Enhanced WCDMA Fingerprinting Localization Using OTDOA Positioning Measurements from LTE

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***Abstract*—The focus of this paper is on the convergence of positioning technology between the WCDMA and the LTE cellular systems. The emerging possibility to use multi-RAT positioning nodes can be exploited to mitigate the lack of a high-precision indoor OTDOA positioning method in WCDMA, which today limits the coverage of self-learning databases for fingerprinting positioning in this cellular system. The problem at hand is solved by use of measured high precision OTDOA positions of opportunity from LTE.**

***Index Terms*—AECID, cellular, confidence, fingerprinting, E-911, localization, LTE, navigation, polygon, signaling, WCDMA.**

I. INTRODUCTION

The main localization technology in the cellular industry today is provided by the assisted global positioning system (A-GPS) [1]-[3]. A major reason for this is the very quick introduction of advanced user equipments (UEs) ("smartphones") that are equipped with GPS receivers that support A-GPS. The new UEs are introducing a shift from the previous situation where cellular localization technology was mainly driven by E-911 emergency positioning requirements [4], to a situation where commercial services are becoming increasingly important. The consequence of this is a more diverse set of requirements, since the location based services offered differ significantly between operators. This requires flexible positioning systems with hybrid positioning solutions [22].

The limited indoor coverage of all satellite based location technologies thereby becomes an increasing problem. It is well known that even with fine time assistance, [2], [5], A-GPS coverage is not easily expanded indoors. Therefore both the Wideband Code Division Multiple Access (WCDMA) and Long Term Evolution (LTE) cellular standards specify downlink high precision terrestrial Observed Time Difference Of Arrival (OTDOA) positioning methods [3], [6]. OTDOA is not as accurate as A-GPS though, and the method relies on a Radio Base Station (RBS) deployment with good geometrical properties, which may become expensive in rural areas, cf. [3], [7]. What is even more troublesome is that the specified radio sensitivity of the WCDMA version of OTDOA is insufficient for detection of a large enough number of neighbor RBSs. The consequence is that the availability and accuracy of the OTDOA method in WCDMA falls short of what is deemed acceptable [8]. This is not a problem in LTE, where appropriate consideration of detection performance was taken into account in the standardization [3]. WCDMA and LTE also support Uplink Time Difference Of Arrival (UTDOA) positioning methods [3], [9]. However, deployment of UTDOA involves additional HW which comes with an additional deployment cost.

The above discussion clearly shows that there is a need for fallback positioning methods, in particular in WCDMA. Here the backbone Cell IDentity (CID) positioning method, normally combined with Round Trip Time (RTT) measurements is a common alternative [10]-[13].

Another technology available in both WCDMA and LTE is the fingerprinting class of positioning methods, [7], [14]-[17]. The fingerprinting information in WCDMA includes CIDs, signal strengths and path loss measurements from the serving and neighbor cells, as well as RTT distances of the serving cell and the cells in soft(er) handover [18]. Fingerprinting positioning is based on the availability of geographical maps of radio signatures. Such maps may be generated by radio propagation predication SW, surveying, or by a combination. To position a UE, radio signatures are measured by the UE. The measured radio signatures are then compared to signatures and locations of the radio signature map. The location that fits the measured radio signatures the best is selected as the estimated position.

Specific problems with typical fingerprinting methods are associated with the generation of the geographical map of radio signatures. Surveying can be very costly in a nationwide network. SW-based prediction of radio signatures is complicated and time consuming due to the need for 3D-modeling of geographical objects like large buildings. Further, neither automatic surveying nor the use of SW can capture effects of varying handheld UE orientation. These effects may cause antenna gain variations exceeding 10 dB, giving positioning uncertainties close to 50% of the cell radius [16].

The Adaptive Enhanced Cell Identity (AECID) positioning method [7], [15] addresses the above drawbacks by performing measurements of fingerprinting information, *whenever* high precision A-GPS measurements occur in the WCDMA network. The high precision measurements with the same fingerprint are then clustered and a 3GPP polygon that describes the boundary of the cluster is computed [15]. Handheld UE orientation is hence captured in the radio map generation, as is the probability that the UE is located in the reported region (the confidence).

