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SELF-ORGANIZED HETEROGENEOUS ADVANCED RADIO NETWORKS GENERATION

Deliverable D6.3

Localization architecture for multi-layer, multi-RAT heterogeneous network

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Abstract:

This deliverable proposes a generic measurement framework for enabling localization in multi-layer, multi-RAT heterogeneous networks using the Radio Frequency (RF) fingerprinting methodology. The aim of the proposed architecture is to enhance the geographical location of Minimization of Drive Tests (MDT) measurements rather than the geographical location of User Equipment (UE) itself, knowing that ultimately this improvement will benefit both purposes. Two alternative solutions are proposed, a control-plane solution and a user-plane solution. The perspectives and constraints of these solutions are discussed highlighting the importance of having a generic automated measurement framework for different applications such as RF fingerprint localization, coverage mapping for Wireless Local Area Networks (WLAN), access network discovery and selection, and network based proximity indication. Performance evaluation of the proposed architecture was carried out by conducting system simulations and measurements in a live Long Term Evolution (LTE) network. Simulation and measurement results suggest that by correlating MDT measurement with detectable WLAN measurements, location precision can be significantly improved.

Keywords: Network architecture, Location estimation, LTE/WLAN interworking

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EXECUTIVE SUMMARY

This deliverable brings into one document the results of the work dealing with automated collection of WLAN coverage measurements, and how to link them to 3G/4G coverage measurements. It covers interaction between different Long Term Evolution (LTE) and Wireless Local Access Network (WLAN) network elements, and utilization of data-intensive algorithms to localize measurement events and devices. The aim of the proposed architecture is to enhance the location accuracy of Minimization of Drive Tests (MDT) measurements, which can serve a variety of applications, in addition of improving localization of User Equipment (UE) itself. The innovation behind the proposed framework is that it enables automated collection of UE coverage measurements from heterogeneous small cell networks consisting of 3G/4G and WLAN radio access technologies. The proposed architecture is an extension to the MDT functionality specified by Third Generation Partnership Project (3GPP) Release 10. MDT has a great importance in cost efficient network coverage optimization especially in heterogeneous environment. However, currently MDT measurements cannot be correlated with WLAN measurements although UE have already some support to provide WLAN measurements to network operators. By complementing the MDT functionality with the measurements from WLAN access nodes, one can significantly enhance the location-awareness of MDT measurements and enable various new use cases including WLAN coverage mapping, automated creation of access network discovery and selection function (ANDSF) databases and network based proximity indication.

The proposed architecture consists of two alternative solutions, namely control-plane (CP) solution and user-plane (UP) solution. In CP solution, WLAN measurements are reported to LTE access node as part of radio resource control (RRC) signaling. This would allow LTE access node to include WLAN measurements directly into MDT trace records. In UP solution, MDT trace assistance information is transmitted to UE e.g., as part of MDT configuration, and it is included into other UE specific measurements such as dedicated WLAN measurements. The trace assistance information helps to link measurements from different sources. This allows operators to correlate the other UE reported measurements with UE's MDT trace records in operator's network management systems (NMS). The control plane solution is aligned as much as possible with 3GPP's Release 12 study item on WLAN / 3GPP radio interworking with regard to measurements and triggering events, whereas the user plane solution relies more on 3rd party solutions like Open Mobile Alliance - Device Management (OMA-DM) protocol, for transmitting the WLAN measurement results to operation and maintenance subsystem (O&M). However, since 3GPP concluded that Release 12 LTE/WLAN interworking solution does not specify WLAN measurement reporting from UE to LTE evolved NodeB (eNB), the proposed user-plane solution seems in the short-medium term a better solution for enabling the enhanced localization functionality of MDT measurements.

The feasibility of the proposed architecture was evaluated with system simulations and network measurements in a live LTE network. Simulation and measurement results suggest that by correlating MDT measurement with detectable WLAN measurements, location-awareness can be significantly improved. Location estimation error for two-thirds of all MDT measurements is decreased by 79 % to 70 % if WLAN measurements are utilized in addition to LTE measurements. Moreover, since WLAN based positioning is already widely used indoors, the proposed approach is seen as an attractive solution to further enhance the availability of detailed location information of MDT measurements collected from indoors locations. Hence, by linking MDT measurements with WLAN measurements operators can collect low cost extensive and detailed coverage maps autonomously improving significantly positioning performance of MDT measurements.

1 INTRODUCTION

It is envisioned that the growth of data traffic demand will be rapid in the near future due to the variety of new types of multimedia services, applications, devices and machines being connected to the Internet. A traffic forecast indicates that typical mobile traffic demand per user is expected to grow by a factor of 30 from 0.5 GB to 15 GB per month by 2020 [1]. Such rapid growth will set stringent requirements on the available capacity per km^2 that operators are expected to deliver in their next-generation networks. To tackle the increased data demand, the densification of network, leading to more aggressive frequency reuse, is inevitable due the scarcity of available spectrum resources. A bulk of this increased mobile data traffic is expected to be carried by a combination of different small cells or access nodes pertaining to different Radio Access technologies Technologies (RAT). Such a Heterogeneous Network (HetNet) environment will enable high-density spatial reuse of communication resources. One approach to address the increased data demand is the deployment of ultra-dense network of small cells using LTE and WLAN cells operating on licensed and unlicensed frequencies, respectively. Using WLAN is an interesting alternative particularly due to the fact that it can already deliver bit rates that are far beyond the bit rates of LTE [2]. However, for ensuring seamless connectivity, mobility and load balancing in such networks, coordination and interworking between the nodes on the different Radio Access Networks (RAN) is needed.

Network densification using LTE and WLAN access nodes increases the offered capacity per area, but on the other hand, makes the network infrastructure more complex, which is likely to increase the operator's costs. Even if the purchase cost of a small base station is reduced to a minimum, the total costs of densely deployed small-cell networks can increase to an intolerable level unless the implementation and the operational expenditures can be reduced significantly. When the number of small base stations increases dramatically it is not feasible for the mobile operators to plan the optimal location or the optimal set of Radio Resource Management (RRM) parameters for each small base station. In certain cases, the deployment of these small cells is even left to the end users. Loosely coordinated deployment requires automated solutions to simplify network operation and management and to control network operation costs. The explosion of the number of base stations and the uncoordinated nature of heterogeneous networks has raised the need for interworking of different network elements in order to automate the network rollout and management. For this reason, the concept of Self-Organizing Networks (SON) has been introduced for LTE where the goal is to increase the degree of automation in the network configuration and optimization processes for reducing the total costs of operating the networks.

1.1 Self-Organization in Cellular Networks

One enabler of self-organizing networks is a concept called Minimization of Drive Tests (MDT) specified by 3GPP. As the name suggests, the purpose of MDT is to avoid conducting time consuming and costly drive tests in the HSPA (High Speed Packet Access) and LTE radio networks by autonomously collecting field measurements with detailed location information from all the available consumer terminals. Example use cases of MDT concept are coverage optimization and verification of quality of service (QoS). Traditionally, the drive tests are performed for verifying and optimizing network performance in the case of deploying new base stations; construction of new highways, railways or major buildings; on triggering of network alarms and customer's complaints; or on a periodical basis for verifying coverage, capacity and quality [3].

Since coverage information is essential for network planning, network optimization and RRM parameter optimization, the autonomous collection of the coverage and quality information from both cellular and WLAN access networks should be supported in next generation interworking deployments. For this reason, a concept of Generalized MDT (GMDT) is proposed in Chapter 4. GMDT is an amendment to the MDT concept for supporting the collection of coverage measurements with detailed location information from heterogeneously deployed LTE and WLAN small cells that need to interwork. Today, commercial phones cannot correlate 3GPP field measurements with WLAN measurements in a standardized manner. This means that measurements obtained from one system can not be complemented with knowledge from another system mainly because MDT measurements are anomymized when stored to O&M databases. The aim of GMDT is to allow correlating 3GPP coverage with that of WLAN, which will help to:

- Improve the positioning accuracy of MDT RF fingerprints by incorporating the information from WLAN access points into the measurement report.
- Create and update Access Network Discovery and Selection Function (ANDSF) databases of WLAN access points (AP) and corresponding policies for access point selection.
- Build WLAN coverage maps and determine geographical regions where more WLAN coverage is needed.
- Improve network based proximity indication.

These use cases are described in more detail in Chapter 4.

1.2 Towards Carrier Grade WLAN

Even though large operator-managed WLAN networks are currently being deployed worldwide, they have not become the mainstream yet. WLANs deployed by mobile operators are still often under-utilized [4], and standardized interworking solutions between WLAN and 3GPP cellular systems are not yet sufficient to embrace the new challenges and requirements posed by customers' needs. Indeed, carrier WLAN quality of experience (QoE) has never been sufficiently satisfactory to leverage its global adoption similarly to cellular networks. WLAN is still suffering from a lack of global, smooth, secure roaming, easy connection, network discovery, and authentication.

On the other hand, many mobile operators are keen on using free spectrum while their own frequency bands become increasingly congested. Operators have understood that WLAN will play an important role in managing the rapidly growing data traffic in the future, and the convergence of 3GPP and WLAN networks is becoming one of their key priorities. Therefore, 3GPP has been making efforts to facilitate the interworking since Release 6 (2004) in which the access to IP Multimedia Subsystem (IMS) and packet services over WLAN was specified [5]. LTE releases, namely, from Release 8 onwards, support seamless connectivity between 3GPP and non-3GPP networks by means of ANDSF as discussed in Section 2.2.1. The main functionality of ANDSF is assisting UEs in discovering non-3GPP networks and providing network selection policies in order to determine when to connect to the advertised non-3GPP networks [6]. At the moment, the core network level LTE/WLAN interworking has been specified by 3GPP, and Release 12 interworking study item will address issues related to the radio access network level interworking [4]. This work is summarized in Section 2.2.2. The solutions studied in [4] should help operators to enhance their control to support more dynamic interworking between LTE and WLAN access nodes. Furthermore, the utilization of WLAN networks should be improved by means of dynamic offloading of UEs. The enhancements regarding access network discovery and selection should take into account RAN level information such as radio link quality per UE, backhaul quality and load for both cellular and WLAN access nodes. This information can be used for avoiding suboptimal quality of service when UE connects to an overloaded WLAN network, and ensuring power efficient network discovery process by avoiding unnecessary scanning of WLANs [4].

2 3GPP RADIO NETWORK ARCHITECTURE

This chapter introduces Evolved Universal Terrestrial Radio Access Network (E-UTRAN) architecture for both location services in LTE and interworking with non-3GPP networks such as WLAN. E-UTRAN positioning capabilities are studied in order to understand their limitations regarding the positioning of MDT samples and whether or not WLAN assisted positioning is already supported. Moreover, interworking between LTE and WLAN networks is studied for understanding how those can support the collection and correlation of LTE and WLAN measurements in such a way that the WLAN measurements can be used by (E-UTRAN) MDT functionality.

