm

The transmission powers which are chosen in the simulations (cf. Table I) result in maximum transmission ranges r_{max} of 106.3, 147.5 and 226.7 meters, respectively. For the analysis, only those APs are considered whose entire coverage areas lie completely within the geographical territory T.

The intervals in the following graphs denote the 95 % confidence intervals that were computed based on the mean values of all base stations and on 10 simulation runs. Appropriate

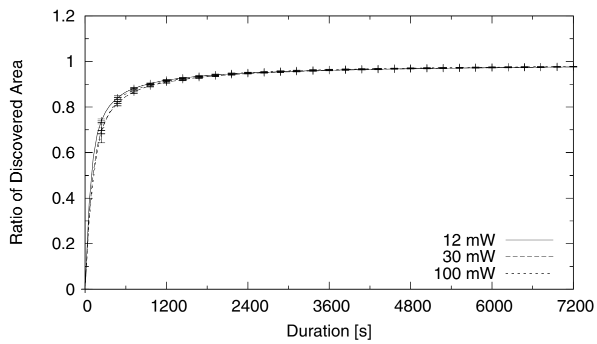


Fig. 2. Duration of coverage area discovery (Gauß-Markov mobility model)

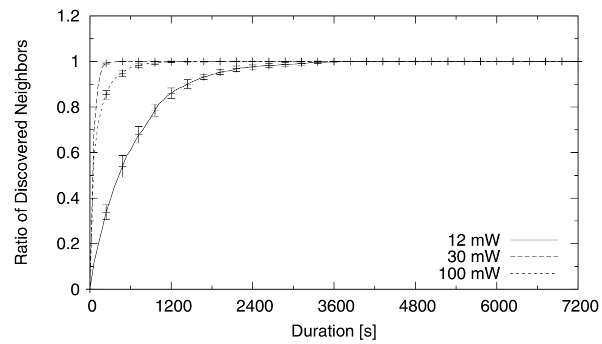


Fig. 4. Duration of neighbor discovery (Gauß-Markov mobility model)

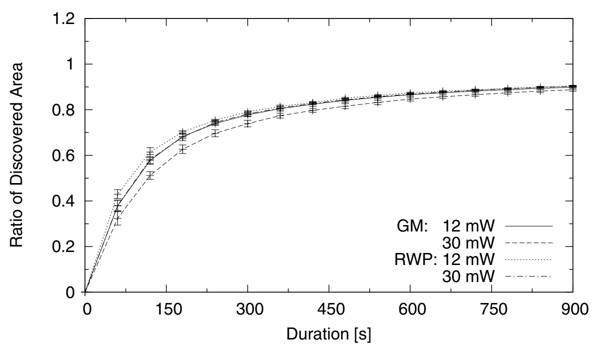


Fig. 3. Influence of mobility model on ratio of discovered coverage area

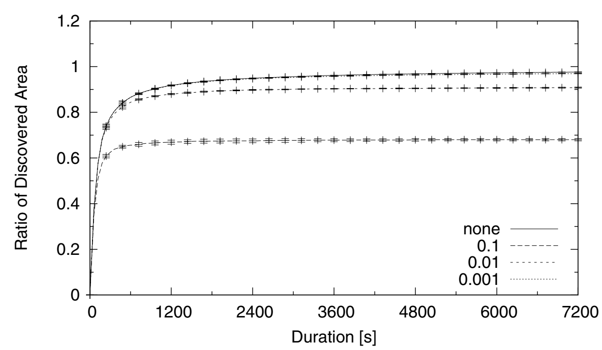


Fig. 5. Effect of limiting the number of LCI reports on the accuracy of the coverage area approximation (12 mW transmission power)

transient phases, e.g. for the random waypoint mobility model, were taken into account before the recording of the values.

Figure 2 illustrates the ratio of the discovered AP coverage area over simulation time. The ratio of the discovered area at a given time during the bootstrapping phase is slightly better for smaller transmission powers whereas the duration of the bootstrapping phase is generally independent of the amount of overlap. Roughly 91% of the coverage areas has been discovered after 20 minutes. Another 3% of the coverage area is gained by doubling the duration of the bootstrapping phase.

The results were validated against the influence of the Gauss-Markov (GM) and random waypoint (RWP) mobility model as shown in Figure 3 for small and medium transmission powers. Even though the difference of the results for the first half of the 20-minute bootstrapping phase is statistically significant, the absolute difference of the reported means is less than ten percent. The same tendency, i.e. a slightly better performance of RWP mobility at the beginning of each bootstrapping phase, is observed throughout all simulations but not illustrated in the following plots due to readability.