The scope of this paper is to propose solutions to the main remaining problem of AECID, namely the lack of *indoor* high precision reference positions of opportunity in WCDMA. The

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contributions of the paper include the use of multi-Radio Access Technology (multi-RAT) positioning to solve the problem. More specifically, the paper suggests the use of OTDOA positions obtained in LTE to solve the AECID geographical database build-up problem in WCDMA, exploiting the fact that UEs with LTE capability can be expected to be WCDMA-capable as well.

The paper is organized as follows. Sections II and III review the relevant positioning technology in WCDMA and LTE. Section IV discusses possible multi-RAT positioning approaches, followed by details on the LTE support of WCDMA fingerprinting in section V. The paper ends with conclusions in section VI.

II. THE AECID FINGERPRINTING POSITIONING METHOD

A. Architecture

The AECID architecture is depicted in Fig. 1, which shows the case where polygons are generated using detected neighbor

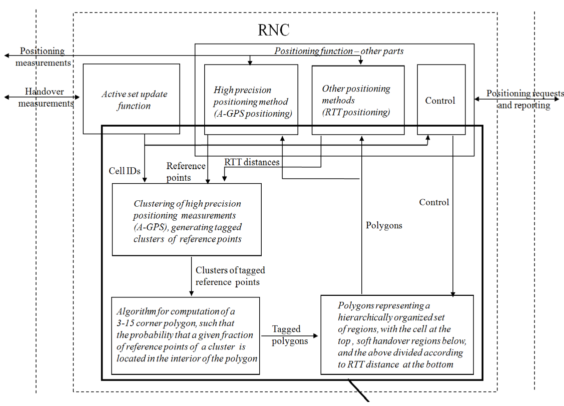

Fig. 1. Block diagram of the AECID positioning method in WCDMA. The positioning measurements include UE based A-GPS [19], RTT [20] and UE RxTx type 1 [19].

cells and RTT measurements represented as computed distances. Whenever a high precision (A-GPS) measurement is received, the IDs of the own cell and the neighbor cells are registered, and the RTT distance is measured [10], [11]. The clustering block then stores high precision position measurements as reference points in clusters, where each cluster corresponds to a list of cell IDs and a coarsely quantized RTT distance (this is denoted the 'fingerprint'). Refined clustering algorithms are discussed in [21]. When a sufficient amount of measurements (at least 10) have been collected in a cluster, a polygon that describes the boundary of the cluster is computed with the polygon contraction algorithm described in section II.B. This provides a description of the cluster extension that can be reported with standardized reporting formats. The result is stored in a database of fingerprinted polygons. When a positioning request is received in the positioning node, the list of own and neighbor cell IDs is retrieved from the neighbor cell tracking block and the RTT distance is obtained by an RTT positioning step, followed by a computation of the fingerprint. The polygon that corresponds to the fingerprint is extracted from the database of computed polygons. The polygon is then sent as the positioning response over the service interface.

B. Main steps of the polygon contraction algorithm

The steps of the polygon contraction algorithm of [7] and [15] are:

1) Step 1

The reference points of the cluster are transformed from World Geodetic System (WGS) 84 latitude and longitude, to Cartesian Earth Tangential (ET) coordinates. All computations are performed in this ET system. The transformations needed are described in [10].

2) *Step 2*

The algorithm is initialized with a polygon that contains all reference points of the cluster in its interior. The procedure of [7] guarantees that the contraction point is in the interior of the cluster. This is necessary to handle curved clusters with much larger lateral than radial extension that occur when RTT distance measurements are used.