2.1 Evolution of User Equipment Positioning

Introducing user equipment positioning in 2G cellular networks started in the late 1990 when 3rd Generation Partnership Project (3GPP) introduced Location Services (LCS) [7] and Radio Resource Location Services Protocol (RRLP) [8]. The main driver for supporting user equipment positioning in cellular networks was the U.S. Federal Communications Commision (FCC) Wireless E911 mandate. This mandate requires that operators must provide the location of emergency calls with certain accuracy, i.e., location error for 68% percent of the emergency calls in country level must be less than 50 meters [9]. To determine user equipment position, LCS utilizes several positioning mechanisms. In the beginning, the first three proposed positioning mechanism for LCS were Uplink Time of Arrival (UTOA), Enhanced Observed Time Difference (E-OTD), and assisted Global Positioning System (GPS) [7].

In LCS architecture, estimation of the location of mobile device involves message exchanges between three main logical nodes. First, LCS client requests positioning services from LCS server to acquire the location of LCS target, i.e., a user terminal. Then the LCS server estimates the location, based on the measured signals it can obtain, and forwards the calculated location to the LCS client. Several functions are needed in various existing logical network nodes to implement LCS server functionality on GSM and UMTS networks [10]. In addition two new logical network nodes were needed, namely, the Serving Mobile Location Center (SMLC) and the Gateway Mobile Location Center (GMLC). GMLC implements the functionality that provides interface to external LCS clients to make location service requests. SMLC manages the overall coordination and scheduling of the resources that are required to perform the positioning of the mobiles. SMLC also calculates the final location estimate and accuracy. RRLP is the protocol that is used to exchange messages between mobile i.e., LCS target, and a SMLC. These messages could be requests and responses to measure position or provide assistance data needed to determine the position [8]. In later releases, the LCS architecture evolved to support other Global Navigation Satellite Systems (GNSS) mechanism such as Assited-Galileo, as well as introducing new positioning methods, such as Cell Identifier (CID) and hyperbolic Time Difference of Arrival (TDOA) methods for non-GNSS devices [11]. In LTE Release 9, the location services functionality was redesigned by introducing Enhanced Serving Mobile Location Center (E-SMLC) and new LTE Positioning Protocol (LPP) replacing RRLP. Since 3GPP LCS architecture is control plane solution for user equipment positioning, Open Mobile Alliance (OMA) started to work with Secure User Plane Location (SUPL) protocol in 2003. SUPL brings location capabilities to the user plane (application domain) over IP-networks in the same way that RRLP and LPP bring them to the control plane. The biggest difference between LCS and SUPL is that SUPL can already provide positioning involving WLAN among several other non-3GPP technologies with LPP extensions (LPPe) whereas LCS and LPP are limited to 3GPP access technologies and Assisted-GNSS [16].

2.1.1 LTE Positioning Architecture and Protocols

The Evolved Packet Core (EPC) positioning architecture in LTE is illustrated in Figure 1. In the control-plane solution, the positioning architecture and its functions are distributed across GMLC, E-SMLC, eNodeBs, Location Measurement Units (LMUs) and UEs [11]. These nodes and the interfaces are described in more detail in Section 2.1.2. The user-plane solution consists of SUPL Location Platform (SLP) and the SUPL Enabled Terminal (SET). The positioning architecture and its functions are distributed across the SUPL Location Centre (SLC) and the SUPL Positioning Centre (SPC). SUPL nodes and the interfaces are described in Section 2.1.3.

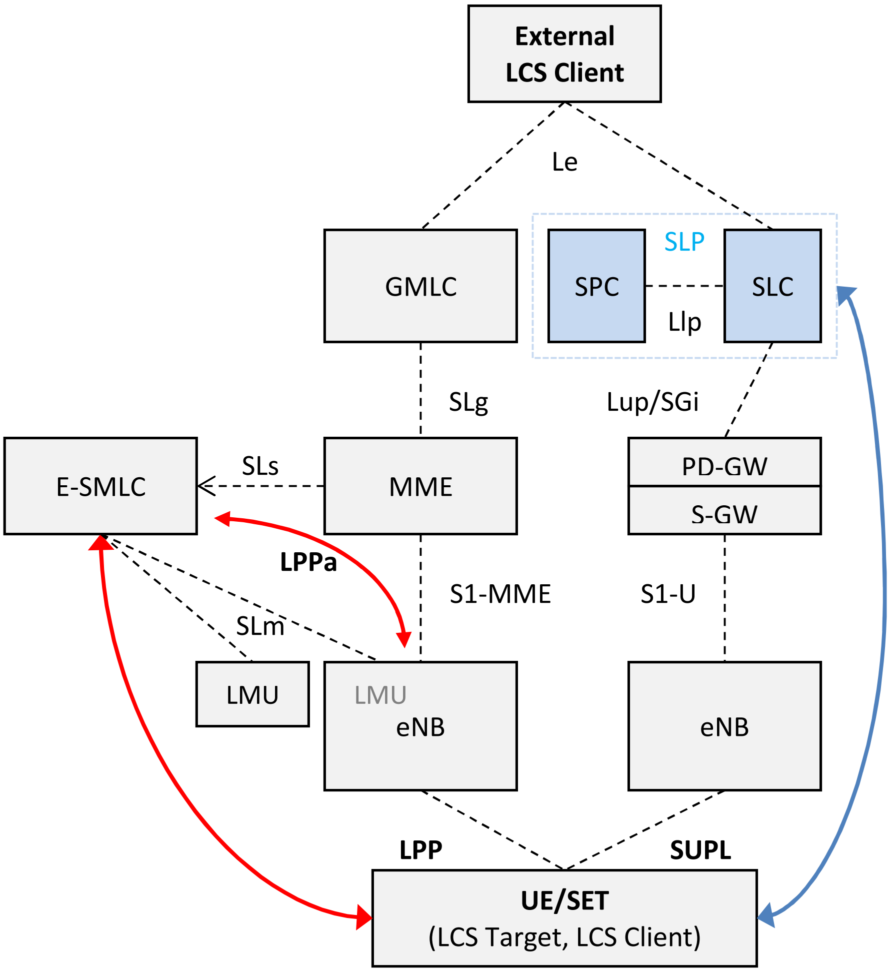

Figure 1: Overview of the E-UTRAN Positioning Architecture

LPP and LPP Annex (LPPa) protocols are used in E-UTRAN control-plane positioning architecture for exchanging the positioning related messages. LPPa, as specified in [12], is a communication protocol between an eNodeB and E-SMLC for control plane positioning. However, in LCS and SUPL interworking scenarios, LPPa can also be used to assist SLP to obtain assistance data from eNodeBs through E-SMLC. LPP is a point-to-point protocol for communicating between positioning server and LCS target as specified in [13]. LPP supports both control-plane and user-plane protocols as underlying transport layer and LPP protocol messages are also used in SUPL architecture. In SUPL architecture, LPP protocol messages are wrapped inside SUPL protocol messages and exhanced using user-plane connection. Hence, OMA SUPL protocol can also exchange LPP and LPP extension (LPPe) protocol messages but these are encapsulated into user plane packets as specified in [14]. The purpose of LPPe is to allow LPP messages to be extended to utilize positioning mechanisms, such as those suited to WLAN and short-range nodes e.g., Bluetooth, without duplicating the work done in 3GPP [16]. Thus, LPPe messages extend the location, measurement and assistance data capabilities beyond 3GPP LPP. SUPL is intended to be as far as possible bearer-independent with respect to non-bearer associated position methods such as A-GNSS and any terrestrial method applicable to a non-serving network. Hence, the LPP point-to-point communications can occur either between E-SMLC and UE or SUPL SLC server and SET.

2.1.2 Control-Plane Positioning Entities and Interfaces

In EPC architecture, the E-SMLC node is the coordinator of the location services. It isresponsible for determining which positioning method to use, providing assistance data, gathering necessary measurements to determine the position of the LCS targets, and delivering the positioning result to the LCS clients. The eNodeBs provide network-based location measurements upon request from the E-SMLC, ensure proper configuration of positioning reference signals and configure User Equipment (UE) measurements. LMUs can make additional location measurements, such as uplink beacons measurements, and communicate them back to the same E-SMLC that made the request.

In a typical network-triggered LCS situation, the Mobility Management Entity (MME) either receives a request for location service from another entity such as GMLC or UE, or decides itself to initiate some location service on behalf of a particular target UE, (e.g., for an IMS emergency call from the UE). The MME then sends a location service request to an E-SMLC to process it. This may include transferring assistance data to the target UE to assist location estimation in case of UE-based or UE-assisted positioning. In UE-based positioning methods, UE reports its own location estimate, whereas in UE-assisted positioning, it only returns assistance data such as measurements to help E-SMLC determine the location of target UE. In uplink based methods, the E-SMLC requests assistance data from LMUs such as measurements of uplink Sounding Reference Symbols (SRS). The E-SMLC then returns the result of the location service back to the MME (e.g., a position estimate for the UE and/or an indication of any assistance data transferred to the UE). In the case that location service was requested by an entity other than the MME, the E-SMLC returns the location service result to the corresponding LCS client via MME and GMLC.

2.1.3 User-Plane Positioning Entities and Interfaces

SUPL is the user-plane location technology for positioning mobile devices over wireless network, based on secure user plane IP tunnels. It is an application layer protocol operating over the Lup interface between the SUPL Location Platform (SLP) and the SUPL Enabled Terminal (SET) which has capability of SUPL transactions. The SLP consists of two functional entities: the SUPL Location Centre (SLC) and the SUPL Positioning Centre (SPC). The SLC is responsible for coordination and administrative functions in order to provide location services, while the SPC is responsible for the positioning function. These are architecturally analogous to the GMLC and the E-SMLC in the control-plane solution. The SLC coordinates the operations of SUPL in the network and performs the location management functions, including privacy, initiation, security, roaming, charging, service management, and triggering positioning calculation. The SPC is responsible for positioning-related functions, including security, assistance data delivery, reference retrial, and positioning calculation. The SLC and SPC could be either integrated into a single system, or remain separated. For the separated mode, the interface between SLC and SPC is the Location Internal Protocol (LIp).

In SUPL architecture, the interface between SET and SLP is Lup which is defined and standardized by OMA; SUPL is the protocol running over Lup. There are two different communication modes between SET and SLP: proxy mode and non-proxy mode. For proxy mode, the SPC system will not have direct communication with the SET. In this environment, the SLC system will act as a proxy between the SET and the SPC. For non-proxy mode, the SPC system will have direct communication with the SET. Interworking between the control-plane LCS architecture and SUPL release 2.0 can exist as described in [11]. If the E-SMLC has an interface to SPC function as defined in OMA SUPL release 2.0 ([14], [15]), it can provide a consistent set of positioning methods for deployments utilizing both control-plane and user-plane. This interworking does enable the SPC to retrieve measurements from eNodeB. However, the interworking does not enable the use of user-plane signalling for part of a control-plane positioning session.