In contrast to the discovery of the coverage areas, the effect of overlapping coverage areas is of huge importantance for the discovery of neighboring access points. Network configurations having a large overlap of adjacent radio cells perform significantly better when it comes to the discovery of the AP's neighbors as plotted in Figure 4.

The larger the overlapping coverage area, the longer is the dwell time of a mobile within this region. Hence the time a STA has possible connectivity to its current AP and at the same time to its neighbors is longer, which in turn increases the chances of successfully scanning and reporting the AP's neighborhood. Thus, in general, increasing the overlap yields a reduction of the bootstrapping phase regarding the neighbor discovery as seen for the 12 and 30 mW cases.

The 100 mW case illustrates the limits of this gain: Here, the coverage area is so large, that an AP has more neighbors as compared to the 12 and 30 mW cases. Accordingly, it takes slightly longer to discover the same percentage of existing neighbors.

Final simulations demonstrate the influence of limiting the number of IEEE 802.11k LCI reports which cause an update of the AP's coverage area approximation. Figure 5 illustrates the effect if only those reports are used if the increase of the approximated coverage area is larger than a given threshold $a_{\min}$. For a threshold of 0.001, the ratio of the discovered area is statistically not distinguishable as compared to updating the approximation with each LCI report (threshold = none). The loss of accuracy for a threshold of 0.01 is still below ten percent whereas a threshold of 0.1 results in a significant accuracy degradation.

Figure 6 shows the number of required vertices describing the approximated areas. At the end of a 20-minute bootstrap-

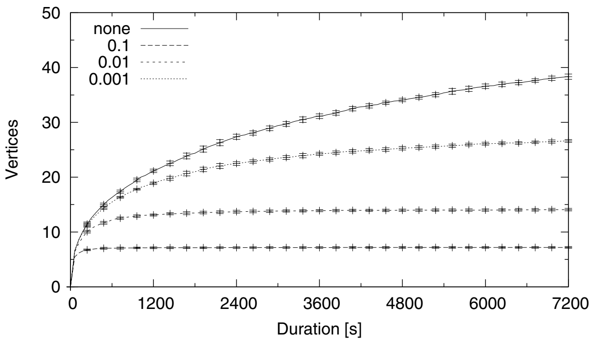


Fig. 6. Reducing the number of vertices of the coverage area's approximation by limiting the number of LCI reports

ping phase, even the smallest threshold of 0.001 can reduce the number of required vertices by more than 18% without effecting the accuracy of the coverage area approximation. By accepting a minor drawback regarding the accuracy of the coverage approximation for a threshold of 0.01, the number of required vertices can be further reduced to 50% as compared to incorporating all measurements in the coverage area approximation. After 120 minutes, the gain is even more obvious as the number of required vertices is reduced to 30.6% and 63.3% for the two thresholds of 0.001 and 0.01 correspondingly.

VII. Conclusion and Outlook

In this paper, we presented the deployment of standard compliant IEEE 802.11k mechanisms for the determination of access point coverage areas and neighbors. Exemplary numerical results were determined, showing the characteristics of the required bootstrapping phase. The gained results are beneficial to e.g. assess the suitability of such a mechanism for the deployment in scenarios with dynamically changing access point coverage areas.

Since the subsequent computational effort for the usage of the coverage area descriptions depends on the number of vertices, the effect of a simple enhancement of the algorithm for the determination of the areas has been investigated. The results showed that a significant reduction of the number of vertices can be achieved by it.

For the presented investigations, simplified models e.g. for the radio channel were deployed. These models led to results which can be easier compared to those of other approaches. In the next steps of our ongoing work, the mechanisms will be implemented and appropriate measurements of the bootstrapping phase will be performed. Even though the results highly depend on the radio propagation in the environment and hence may not be comparable to others, these will validate the feasability of the presented approach using existing commercial off-the-shelf equipment. Such an implementation will also highlight the capabilities of the algorithm to approximate the AP's coverage in a real world environment. Furthermore, the influence of inaccurate location information on the deviation between the retrieved and original coverage regions will be analyzed. Based on the insights that have been gained by the investigations presented in this paper, algorithms for an adaption of the mechanisms to different dynamical behaviors will be designed and tested.

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