3) Step 3

A loop is executed, which iteratively moves one corner at a time inwards towards the contraction point. The inward motion is selected to maximize the area reduction of the polygon at each iteration step, while maintaining the constraint that the polygon must not contain any self-intersections. Each step of the iteration is such that one reference point is excluded from the interior of the polygon. The loop ends when a pre-specified fraction of the reference points remain in the interior of the polygon. The re-sampling procedure of [7] is inserted repeatedly after a pre-specified number of steps. This procedure redistributes the corners at even distances around the polygon. This is needed for accurate computation of polygons for clusters with significantly larger lateral than radial extension. see [7] for further details.

4) Step 4

The corners of the polygon are transformed [10] from the ET system to WGS84 latitude and longitude, encoded according to [12]. An example result appears in Fig. 2.

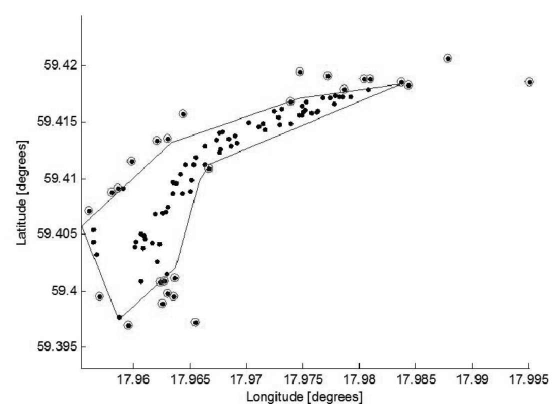

Fig. 2. An example of the output of the contracting polygon algorithm. Dots represent reference measurements and solid lines the computed polygon. Dots inside circles are reference points excluded by the contraction algorithm.

C. AECID in WCDMA

In WCDMA, the AECID algorithm can utilize A-GPS measurements [2] to obtain outdoor reference positions. As discussed in section III, WCDMA OTDOA performs too poorly to provide useful indoor reference positions, whereas the deployment cost affects the UTDOA method negatively. The fingerprinting information that is easily used includes cell IDs of the serving and neighbor cells, RTT distance measurements of the serving cell and cells in soft(er) handover [20], as well as pathloss measurements [19] with respect to the serving and neighbor cells. Normally, the polygon format of [12] is used for reporting of the result; however, sometimes shape conversion is required by reporting format standards at the reporting and receiving entities.

III. THE OTDOA POSITIONING METHOD

A. OTDOA positioning algorithm

The OTDOA positioning method relies on measurements, typically on some pilot radio signal, from multiple RBSs. Apart from the measurements, the method is the same in WCDMA and LTE. In general the measurement is performed by means of correlation in the UE with the known signal sequences of the measured cells.

Assuming that the measurements are successful for a number of cells the following relations between the measured Time Of Arrivals (TOAs) in the UE, the transmission times from the RBSs, and the distances between the UEs and the RBSs follow,

$$\begin{aligned} t_{TOA,1} + b_{clock} &= T_1 + \left\|\mathbf{r}_1 - \mathbf{r}_{UE}\right\| / c \\ &\vdots \\ t_{TOA,n} + b_{clock} &= T_n + \left\|\mathbf{r}_n - \mathbf{r}_{UE}\right\| / c. \end{aligned} \tag{1}$$

Here $t_{TOA,i}$, $i = 1,\ldots,n$ denote the measured time of arrivals (TOAs) in the UE, T_i, $i = 1,\ldots,n$ denote the transmission times from the RBSs and c is the speed of light. The boldface quantities are the (vector) locations of the RBSs and the UE. b_{clock} denotes the unknown clock bias of the UE with respect to cellular system time. In OTDOA positioning, time differences of arrival with respect to a selected reference cell are then formed according to

$$\begin{aligned} t_{TDOA,2} &= t_{TOA,2} - t_{TOA,1} = T_2 - T_1 + \left\|\mathbf{r}_2 - \mathbf{r}_{UE}\right\| / c - \left\|\mathbf{r}_1 - \mathbf{r}_{UE}\right\| / c \\ &\vdots \\ t_{TDOA,n} &= t_{TOA,n} - t_{TOA,1} = T_n - T_1 + \left\|\mathbf{r}_n - \mathbf{r}_{UE}\right\| / c - \left\|\mathbf{r}_1 - \mathbf{r}_{UE}\right\| / c\,. \end{aligned} \tag{2}$$