2.1.4 Positioning methods

Besides control and user-plane positioning architectures, 3GPP networks support also a wide range of complementary positioning methods. Basic positioning method is CID that utilizes cellular system knowledge about the geographical location of the UE’s serving cell. CID method has been mandatory in LTE since Release 8. Other methods such as Enhanced CID (E-CID), Observed Time Difference of Arrival (OTDOA), Uplink Time Difference of Arrival (UTDOA) and Assisted Global Navigation Satellite System (A-GNSS) methods were made available in later releases. In addition to the standardized positioning methods, several other methods are available via SUPL that do not need be standardized such as RF fingerprinting or hybrid positioning methods. Available positioning methods and their descriptions are listed in Table 1 according to [17].

Table 1. Positioning methods available for LTE

Method	Description	Horizontal Uncertainty
E-CID	UE-assisted and network-based methods that utilize CIDs, RF measurements from multiple cells, timing advance, and Angle of Arrival (AoA) measurements.	Medium
OTDOA	UE-assisted method based on reference signal time difference measurements conducted on downlink positioning reference signals received from multiple locations, where the user location is calculated by multilateration.	< 100m
UTDOA	An uplink alternative method to OTDOA that utilizes uplink time of arrival or TDOA measurements performed at multiple receiving points. Measurements will be based on Sounding Reference Signals.	< 100m
A-GNSS	UE-based and UE-assisted methods that use satellite signal measurements retrieved by systems such as Galileo and GPS.	< 5m
RF finger printing	A method of finding a user position by mapping RF measurements obtained from the UE onto an RF map, where the map is typically based on detailed RF predictions or site surveying results.	low or medium
Hybrid	A technique that combines measurements used by different positioning methods and/or results delivered by different methods.	low or medium

2.2 Interworking with Non-3GPP technologies

Important design objective of the Evolved Packet Core (EPC) has been to support efficient interworking with legacy mobile networks and other non-3GPP networks such as WLAN. Thus, support for IP mobility protocols and general handover in EPC involving WLAN has been in 3GPP specifications since Release 8 but connectivity from WLAN to 3GPP domain has been supported even earlier since 3GPP Release 6 on the interworking WLAN (I-WLAN) specifications [5]. However, WLAN interworking and integration is currently supported at the Core Network (CN) level, including both seamless and non-seamless mobility to WLAN. This is not concerning enough the future scenarios in heterogeneous networks, and therefore, 3GPP has agreed to study the potential of RAN level enhancements for WLAN/3GPP Interworking in Rel-12. These studies are summarized in Section 2.2.2.

The 3GPP architecture that is involved in interworking with non-3GPP access support is illustrated in Figure 2 showing logical architecture nodes and related interfaces between them according to [6]. Solid lines between architecture nodes illustrate path for user-plane traffic and dashed lines are control signalling interfaces. It is worth noting that host-based solution relying on s2c interface is omitted in the Figure 2 and only network-based architecture for trusted and untrusted network interworking is depicted. The Difference between trusted and untrusted architectures is that, in trusted network operator trusts (or proves) the connection to WLAN APs whereas in untrusted case the connection between ePDG and WLAN APs is provided by third party.

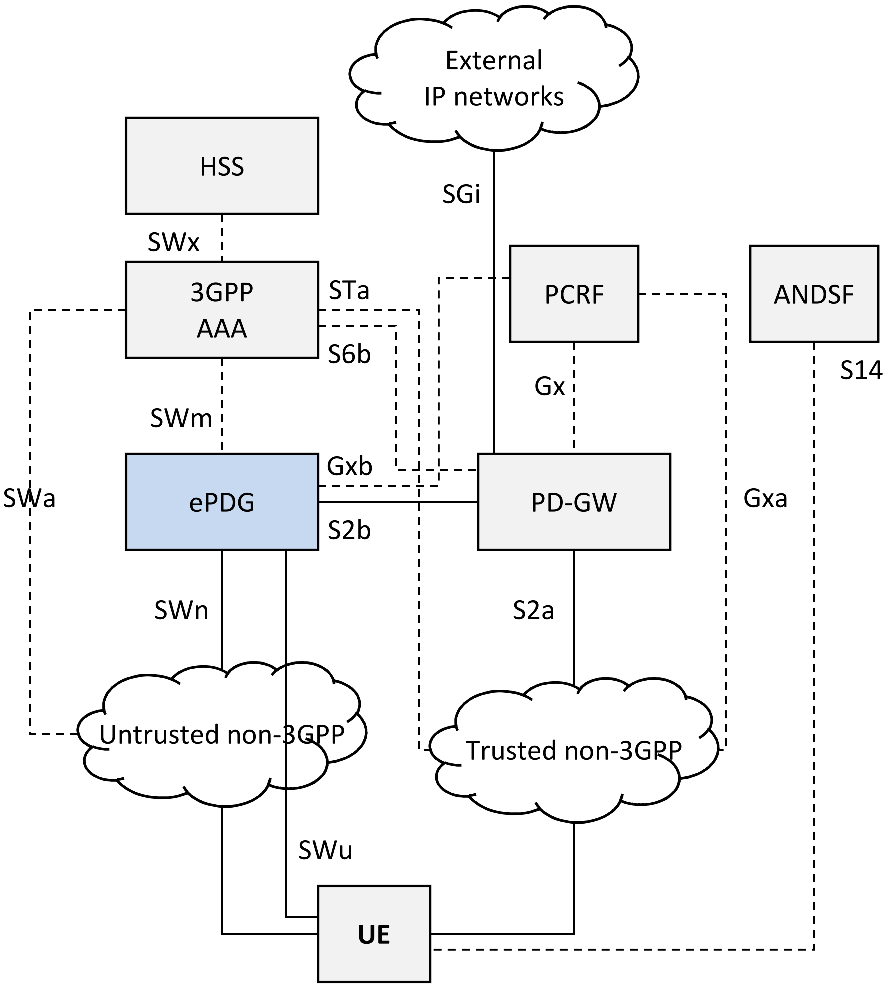

Figure 2: Overview of the E-UTRAN Interworking Architecture

In trusted non-3GPP access, S2a, STa and Gxa interfaces are used. Sta and Gxa are used for user data management and policy control as they interact with Policy and Charging Rules Function (PCRF) and Authentication, Authorization and Accounting (AAA) server, whereas S2a is used for data connectivity in network-based mobility schemes in trusted access networks.

In untrusted case, the operator may not trust the access network that is used by the accessing device, and therefore, S2bm, Gxb and SWn interfaces do not connect with the access network, but instead, they connect to the evolved Packet Data Gateway (ePDG). The interface between the untrusted access network and ePDG is SWn and it carries all signalling and data between the two networks. The interface Swu between the ePDG and UE carries user data and signalling needed to manage the secured tunnel between the two nodes. Secured tunnels are used to ensure that devices can communicate with ePDG in secure way and all SWu traffic is sent over the SWn interface.

2.2.1 Access Network Discovery and Selection

The Access Network Discovery and Selection Function (ANDSF) is a function that is used to deliver network selection policies to UEs for influencing how users prioritize different access technologies if several non-3GPP networks are available [6]. ANDSF architecture consists of S14 interface between UE and ANDSF server. The protocol on S14 is IP based and utilizes OMA Device Management (OMA-DM) protocol. Since ANDSF uses IP based protocol, i.e., user-plane solution, UEs can connect to ANDSF via any IP-based access such as 3GPP network or non-3GPP network. However, it also means that ANDSF functionality has very limited access to the network selection information at the 3GPP network elements, in case UE communicates with ANDSF server using E-UTRAN. The solution supports either UE to request the information from the server or the server to trigger the information transfer to UE. Moreover, UE may provide some information such as GPS coordinates or cell identities of nearby radio base stations, to the ANDSF server to assist in the generation of the access selection information. However, ANDSF is not intended to be used as a very dynamic mechanism for controlling access selection in real time.

The ANDSF can provide three types of information to UE such as Access Network Discovery and Selection information, Inter-System Mobility Policies, and Inter-System Routing Policies. The Access Network Discovery information includes list of access networks (3GPP and non-3GPP) available for the UE. This can help the UE in discovering networks and speeding up the needed scanning.

2.2.2 LTE/WLAN Offloading in LTE Release 12

In 3GPP Release 10, the support for simultaneous multi-access was introduced where UE can connect to 3GPP and non-3GPP networks simultaneously to better support the data offloading to WLAN. Moreover, in 3GPP Release 11, trusted non-3GPP concept was extended specifically to better support WLAN connectivity. However, even tighter coordination between 3GPP radio access network and WLAN access network was seen needed and therefore 3GPP has agreed to study potential RAN level enhancements for WLAN/3GPP interworking in Release 12. The results of these studies are collected into [4]. RAN level enhancements for interworking are seen necessary because operator-deployed WLAN networks are still often under-utilized. The goal of Release 12 interworking study was to identify solutions that allow enhanced operator control for WLAN interworking and enable WLAN to be included in the operator’s cellular Radio Resource Management (RRM). Specifically, enhancements for access network selection and mobility that were seen important are those that can take into account information such as radio link quality per UE, backhaul capability and loading for both cellular and WLAN access methods.

The solutions should provide improved bi-directional load balancing between WLAN and 3GPP radio access networks and therefore provide improved system capacity and improve the utilization of WLAN. Moreover, solutions should be compatible with the existing CN WLAN related functionality and be backward compatible with existing 3GPP and WLAN specifications thereby avoiding changes to IEEE and WiFi Alliance specifications. In addition, solutions should reduce or maintain battery consumption which may be due to WLAN scanning. In a typical use case scenario, there can be several WLAN APs within the coverage of a single UTRAN/E-UTRAN cell and the eNB/RNC may know the location of the WLAN AP among other WLAN AP parameters such as its identifier. However scenarios where such information is not available should be supported as well. Currently, there is no RAN-level information exchange between eNBs/RNCs and APs via standardized interfaces. However, some information may be exchanged via O&M. At the very beginning of the Release 12 interworking study, three alternative solution candidates were proposed.

In solution 1, RAN provides RAN assistance information such as E-UTRAN signal strength and quality thresholds, WLAN received signal strength indication (RSSI) threshold and list of target WLAN access nodes, to the UE through broadcast signalling (and optionally dedicated signalling). The UE uses RAN assistance information, UE measurements, information provided by WLAN, and policies that are obtained via the ANDSF, via existing OMA-DM mechanisms or pre-configured at the UE, to steer traffic to WLAN or to RAN. The main purpose is to enable dynamic update procedure for ANDSF Management Object (ANDSF-MO) thresholds. In solution 2, the offloading rules are specified in RAN specifications. The RAN provides (through dedicated and/or broadcast signalling) thresholds which are used in the rules. The main difference between solution 1 and solution 2 is that, solution 2 does not require implementation of ANDSF functionality, and the rules specified in RAN specifications can have higher priority than rules specified in ANDSF MO.

In solution 3, traffic steering for UEs that have established RRC connection is controlled by the network using dedicated traffic steering commands, potentially based also on WLAN measurements (reported by the UE). For UEs in IDLE mode the solution is similar to solution 1 or 2. In addition, UEs can be configured to connect to RAN first and wait for the dedicated traffic steering commands. Solution 3 consists of three steps. First, UE is configured to do

WLAN measurements. The measurement control consists of measurement events that trigger WLAN measurements, target identification information to inform which WLAN APs UE should measure and the measurement report itself. In the second step, UE reports the configured WLAN measurements to RAN. In the third step, RAN sends dedicated traffic steering commands to UE based on the reported WLAN measurements. Proposal for measurement events, WLAN target identifiers and measurement reports in solution 3 are shown in Table 2, Table 3 and Table 4.

Table 2: Candidate measurement events for reporting WLAN in solution 3 [4]

Measurement Event	Description
W1	WLAN becomes better than a threshold
W2	WLAN becomes worse than a threshold
W3	3GPP Cell's radio quality becomes worse than threshold1 and WLAN's radio quality becomes better than threshold2
W4	WLAN's radio quality becomes worse than threshold1 and 3GPP Cell's radio quality becomes better than threshold2

Table 3: Candidate target identifiers for WLAN in solution 3 [4]

Identifier	Description	Availability in WLAN
BSSID	Basic Service Set Identifier: For infrastructure BSS, the BSSID is the MAC address of the wireless access point.	Beacon or Probe Response
SSID	Service Set Identifier: The SSID can be used in multiple, possibly overlapping, BSSs	Beacon or Probe Response
HESSID	Homogeneous Extended Service Set Identifier: A MAC address whose value shall be configured by the Hotspot Operator with the same value as the BSSID of one of the Aps in the network. All Aps in the wireless network shall be configured with the same HESSID value.	Beacon or Probe Response (802.11)
Domain Name List	Domain Name List element provides a list of one or more domain names of the entity operating the WLAN access network.	ANQP (HS 2.0)
Operating class, channel number	Indication of the target WLAN frequency. See Annex E of 802.11 [5] for definitions of the different operating classes	N/A

Table 4: Candidate measurement to report for WLAN in solution 3 [4]

Identifier	Description	Availability in WLAN
RCPI	Received Channel Power Indicator: Measure of the received RF power in the selected channel for a received frame in the range of -110 to 0 dBm	Measurement
RSNI	Received Signal to Noise Indicator: An indication of the signal to noise plus interference ratio of a received IEEE 802.11 frame. Defined by the ratio of the received signal power (RCPI-ANPI) to the noise plus interference power (ANPI) in steps of 0.5 dB in the range from –10 dB to + 117 dB	Measurement
BSS Load	Contains information on the current STA population and traffic levels in the BSS.	Beacon or Probe Response (802.11k)
WAN metrics	Includes estimates of DL and UL speeds and loading as well as link status and whether the WLAN AP is at capacity.	ANQP (HS 2.0)

It is worth noting that in 3GPP RAN2 meeting #85, it was agreed not to proceed with solution 3 and remaining discussion focused on the other two solutions. 3GPP completed the work on the WLAN/3GPP radio interworking in 3GPP RAN2 meeting #87. The final solution is relying on E-UTRAN assisted UE based bi-directional traffic steering between E-UTRAN and WLAN. The solution works for UEs in IDLE and CONNECTED state since E-UTRAN can provide assistance parameters to UEs via broadcast and dedicated signalling using System Information Block (SIB) 17. The UE uses the RAN assistance parameters in the selection of access network and for traffic steering between E-UTRAN and WLAN as specified in TS 23.402 [6]. If UE is configured with ANDSF policies, it forwards the received RAN assistance parameters to upper layers. Otherwise the UE shall use them in the access network selection and traffic steering using the rules as defined in TS 36.304 [19]. However, the access network selection and traffic steering rules defined in TS 36.304 are only applied to the WLANs whose identifiers are provided by the E-UTRAN.

The RAN assistance parameters may include E-UTRAN signal strength and quality thresholds, WLAN channel utilization thresholds, WLAN backhaul data rate thresholds, WLAN received signal strength indication (RSSI) threshold measured from beacon frames and Offload Preference Indicator. Network can also signal a list of WLAN identifiers to the UEs via broadcast signalling. The UE in CONNECTED state shall apply the parameters obtained via dedicated signalling if such parameters have been received from the serving cell. Otherwise, the UE shall apply the parameters obtained via broadcast signalling. Moreover, in case of RAN sharing, each network sharing the RAN can provide independent sets of RAN assistance parameters. It is worth noting that it is not specified how E-UTRAN collects and maintains the list of target identifiers. The proposed GMDT described in Chapter 4 describes one straightforward way to automate the collection of target WLAN identifiers together with MDT measurements.

3 MINIMIZATION OF DRIVE TESTS

This chapter introduces a SON related topic called minimization of drive tests, whose target is to reduce the required efforts to carry out drive tests in deployed radio networks. The enabler behind minimization of drive tests is the operator's capability to request user equipment (UE) to make measurements and report them back to the network with location information. Therefore, no dedicated drive tests are necessarily needed given that there are enough UEs to cover the desired areas moving around in the network. Although SON and MDT are clearly related, the solutions for MDT are able to work independently from SON support in the network [20].

MDT use cases for self-organizing networks were introduced by the operators alliance Next Generation Mobile Networks (NGMN) during 2008 [22] and since then, the MDT concept has been studied by the network vendors and operators in 3GPP [3], [23]. The aim of the MDT research in 3GPP has been to define a set of measurements, measurement reporting principles and procedures, which would help to collect coverage related information from UEs. MDT feasibility study phase [3] started at late 2009 and during 2010 it focused on defining the reported measurement entities and MDT use cases such as coverage optimization and quality of service verification. Coverage optimization use case targets the detection of network problems such as coverage holes, weak coverage, pilot pollution, overshoot coverage, and issues with uplink coverage [3]. After the feasibility study, the research focused on defining MDT measurement, reporting and configuration schemes for LTE release 10 during 2011 [23]. Later, the focus of MDT work has been on enhancements in the availability of the detailed location information and improvements in QoS verification [24]. In Release 11, several new features were added to MDT such as downlink and uplink throughput measurements and traffic volume measurement, which increase the usability of MDT [25]. After all, the traffic profile of a UE has great impact on the radio interface behavior (Transmission Time Interval (TTI) and resource block allocation etc.). A support for data volume measurement is also added for detecting traffic hotspots and helping the planning of possible capacity extensions. Moreover, Release 11 brings improvements to radio link failure and RRC connection failure reporting [25]. In addition, there are several applications in which drive tests are helpful and thus MDT can also be applied. For example, in this deliverable the focus is on hybrid localization which becomes possible due to extensive measurement databases that MDT can provide. Other MDT use cases, in addition to those already mentioned, include at least faster deployment of new base stations, learning based mobility optimization, capacity optimization and parametrization for control channels.

3.1.1 Architecture

Minimization of drive tests feature was specified in 3GPP Release 10 for centralized collection of UE and radio access network (RAN) measurements associated with location information. The overall MDT functionality is described in [20]. For an easy-to-read overall description about the MDT architecture, reader may also refer to [26], [25]. MDT functionality uses the User and Equipment Trace framework [27], allowing operations & maintenance subsystem to record RRC signaling messages between UE and RAN nodes. In order to guarantee the visibility of MDT measurement results in the eNodeB, the control plane architecture for MDT signaling was selected. The MDT specification identifies the following entities involved in MDT process: O&M system which controls MDT data collection, trace element (TCE) where MDT trace records are forwarded for post processing the data, UEs from which the data is collected and RAN nodes. Element manager (EM) located in operator's O&M system is needed for activating the tracing and providing the MDT configuration. MDT measurement is always a network initiated process. Figure 3 visualizes the MDT architecture showing also the MDT signaling, as UE moves from connected mode to idle mode and back.

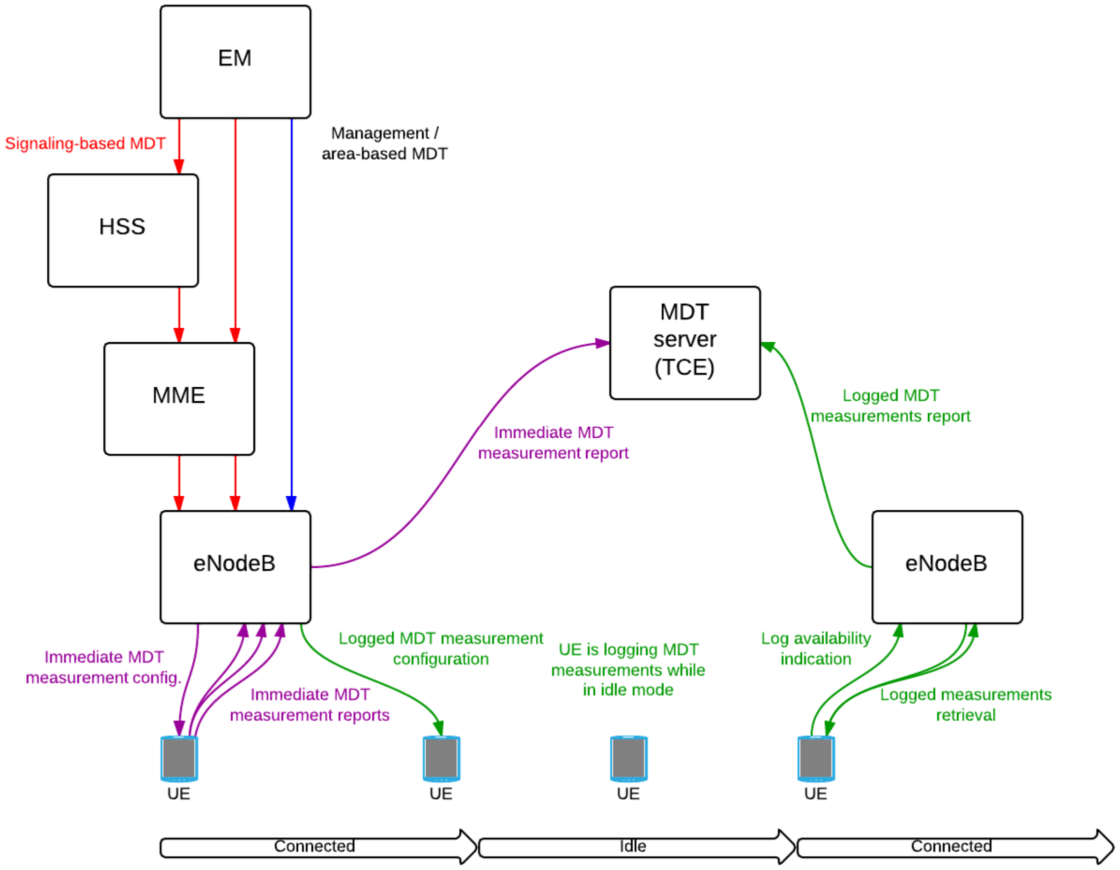

Figure 3. MDT measurements and measurement configuration

3.1.2 Measurements

There are two options for configuring LTE Release 10 MDT measurements: management based or signaling-based configuration procedure [23], [27]. In the management-based configuration, the base station configures all selected UEs in a particular area to do the MDT measurements [23], [27]. The signaling-based MDT is an enhancement to a signaling-based subscriber and equipment trace functionality [27] where the MDT data is collected from one specific UE instead of a set of UEs in a particular area. The network may also consider UE capabilities when selecting UEs for MDT measurements. Detailed signaling flows for activating MDT measurements are described in [27]. The MDT measurement and reporting schemes are immediate MDT and logged MDT. The immediate MDT scheme extends RRC measurement reporting to include the available location information into the measurement reports for UEs which are in connected mode [23]. In the logged MDT scheme, the UEs can be configured to collect measurements in idle mode and report the logged data to the network later [23]. The MDT measurements can be collected periodically or be triggered by a selected network event [3], [23].