In these *n-1* equations, the left-hand sides are known (with some additional measurement error). The time of transmission differences (denoted the real time differences) can be measured. using RBS internal synchronization procedures. Further the locations of the base stations, $\mathbf{r}_i$, $i = 1,\ldots,n$, can be surveyed to within a few meters and so they are known as well. What remains unknown is the UE location, i.e.

$$\mathbf{r}_{UEl} = \begin{pmatrix} x_{UE} & y_{UE} & z_{UE} \end{pmatrix}^T . \tag{3}$$

In the more common case when a two-dimensional positioning is performed the unknown position is instead

$$\mathbf{r}_{UE} = \begin{pmatrix} x_{UE} & y_{UE} \end{pmatrix}^T . \tag{4}$$

It then follows that at least three time of arrival differences are needed in order to find a 3D UE position and that at least two time of arrival differences are needed in order to find a 2D UE position. This, in turn, means that at least four sites need to be detected for 3D UE positioning and at least three sites need to be detected for 2D UE positioning. In practice, more measurements are needed to achieve a sufficient accuracy.

B. Performance of OTDOA in WCDMA and LTE

As indicated above, the WCDMA version of OTDOA lacks the detection performance to provide accurate enough indoor reference positions for AECID fingerprinting database build-up. The contribution [8] combined simulated detection performance expressed in terms of the detected number of neighbor RBSs of the WCDMA standard for OTDOA with live measurements of TDOA accuracy, also parameterized in terms of the number of detected RBSs, to arrive at a realistic prediction of the performance of OTDOA in WCDMA. The results are depicted in Fig. 3 and Fig. 4. It can be seen that the specified 3GPP detection sensitivity of -20 dB E_c / N_0 is clearly insufficient to provide high accuracy indoor reference positions for AECID in WCDMA. It should be noted that this is the case despite the fact that a coordinated turn off (idle periods in the downlink, IPDL [8]) of the serving cell downlink transmissions was used in the simulations, in order to mitigate the severe near-far problems that affect OTDOA in WCDMA.

The neighbor RBS detection sensitivity is much better adapted in LTE, the reader is referred to [3] and the references therein for further details.

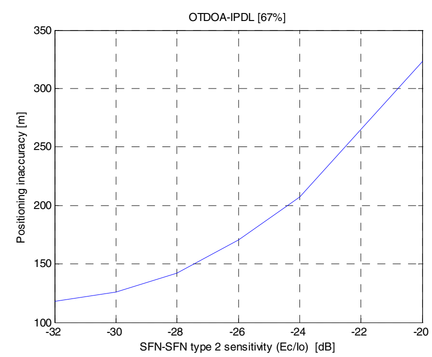

Fig. 3. The 67% percentile of the predicted OTDOA inaccuracy in WCDMA, as a function of the detection sensitivity in E_c / N_0 for the SFN-SFN measurement specified by 3GPP.

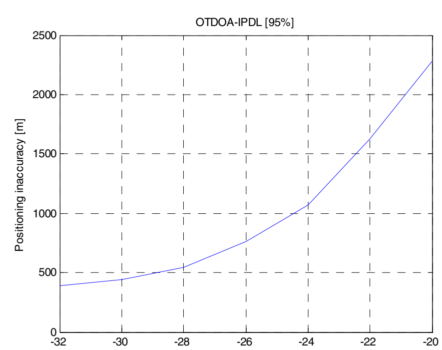

Fig. 4. The 95% percentile of the predicted OTDOA inaccuracy in WCDMA, as a function of the detection sensitivity in E_c / N_0 for the SFN-SFN measurement specified by 3GPP.

IV. MULTI-RAT POSITIONING

A. Positioning procedures in WCDMA

In WCDMA, the signalling service between the radio access network (RAN) and the core network (CN) is provided by the radio network layer signalling protocol called the Radio Access Network Application Part (RANAP) [13].