Measurement report consists of available location information, time, cell identification data and radio measurement data. The radio measurements for the serving and the neighboring cells include reference signal received power (RSRP) and reference signal received quality (RSRQ) for LTE system, and common pilot channel received signal code power (RSCP) and received signal quality (EC/N0) for HSPA system [3], [23]. There are different mechanisms for the estimation of user location. The availability of location information also depends on the UE implementation [20]. The coarsest location estimation is the serving cell global identification (CGI) and in the best case the detailed location estimate is obtained from the Global Navigation Satellite System (GNSS). The cell identification information consists of the serving cell CGI or physical cell identifications (PCI) of the detected neighboring cells. UE power constraints may also limit the availability of different positioning methods [20].

3.1.3 Measurement Trace Activation

Before the MDT tracing can be started, a base station – E-UTRAN NodeB (eNB) – is activated and configured to collect MDT measurements. In step 1, EM sends a cell trace session activation request to the eNB including MDT trace configuration. The trace configuration consists of trace parameters such as trace job type, trace reference (TR) and TCE address, so that the eNB can later report the trace records back to the trace element. Trace reference is a globally unique reference for identifying the trace session [27]. TCE address defines the IP (Internet Protocol) address of the trace collection entity [27]. After cell traffic trace activation, the eNB selects the UEs for MDT while taking into account the user consent such as user's permission for an operator to collect the MDT measurements. The eNB sends the RRC measurement configurations to the selected UEs. This includes reporting triggers, intervals and list of intra-frequency, inter-frequency and inter-RAT measurements from 2G and 3G networks with a requirement that UEs include the available location information into the measurement reports as specified in the RRC specification information element (IE) ReportConfigEUTRA field [28]. Currently available triggers for reporting network events are listed in Table 5. When the RRC measurement condition is fulfilled e.g., a periodical timer expires or a certain network event occurs, the UE sends available RSRP and RSRQ measurements to the eNB with the available LocationInfo IE added to the measurement report [28].

Table 5. Criteria for triggering an E-UTRA measurement reporting event [28].

Event	Description
Event A1:	Serving becomes better than absolute threshold
Event A2:	Serving becomes worse than absolute threshold
Event A3:	Neighbour becomes amount of offset better than Pcell
Event A4:	Neighbour becomes better than absolute threshold
Event A5:	Pcell becomes worse than absolute threshold1 AND Neighbour becomes better than another absolute threshold2
Event A6:	Neighbour becomes amount of offset better than Scell

It is worth noting that for MDT purposes, A2 event can also trigger periodical reporting of RRC measurements for MDT purposes. However, similar reporting behaviour can also be achieved if measurements are reconfigured to be done periodically after a certain conditional trigger is fulfilled.

3.1.4 Immediate Mode

Immediate MDT is based on the existing RRC measurement procedure with an extension to include the available UE location information to the measurement reports. LTE release 10 RRC specifications [28] allow operators to configure RRC measurements in a way that RSRP and RSRQ measurements are reported periodically from the serving cell and intra-frequency, inter-frequency and inter-RAT neighboring cells from 2G and 3G networks with the available location information. The immediate MDT measurement reporting principles are illustraded in Figure 4 as described in [27].

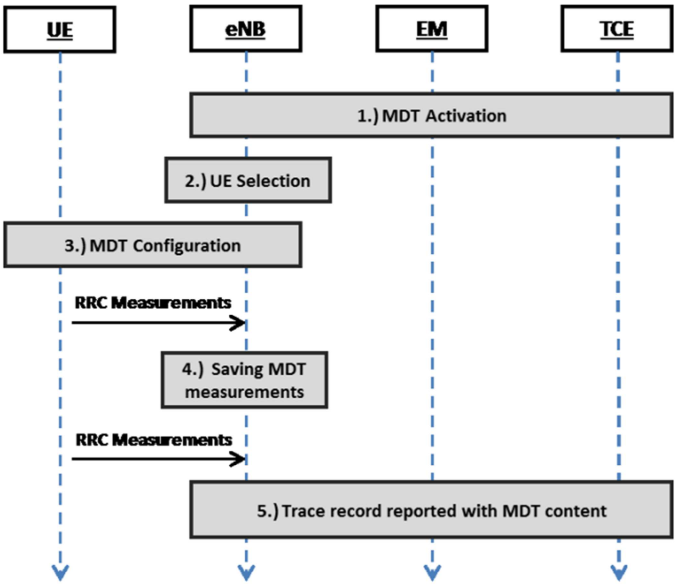

Figure 4: MDT measurement collection procedure

If detailed location information is available, then the latitude and the longitude are included into the measurement report. If the detailed location information is obtained using GNSS positioning method, then UE shall attach time information to the report as well [3]. This GNSS time information is used to validate the detailed location information. Note that in the case of immediate MDT, UE does not send absolute time information (other than GNSS sampling time) as it does in the case of logged MDT. The eNB is responsible for adding the time stamp to the received MDT measurement reports, when saving the measurements to the trace record.

3.1.5 Logged Mode

Logged MDT scheme enables measurement data gathering from the UEs which are in RRC idle state. The logged MDT configuration is provided to the UEs via RRC signaling by sending *LoggedMeasurementConfiguration* message while UEs are in RRC connected state. Logged mode configuration parameters are listed and described with more details in [23]. As illustraded in Figure **3**, MDT measurement data, time, location information and radio measurements are logged to the UE’s memory when the UE moves to the RRC idle state. Later, when UE re-establishes the RRC connection, it indicates whether or not it has logged data available. Based on this indicator, the network can ask the UE to use RRC signaling to report the logged data. In the logged MDT, the number of logged neighboring cells is limited to a fixed number per frequency band due to the UE memory restrictions. If the UE is connected to an LTE network, it should try to log the measurement results for 6 intra-frequency neighboring cells, 3 inter-frequency neighboring cells, 3 GSM neighboring cells and 3 UMTS neighboring cells [23]. Currently, there can be only one RAT specific logged MDT configuration per UE, which is valid only for the RAN providing the configuration. If earlier configuration exists, it will be replaced by the newer one [23]. Thus, logging is done when UE is camping on the RAN that has provided the configuration and UE shall not try to report the logs to any other RAT.

4 ENHANCEMENT TO 3GPP MDT ARCHITECTURE

This section describes a proposal to enhance 3GPP MDT functionality to support collection and correlation of WLAN coverage measurements with MDT measurements. The proposed architecture consists of two alternative designs: user-plane architecture and control-plane architectures for generic MDT.

4.1 Generalized MDT Measurement Architecture

Based on the requirements identified by use case scenarios in SHARING work package 2 and the results of the studies addressing the localization challenges in HetNet infrastructures (e.g., femtocells and WLAN), a generic measurement architecture is designed. The proposed architecture target is to automate the collection of UE WLAN radio measurements and minimizing the need of manual drive-tests in heterogeneous small cell networks consisting of LTE and WLAN access nodes. We call this architecture *generalized MDT* (GMDT). The simple idea of GMDT is that additional measurement results about WLAN APs could be added to the MDT reports containing E-UTRAN and UTRAN network measurements in addition to UE location. Such added information can be very useful for improving RF fingerprint positioning accuracy, building WLAN coverage maps, and improving small cell discovery. It can also be used for ANDSF database and policy management. Thus the benefits of GMDT are visible to operators and end users, for example, in more accurate indoor positioning or more efficient WLAN offloading.

This chapter describes the appropriate architecture changes and identifies the localization functional blocks and logical interfaces as well as the information exchanged through them. The proposed architecture is aligned as much as possible with 3GPP *Study Item on WLAN/3GPP radio interworking* [4] for measurements and triggering events. It also relates to the usability of the GMDT as a potential enabler of self-organizing WLAN networks. The importance of GMDT increases as operators accelerate the deployments of WLAN networks. This is expected to happen due to the fact that even though 3GPP technology is constantly developing, it is not necessarily enough for carrying the ever expanding amount of mobile data [1] generated on certain hot spot areas. On the other hand, the capacity of operator's cellular networks is restricted by the available frequency bands, which makes it tempting for mobile operators to exploit also the unlicensed ISM (Industrial, Scientific and Medical) bands. Therefore, the importance of the generalized MDT seems to increase during the next five years and it will play an important role in facilitating the multi-layer, multi-RAT heterogeneous networks interworking.

4.1.1 User Plane GMDT Solution

One solution allowing operators to correlate MDT and WLAN radio measurements is to use the existing user plane signaling with assistance information. This approach is depicted in Figure 5. In the user plane solution, WLAN measurements are reported independently to O&M using any existing user plane signaling. For example, a third-party client software or OMA-DM protocol can be used[1]. Since user plane solutions are transparent to RAN nodes, eNB cannot include the WLAN measurements to MDT trace records and forward them to TCE, although UE is connected to the eNB and has been configured for MDT. Hence, for being able to correlate the WLAN measurements with the MDT measurements in O&M, operator needs assistance information to be included into either 3GPP or WLAN MDT measurements. One simple way to provide the assistance information is to use the logged MDT principle, where eNB uses dedicated RRC signalling to deliver trace reference, trace recording session reference and TCE identifier parameters to UE [27]. These parameters are stored and reported later to network together with the logged data. From RRC signaling point of view, this approach can be reused in GMDT, if RAN node provides logged MDT configuration to UE. Thus, the existing functionality is already applicable, e.g., in the case where UE has released the RRC connection to 3GPP network and is in IDLE state, and performs logged MDT measurements, while it is connected to WLAN AP.

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[1] The current ANDSF signaling is also carried out on user plane over s14 interface

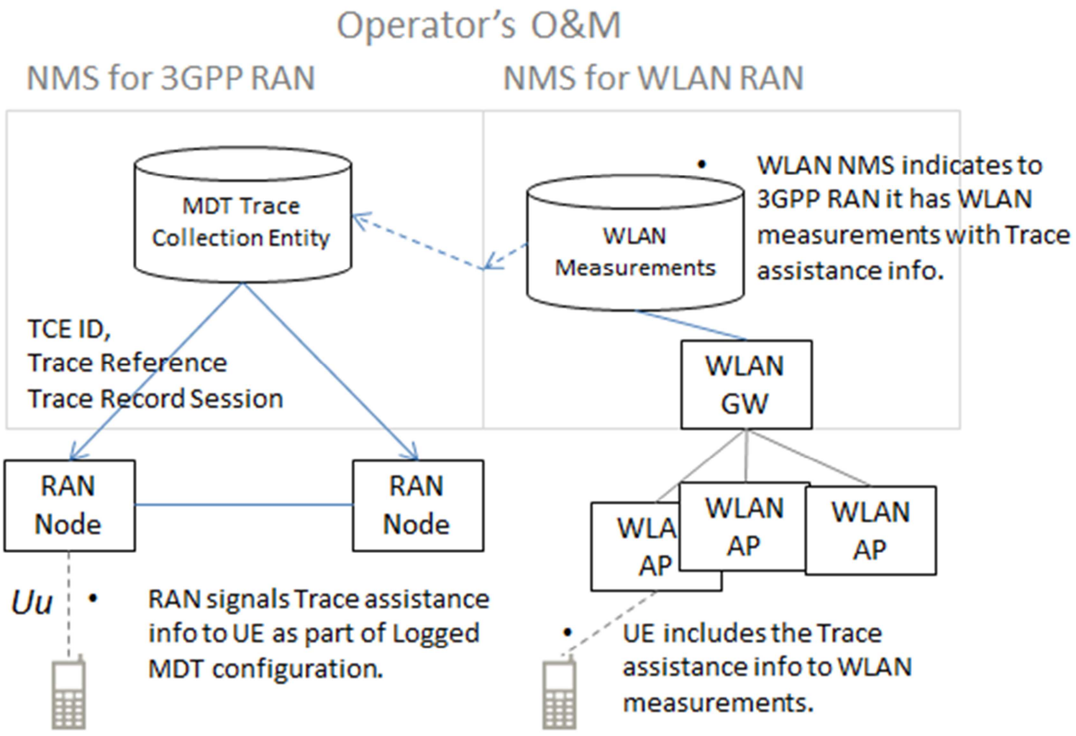

Figure 5. User plane architecture for GMDT.

For user-plane GMDT solution, we propose to report at least the following WLAN measurements, when available:

- Sequence of the WLAN measurements
- Trace assistance information
- Time stamp

Moreover, the sequence of the WLAN measurements consists of:

- Received Signal Strength Indicator (RSSI) measured from beacon frames (1 Byte)
- Basic Service Set Identifier (32 Bytes)
- Service Set Identifier (6 Bytes)
- Homogenous Extended Service Set Identifier (6 Bytes)

If UE is configured to report WLAN measurements using any user plane protocol, then correlation between MDT trace records and GMDT WLAN measurements can be done in O&M by using the trace assistance information incorporated in the WLAN measurements. The prospects of using the user plane solution for correlating MDT and WLAN measurements is that, it does not require changes to the RRC signaling over the Uu interface. All needed assistance information can be conveyed to UE, by either configuring logged MDT measurements properly in RAN nodes or conveying trace assistance information through user plane. If logged and immediate MDT measurements are configured simultaneously, currently only logged MDT trace assistance information is signalled to UE. Since trace parameters (TR and TRSR) are different for logged and immeadiate MDT measurements, RAN would have to ensure that both trace records can be correlated later. This would ensure that trace assistance information is available and can be used by the user plane GMDT application. Moreover, if different dedicated applications are used for MDT measurements and WLAN measurements, more information can be collected. A dedicated application tailored for the needs of WLAN operator is likely to report much more measurement information about the WLAN APs than what would be feasible to include in the 3GPP MDT trace records. The main constraint of using the user plane solution with trace assistance information is the fact that it requires software updates to the UE modem firmware and to user plane measurement application for making the trace assistance information available on upper application layers. On the other hand, trace assistance information alone is not sensitive information from operator or user privacy perspecitve so there is no strong argumentation not to do so. In addition, new O&M signalling is needed between RAN and GMDT server for fetching the measurement data. GMDT server can be part of the O&M or WLAN Network Management System (NMS) and interface for exchanging measurement data does not exist at the moment. However, building such support using existing protocols and interfaces should be possible with small effort. It is worth noting that GMDT server cannot acquire the routing data based on the trace assistance information without coordinating with RAN nodes for decoding the location and IP address of TCE based on TCE ID. Another minor constraint is the configurability of the measurements. Just by making available the trace assistance information, the correlation between the MDT and WLAN measurements can be ensured. However, little can be done for configuring which WLAN APs are measured with the MDT trace assistance information. Hence, for enhancing the user plane solution, more coordination between the 3GPP and WLAN NMS is needed. One way of providing such coordination is to rely on Release-12 LTE/WLAN interworking solution that allows providing candidate WLAN AP identifiers to UE either through RRC signalling or via ANDSF functionality.

4.1.2 Control Plane GMDT Solution

The control plane solution of GMDT employs the same network elements as Release 10 MDT architecture but small modifications to measurements and signaling are needed. The main difference is that in GMDT, UE measures WLAN APs and includes the measurements either to RRC measurement signaling or Logged MDT signaling. Hence, both logged and immediate GMDT reporting modes are available and there are no differences in that sense comparing to the current MDT specification. The content of proposed GMDT measurements and triggering network events are aligned with the access network selection and traffic steering solution 3 described in Section 2.2.2. In this solution, UEs in IDLE and CONNECTED state are controlled by eNB using either dedicated or broadcast signaling, potentially based also on WLAN measurements reported by the UE. In order to do WLAN measurements, the RAN node will have to configure them. In the proposed architecture, this would be carried out by transmitting target WLAN identifiers to UE. These indetifiers specify the identity of WLAN APs to be measured, as well as, the related parameters such as the operating channels to be searched for [4]. It should be noted that only the access points owned by operator or its partner are to be configured for measurements. The proposed target identifier fields to be signaled are shown in Table 3. As described in section 3.1.3, the information element ReportConfigEUTRA specifies criteria for triggering of an E-UTRA measurement reporting event for MDT.

It is anticipated that if eNB uses dedicated signaling for traffic steering between LTE and WLAN as proposed in solution 3 [4], then RRC signaling can be used for configuring the measurements of other radio access technologies. If so, new events triggering the measurement reporting for WLAN are needed as proposed in 3GPP LTE/WLAN Interworking study item [4]. These measurement triggers proposed for WLAN were listed in

Table **2**. Event W1 can be used to trigger WLAN measurements for the purpose of coverage mapping, RF fingerprinting or ANDSF database update. Event W2 could possibly be used for detecting coverage problems and coverage holes. However, it should be noted that events W3 and W4 are relevant to the traffic offloading presented in [4] but not necessarily to GMDT and are mentioned here merely for the sake of completeness. In addition to the triggers listed in

Table **2**, GMDT benefits if WLAN measurements can also be started periodically, in which case the reporting procedure is similar to the current MDT procedure. For control-plane GMDT solution, we propose to include the following WLAN measurements, when available, into the RRC measurement reports for immediate and logged MDT:

- Received Signal Strength Indicator (RSSI) measured from beacon frames
- Basic Service Set Identifier (BSSID)
- Service Set Identifier (SSID)

- Homogenous Extended Service Set Identifier (HESSID)

Similarly to the reporting of CGI of the serving LTE cell and PCI of neighboring LTE cells, we propose to additionally report the SSIDs, BSSIDs or HESSIDs of WLAN access points with highest RSSI values measured from the WLAN beacon frames. RCPI and RSNI measurements were first considered to be used instead of WLAN RSSI measurement to align GMDT control-plane solution with LTE/WLAN interworking solution 3. RSSI and RCPI provide the same information but since RSSI is mandatory in [39], while RCPI is optional, RSSI was chosen. It is worth noting that although RSSI is mandatory, it is not fully specified currently, which means that WLAN APs from different manufacturers are likely to report different RSSI values in identical radio conditions [36]. RCPI has a ±5 dB (95% confidence interval) accuracy requirement, while RSSI does not have any. However, there is no reason why RSSI could not achieve similar accuracy. Moreover, since RSNI is not well defined and cannot even be computed in some cases, it does not necessarily reflect the signal quality of the received packet as expected. Therefore, RSNI value as defined in [39] is not a suitable metric for signal quality in the downlink direction. It should also be noted that LTE uplink transmission on certain frequency bands may introduce in-device coexistence (IDC) interference to simultaneous WLAN measurements [36]. Similarly, if WLAN active scanning is used by UE, IDC issues may arise with regard to LTE downlink transmissions [36].

Mere WLAN coverage is of little interest to WLAN capable UEs, if in reality there are no available radio resources in the access points. Since WLAN release 802.11-2012 [39], BSS load indicator can be transmitted inside the management frame transmitted by WLAN AP. BSS load indicator consists of several fields including station count, channel utilization and available admission capacity. It is possible to record this information while doing WLAN measurements as a part of GMDT procedure. BSS load indicator information could be added to the measurement report in order to collect also capacity related information. Other mechanisms, such as channel idle time measurements or probe packets, could also be used for measuring WLAN AP congestion. However, from the point of view of GMDT these methods involve either too much measurement reporting or are too complex. Therefore, only the load indicator that is readily reported by AP is proposed to be recorded. While being clearly more relevant in 3GPP to WLAN offloading, the BSS load indicator can be useful in GMDT uses cases such as ANDSF database update and WLAN load/capacity mapping.

If WLAN measurement events are triggered, then UE performs the measurements and either includes them into logged MDT data or sends the measurement results to eNB, which can include them into MDT trace records. Operator may also want to initiate periodical WLAN measurements for several reasons such as updating ANDSF database. It is also anticipated in [4] that if traffic steering is controlled by dedicated RRC commands, eNB needs to signal the identity of the AP to be measured. Periodical measurements can be used for APs discovery in order to assist measurement configuration. If GMDT measurements are started periodically, the measurement procedure is identical to the current MDT procedure. However, WLAN measurements shall be done in a best effort manner from UE point of view. This means that periodical WLAN measurements are carried out and reported only if UE has switched WLAN on and either does the measurements for traffic steering purposes or is already connected to a WLAN AP. Thus, network should not force UE to switch WLAN on. Such behaviour is well inline with the MDT operation principles.

In densely populated areas, it is possible to receive dozens of access point signals in various locations as studied in Chapter 5. In order to enhance the localization accuracy of MDT and GMDT measurements, we propose the possibility to report WLAN RF fingerprints consisting of the highest RSSI values of multiple APs and the corresponding basic service set identifiers. However, using all detectable access points in RF fingerprinting may not be feasible nor give the best performance in terms of localization accuracy [40]. The maximum number of APs to report cannot be determined in a straightforward manner based on the assumed network layout, because few assumptions can be made on the AP locations relative to each other. In the case of logged MDT, LTE fingerprint consists of PCI and RSRP values for up to six intra-frequency neighbour cells, which is well suited for a hexagonal tessellation where each cell is surrounded by six other cells on the first tier. Based on the results in [40], one could conclude that for WLAN, it is enough to report at most 10 AP in order to establish a good RF fingerprint.