It is specified [13] that a Location service request shall include, Client identity, Client Type, and also, if needed, requested QoS information. The Client Type information is very important in practice since it allows for configuration of the positioning functionality of the RAN according to the needs of the requesting end user. This is performed by configurable position method selection logic, [11].

The following Client Type values can be signaled in the LOCATION REPORTING CONTROL request message [13]: Emergency Services, Value Added Services, PLMN Operator Services, Lawful Intercept Services, PLMN Operator Broadcast Services, PLMN Operator Operation and Maintenance Services, PLMN Operator Anonymous Statistics Services, and PLMN Operator Target MS Services Support.

The requested QoS is defined by the following information elements of the LOCATION REPORTING CONTROL message [13]: Response Time (high/low, not mapped to time), Accuracy Code (encoded with 128 values, which is interpreted as the radius in meters of an uncertainty circle when decoded), and Vertical Accuracy Code (encoded with 128 values, interpreted as the vertical uncertainty interval in meters).

The reporting functionality provided in WCDMA returns the computed position as information elements in the RANAP message LOCATION REPORT. 3GPP supports 7 formats, these being defined in [12]. The selected format depends on the positioning method and on the reporting capabilities at the sending and receiving entities. The formats include Polygon, Ellipsoid Arc, Ellipsoid Point, Ellipsoid Point with Uncertainty Circle, Ellipsoid Point with Uncertainty Ellipse, Ellipsoid Point with Altitude, and Ellipsoid Point with Altitude and Uncertainty Ellipsoid.

Positioning functionality for WCDMA can be further divided into a so-called SAS-centric and an RNC-centric architecture. The SAS-centric architecture is relevant for the present paper since the positioning functionality of the RNC is broken out to the so-called SAS node, making the architecture the same as in LTE. This SAS node is thus very similar to the positioning node of LTE, i.e. the enhanced SMLC (E-SMLC) in the control plane.

B. Positioning procedures in LTE

In LTE, the basic Evolved Packet System (EPS) architecture consists of two nodes in the user plane, an RBS denoted the eNodeB, and an Evolved Packet Core (EPC) network Gateway (GW) [3]. The node that performs control-plane functionality (MME) is separated from the node that performs bearer-plane functionality. Signaling service between the LTE RAN and EPC is provided over the S1 interface by means of the S1 Application Protocol (S1AP), see [3] and the references therein. The S1 interface between eNodeB and MME is called S1-MME and is utilized in control-plane positioning solution.

S1AP messages as such do not contain information on the requested Quality of Service (QoS). This information is carried by the LTE Positioning Protocol (LPP) [3]. LPP is a point-to-point protocol used between a location server and a target device in order to position the target device using position-related measurements obtained by one or more reference sources. For LPP messages, a server could, for example, be the E-SMLC, while a target could be a UE.

The LTE Positioning Protocol Annex (LPPa) [3], is a protocol between eNodeB and E-SMLC which conducts the LPPa Location Information Transfer procedures for positioning-related information and LPPa Management procedures not specifically related to location services.

The Client types and reporting formats specified for LTE are identical to the ones of WCDMA. The QoS information differs slightly. In LTE the QoS request information includes: Response Time (1-128 seconds), Horizontal Accuracy (128 accuracy codes, 100 confidence codes), and Vertical Accuracy (128 accuracy codes, 100 confidence codes).

C. Multi-RAT positioning architecture of WCDMA and LTE

The proposed multi-RAT positioning architecture is depicted in Fig. 5. It is enabled by the fact that Client types and reporting formats are identical in WCDMA and LTE. As can be seen in Fig. 5, positioning requests arrive from different CNs corresponding to different RANs/RATs and to the corresponding user plane systems. These interfaces are also used to return the obtained position result after the positioning has terminated. The key technical advantage is that the positioning node has access to all the RANs/RATs in order to obtain a position. Since most terminals handle multiple RATs today, this main advantage is due to new functionality for position method selection (cf. [11]) that is capable of selecting positioning methods/measurements from all RANs/RATs, in order to achieve the requested result.