Constraints limiting the applicability and usefulness of MDT are applicable to GMDT as well. Additionally, GMDT requires WLAN receiver to be turned on and scanning for APs in order to make measurements. This naturally imposes certain battery life and UE implementation related constraints. For this reason, it is assumed that WLAN information is only used when user has selected to turn on the WLAN receiver in the UE. GMDT also contributes to an increased amount of measurement report signaling as well as to higher memory requirements for UEs doing logged GMDT due to larger quantity of collected measurement data.

4.2 GMDT Use cases and Applications

This section presents some of the possible use cases for generalized MDT. A data-intensive approach and the use of multiple sources of position information from different HetNet components are common to most of the use cases. The idea is to exploit the diversity in the localization capabilities provided by HetNet components to provide custom in terms of considered quality metrics (e.g., accuracy of positioning information, timeliness of position estimates, etc.). In many use cases, such as in the network based proximity indication, the concept is forward-compatible in terms of individual hetnet components, thus being able to accommodate additional hetnet components in a generic manner. For example in the mentioned use cases, measurements from another short range-radio system could be used to further improve the proximity indication accuracy.

4.2.1 Enhanced Location Services

The ability to collect UE measurements that reliably reflect the network coverage and quality at a specific location is a key feature of MDT functionality. Therefore, one objective of 3GPP Release 11 research was to specify enhancements to Release 10 MDT functionality to improve the availability of the detailed location information [25]. One of the enhancements allows operator to request the UE to acquire GNSS location for already configured MDT session [25]. This improves the probability of MDT reports being associated with the detailed location in outdoors where satellites can be detected. However, it does not work well in urban canyons or indoor locations where UEs transmit most of the data [29]. Moreover, not all the UEs are equipped with GNSS receiver in the first place. It is well known that the state-of-the-art on indoor localization architectures with a positioning accuracy order of magnitude of few meters rely on WLAN based RF fingerprint methods [30]. RF fingerprinting can be considered as a two phased process. In the training phase, extensive signal strength measurements from LTE base stations and WLAN access points are carried out, which are coupled with the location information of the measurement point [30]. The set of measurements from a location is called RF fingerprint and these fingerprints form a correlation database. In the runtime phase, these stored measurements can be used to map reported signal strengths from a set of access nodes to a location estimate [30]. The location estimate is derived from the most similar fingerprint compared to the measurements from the unknown location [30]. The fingerprint correlation process is similar whether the measurement results consist only of LTE cells or a combination of LTE cells and WLAN access points. Same methods for calculating the best location estimate can be used (cf. [31] and [32] for position estimation algorithms) provided that the correlation database contains entries for both RATs.

It is foreseen that if MDT reports can be associated with WLAN measurements, the operators and network vendors are able to develop hybrid multi-RAT localization algorithms which can provide detailed location information in indoor and outdoor environments. This would allow improvements to MDT coverage optimization, by discriminating between the indoor and the outdoor coverage, or determining the location and coverage of uncoordinatedly deployed WLAN APs. The improvements on location accuracy due to small cells RF fingerprinting in a HetNet scenario are studied in [31] and [32]. Although the small cell layer is assumed to be deployed with LTE pico cells, it works on a different frequency band from the macro layer, and therefore the results in [31] and [32] are also indicative of the localization performance of LTE macro network combined with a layer of WLAN access points. According to [32], localization accuracy is improved from 38 m to 21 m for 68 % of the users and from 113 m to 95 m for 95 % of the users when the RF fingerprints are extended by incorporating the small cell layer measurements. To put these results into context, the Federal Communications Commission (FCC) has defined the required minimum localization accuracies for mobile operators in [33]. The maximum location error should not exceed 50 m for 68 % of the users and 150 m for 95 % of the users [33]. Therefore, LTE system incorporated with small cells is capable of meeting the FCC localization accuracy targets with the assumptions specified in [32]. One of the biggest challenges of any RF fingerprinting based method is the burden of maintaining the correlation databases [31], [32]. However, the cost and complexity of maintaining the databases can be significantly reduced since minimization of drive testing functionality allows to autonomously update the cellular and WLAN databases if MDT functionality is extended to support the WLAN as well.

4.2.2 Generation of WLAN Coverage Maps

Coverage is one of the most important criteria when a user is metering the quality of a network [3]. Coverage mapping is essential for operators, who want to be able to measure their WLAN coverage in order to use this information in network planning and optimization, marketing or simply assessing their WLAN investments. The additional measurement results from WLAN APs could be included into the MDT report containing the LTE network measurements and the UE location, which can be very useful in building WLAN coverage maps. The use case of WLAN coverage mapping is fairly similar to the original MDT use case of coverage optimization [3] and can also target the detection of coverage holes and weak coverage. GMDT provides very cost efficient tool for detecting coverage holes as no drive test measurements are needed. Automated coverage mapping can even eliminate the indoor coverage verification phase when deploying indoor WLAN networks and help to detect interference issues by observing the number of overlapping access points on each channel cf. pilot pollution in 3GPP terminology.

4.2.3 ANDSF Database Management

ANDSF and GMDT can be seen as techniques complementing each other. As the name suggests, the main functionality of ANDSF is assisting UEs in discovering available non-3GPP networks. ANDSF also provides UEs with policies to use when connecting to any of the advertised networks [34]. Despite different use cases, the two technologies have also similarities, e.g., both allow UE to transmit its current location to network. This enables network to advertise only geographically relevant access points to the UE [34]. Contrary to GMDT, ANDSF is not intended to be used to report RF measurements to network, which means that the UE-based automatic access point database update using ANDSF is inpractical. This is where MDT and GMDT come into the play as these are designed to collect measurement information from radio networks. The radio measurements about available WLAN APs within the area of a 3GPP cell, which is provided by GMDT, can be used to create and update ANDSF databases.

ANDSF can provide following information to a UE: *inter-system mobility policy* (ISMP), *inter-system routing policy* (ISRP) and *discovery information* [6], as introduced in 2.2.1. In order to enable UEs to discover WLAN networks, ANDSF server needs to be aware of the geographical locations of mobile operator’s (or partner’s) WLAN access points which is referred to as a discovery information. WLAN AP identity i.e., SSID, BSSID or HESSID, and the approximate location of AP can be obtained using GMDT by correlating WLAN AP identities with MDT measurements and using both for location estimation. Overview of this architecture is depicted in Figure 6. In the first phase, UEs measure the signal strength of a nearby WLAN access point. The measurements are then reported to a RAN node e.g., using control-plane GMDT, which further reports them to the *GMDT trace collection entity.* The GMDT trace collection can utilize GMDT measurements to estimate the location of WLAN access points and provides ANDSF database with the location of measured access point which will eventually be used in assisting other UEs to discover the access points. Automatically populating ANDSF database based on information collected from GMDT has two advantages: it eliminates the need to add the access point discovery information manually to the database and secondly, actual coverage areas of WLAN access points can be used instead of estimates. Therefore, it can result in a more cost efficient operation of the WLAN network. One algorithm for ANDSF assisted network discovery is presented in [35]. It is left for future studies how the discovery information is transported from GMDT server to ANDSF server in O&M.

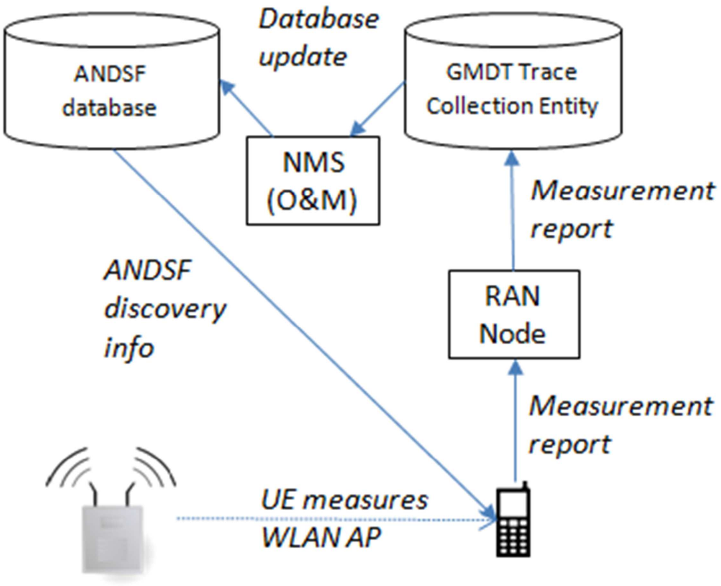

Figure 6. Control-plane GMDT assisted ANDSF database update

Information gathered from GMDT could also be used for updating ANDSF policies, namely inter-system mobility policy. ISMP can be updated based on the BSS load indicator information transmitted by WLAN AP and forwarded to the GMDT trace collection entity by the UE as a part of the user-plane GMDT reports. BSS load indicator consists of several fields including station count, channel utilization and available admission capacity [39]. One or several of the fields can be used to determine if access point is congested or not based on predefined threshold values for each of the fields. If congestion is detected, GMDT trace entity proposes an updated policy to ANDSF database deprioritizing the congested WLAN access point.

4.2.4 Enhanced Network Based Proximity Indication

Proximity Indication (PI) refers to methods where one network element e.g., macro base station, becomes aware that UE approaches or is in a proximity of another network element e.g., small cell. One use case for PI information is to use it for power efficient small cell discovery by configuring the cell search only when UEs are in vicinity of the small cells. This helps to avoid the exhaustive and power inefficient always-on scanning of the small cells. In 3GPP, network based PI is proposed to be one solution to configure UE’s radio measurements on small cell layer based on the radio measurements of the serving and the neighboring cells on the macro layer [41]. Similar approach can be used to trigger the measurements on non-3GPP RAN, such as WLAN, based on the radio measurements on 3GPP RAN. This is in line with the power efficient WLAN scanning principle of LTE / WLAN interworking solutions in [4] but requires creation of correlation databases consisting of geographical locations of WLAN APs associated with the RF fingerprints on 3GPP RAN. Such database can be created by correlating MDT measurements with the WLAN measurements using the proposed GMDT architecture.

5 PERFORMANCE EVALUATION

Performance evaluation for the RF fingerprint positioning in GMDT architecture was carried out by conducting dynamic system lelvel simulations to study the mathematical framework of RF fingerprinting based localization. In addition, LTE network measurement campaign was carried out to evaluate the performance of the RF fingerprinting accuracy in real urban environment. In the performance analysis, three main KPIs were considered, namely, 68 percentile and 95 percentile positioning errors and amount of discarded analyzed testing samples. In the analysis, performance comparison between MDT measurements and GMDT measurements was done to highlight the benefits of correlating the WLAN measurements with the MDT measurement results.

5.1 System Simulation Campaign

In the system simulation campaign, a dynamic LTE system simulator was used to generate a large database of GMDT measurements. The measurements consisted of time stamp, GNSS location and Receved Signal Strength (RSS) for two LTE bands operating on adjacent carriers around 2 GHz center frequencies. The system simulator was modelling LTE downlink with several radio resource management, scheduling, mobility, handover and traffic modeling functionalities. Simulation parameters and mathematical models were based on 3GPP specifications (especially the simulation assumptions in 3GPP TR 36.839), defining parameterization for used bandwidth, center frequency, pathloss, slow fading, and fast fading. Moreover, UE RF measurements, such as RSRP, were implemented in the simulator taking into account the technical requirements for the absolute and relative measurement errors and -6 dB Es/Iot (received energy per resource element divided by received power spectral density of total noise and interference power per resource element) synchronization channel cell detection criterions as defined in 3GPP TR 36.133.