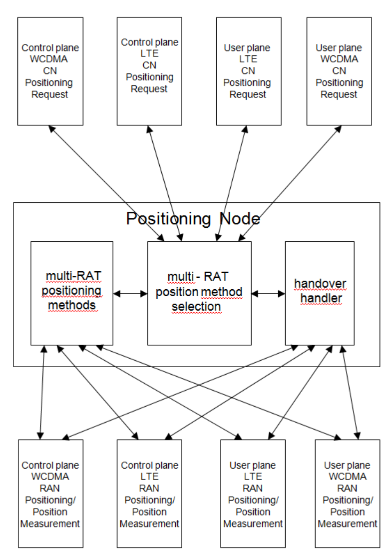

Fig. 5. A multi-RAT positioning architecture.

Sometimes inter-RAT measurements are available to retrieve information from other RANs/RATs. If additional position information is needed, the positioning method selection mechanism may request handover to another RAN/RAT for positioning purposes or ensure that the required RAT measurements are possible during the specified time intervals. There is also a handover handler in the positioning node for this purpose. Such a mechanism is not yet available in the standards. As shown in Fig. 5, the positioning method selection mechanism is via the positioning method selection block interfaced to all the RANs/RATs served by the positioning node. These interfaces are the standard ones, as described above, for retrieving positioning results in terms of positions or positioning measurements from the different RANs/RATs.

V. ENHANCING AECID IN WCDMA WITH OTDOA IN LTE

The fact that most LTE terminals also support WCDMA makes it possible to improve AECID in WCDMA. Measurements from such multi-RAT terminals can then be used to construct the fingerprinting database for areas and regions where insufficient performance is achievable for the positioning methods available for a pure WCDMA system. The procedure illustrated in Fig. 6 begins when the LTE system determines that an OTDOA positioning is to be performed for UE1. Typically this means that an A-GPS positioning has failed since the A-GPS positioning method is normally the first choice. Note that a failure of A-GPS and a success of OTDOA is a strong indication of an indoor UE location.

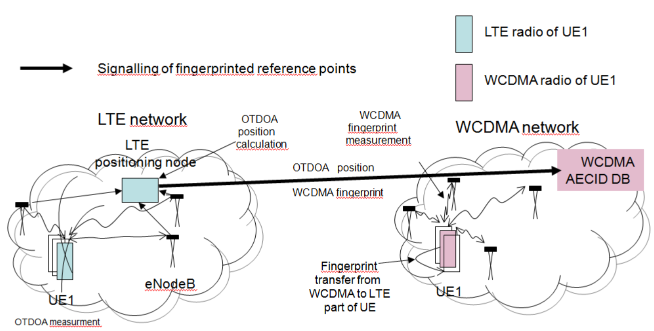

Fig. 6. Architecture for population of the WCDMA AECID database with fingerprinted OTDOA measurements from LTE.

The LTE Radio of UE1 hence first performs OTDOA measurements that are reported to the E-SMLC (the LTE positioning node). These measurements are then combined to an OTDOA position. Then the WCDMA radio of UE1 performs inter RAT measurements on the WCDMA network, determining e.g. cell IDs of adjacent WCDMA base stations as well as radio measurements with respect to WCDMA RBSs. The measured results are reported to the positioning node as well. At this time, an OTDOA position, together with associated measurements that can form WCDMA fingerprints are available in the E-SMLC. The information is signaled to the AECID database of the WCDMA system, where it is stored.

VI. CONCLUSIONS

The paper has presented a multi-RAT positioning concept, which can be used to enhance the positioning performance in the WCDMA and LTE networks. In addition, the multi-RAT architecture enables the use of fingerprinted high-precision reference positions obtained with OTDOA positioning in LTE for buildup of the indoor part of the AECID fingerprinting database for WCDMA. This gives the AECID positioning method a complete indoor and outdoor coverage in WCDMA.

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