The simulated network deployment consisted of 57 macro eNBs having inter-site distance of 500m and operating on 1800 MHz band. In addition, 36 small cells operating on 2000 MHz band equipped with omni-directional antennas were randomly deployed in the coverage area of 12 centermost macro BSs as depicted in Figure 7 with red circles.

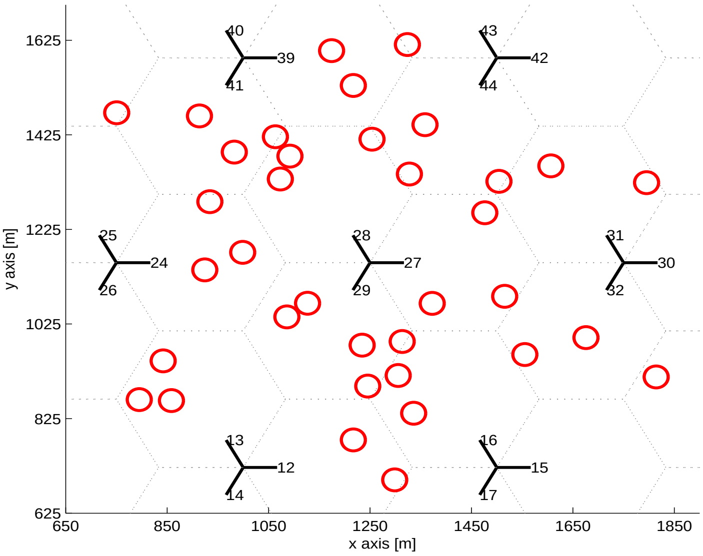

Figure 7: Simulated Network Deployment

Inter-site distance to the nearest small cell varied from 50 meters to 170 meters with the average distance being 95 meters. In this simulation, UEs were moving in the area of 12 centermost macro eNBs and they were able to monitor all detected cells. In total, 1200 randomly moving outdoor vehicular UEs (30 km/h) were distributed uniformly in the simulation area. Traffic profile consisted of data generated by MDT reports which were sent once per second. In addition, 100% resource block loading was used for creating interference limited simulation environment. This is more challenging from cell detection point of view resulting in a smaller set of detected cells. More details about the used simulation parameters and methodology can be found in [31], [32] and [43].

5.1.1 Mathematical Framework

Our localization architecture is based on RF fingerprinting, which is a database correlation method where location is estimated by comparing the cell identities and radio measurements with the training fingerprints in the correlation database. The training fingerprints consist of received signal strength (RSS) radio measurements from several base stations (BS) that are used to provide a fingerprint of the radio conditions at a specific geographical location. Typically, this location is determined with an accurate positioning method, for example GNSS. The main benefit of using fingerprinting in location estimation is its simplicity. If reasonably good training data bases can be constructed containing sufficient amount of accurate reference measurements, location estimation is very straigthforward. The main drawback of fingerprinting is that without automated solution, the construction of large training data bases can be troublesome and expensive. Moreover, computational complexity of searching the best matching fingerprints from large data bases could be cumbersome.

In our localization architecture, grid-based search space structure is used to store training measurements. The advantage of using grid-based search space is that it allows combining measurements from training samples, which are in the vicinity of each other. This helps to compress the size of the search space, i.e., amount of training fingerprints, which results in reducing the amount of memory needed to store the training data base, as well as, lowering the computational complexity of searching the best matching fingerprints. Moreover, the grid-based processing of the training measurements allows to derive new metrics from the RF measurement, such as covariances between the RF measurements from different eNBs, that can improve the positioning accuracy. In the grid-based approach, RF fingerprinting correlation database is compressed to present the geographical space $G=\{g_1, g_2, \ldots, g_N\}$, e.g., “area of interests” as a regular tessellation of N square grid units g_i as depicted in Figure 8. Each grid unit is associated with a center point having coordinates $c_i=\{x_i,y_i\}$ and a set of training fingerprints $S_i=\{s_{i,1}, s_{i,2}, \ldots, s_{i,k}\}$. Hence, a training signature $s_{i,j}$ is the *j*th signature associated with *i*th grid unit and it is constructed from several GMDT measurement that falls in the area of the grid unit and share the same set of base station/access node identities.

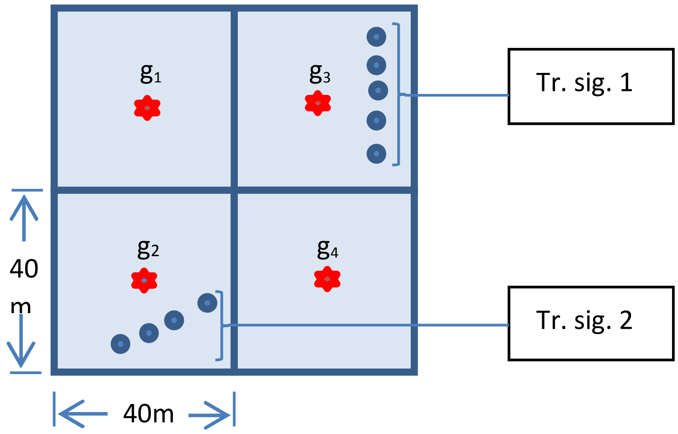

Figure 8: Illustration of 40m-by-40m rectancular grid tessalation

Each sample in the measurement matrix $M_{i,j}$ contains detailed location information, namely, x and y coordinates obtained from GNSS receiver, and *m* RSS measurements, i.e., Reference Signal Received Power (RSRP) in EUTRAN, from different eNBs. The $M_{i,j}$ is represented as

$$\mathbf{M}_{i,j} = \begin{bmatrix} x_1 & y_1 \; rsrp_{1,1} & \cdots & rsrp_{1,\mathrm{m}} \\ \vdots & \vdots \quad \vdots & \ddots & \vdots \\ x_n & y_n \; rsrp_{\mathrm{n},1} & \cdots & rsrp_{\mathrm{n,m}} \end{bmatrix}, \qquad (1)$$

where $rsrp_{1,m}$ is the first RSRP measurement with an eNB identifier m. Training signatures are formed from the measurements samples in the measurement matrix $\mathbf{M}_{i,j}$ whose accurate location is known. The location is needed to associate the signatures with the closest grid unit. In the testing phase, all training signatures that match with the testing signature (signature whose location is not known) are searched based on the matching eNB identifiers. For finding the best matching training signature, various pattern matching methods can be used. In our architecture, Kullback-Leibler Divergence (KLD) method was used for analyzing simulation results since it has been found to be particularly useful in WLAN RF fingerprinting [30]. In KLD method, training and testing phase signatures, i.e., mean vectors $\mathbf{u}$ and covariance matrices $\mathbf{\Sigma}$, parameterize multivariate Gaussian distributions $p(\mathbf{x}|\mathbf{u}, \mathbf{\Sigma})$, and therefore, the method aims to exploit interdependencies among the received signal strengths between BSs by using covariance matrices for training and testing phase signatures as given by the following closed form KLD equation:

$$d(p_u||p_{i,t}) = \tfrac{1}{2}\left(\left(\mathbf{u}_u - \hat{\mathbf{u}}_{i,t}\right)^T \hat{\mathbf{\Sigma}}_{\mathrm{i,t}}^{-1}\left(\mathbf{u}_u - \hat{\mathbf{u}}_{i,t}\right) + \mathrm{tr}\{\mathbf{\Sigma}_{\mathrm{u}}\hat{\mathbf{\Sigma}}_{\mathrm{i,t}}^{-1} - \mathrm{I}\} - \ln\left|\mathbf{\Sigma}_{\mathrm{u}}\hat{\mathbf{\Sigma}}_{\mathrm{i,t}}^{-1}\right|\right), \qquad (2)$$

where $d(p_u||p_{i,t})$ is non-symmetric KLD metric measuring the similarity between training and testing signatures. Moreover, vectors $\mathbf{u}_u$, and $\hat{\mathbf{u}}_{i,t}$ corresponds to the mean received signal strength values, while $\mathbf{\Sigma}_u$ and $\mathbf{\Sigma}_{i,t}$ represents the covariance matrices of the received signal strength values of the testing and training signatures respectively. Here, tr{.} denotes the trace of matrix, $\mathbf{\Sigma}^{-1}$ denotes the inverse of covariance matrix $\mathbf{\Sigma}$ and $\mathbf{I}$ is the identity matrix. KLD is a non-symmetric measure of the difference between testing and training signature probability distributions p_u and $p_{i,t}$. It is worth pointing out that the measurements used to construct the grid of training signatures can be reused to enhance the performance of the grid-based search. One of the enhancements is the creation of several partly overlapping grid units as studied in [43].

5.1.2 Performance Results

Table 6 illustrates the performance of RF fingerprint positioning in the simulated HetNet scenario [43]. Positioning error analysis is done with two different grid unit sizes, namely, 10-by-10 meters and 40-by-40 meters. The analysis is done for Single Grid Layout (SGL) and Overlapping Grid Layout (OGL) as explained in [43]. For both cases the sparse (10% samples used for training) and the dense (90% samples used for training) training were analyzed.

Table 6: Positioning error in simulation scenario [43]

Training Data (%)	**RF Fingerprint Algorithm**	**For 10-by-10 m Grid**		**For 40-by-40 m Grid**	
		68% PE (m)	**95% PE (m)**	**68% PE (m)**	**95% PE (m)**
90% (good)	SGL Based	21.12 m	58.08 m	33.73 m	76.43 m
	OGL Based	19.45 m (-7.9%)	50.94 m (-12.2%)	27.57 m (-18.2%)	64.87 m (-15.1%)
10% (low)	SGL Based	27.23 m	73.61 m	34.83 m	80.86 m
	OGL Based	25.14 m (-7.6%)	66.47 m (-9.6%)	28.28 m (-18.8%)	68.71 m (-15.0%)

Simulation results suggested that for analyzed testing fingerprints, the simulated positioning error for 68%-ile point varies from 34.83 meters to 19.45 meters depending on the grid layout and amount of the training fingerprints. Moreover, the 95%-ile positioning error was clearly less than 150 meters varying from 80.86 meters to 50.94 meters. In [31] and [32], positioning error was analyzed in similar scenario with and without small cells. In those simulations, it was found out that if RF fingerprint database is constructed only using macro eNBs operating on one frequency band, the RF fingerprint performance degrades significantly. In case the macro cell inter-site distance is 1750 meters, 68%-ile and 95%-ile positioning errors for 40-by-40 meter grid units were 268 meters and 532 meters, respectively [32]. In denser macro cell scenario with inter-site distance of 500 meters, 68%-ile and 95%-ile positioning errors for 40-by-40 meter grid units were only 45 meters and 145 meters [32]. However, in these macro-only simulations, the Es/IoT cell detection threshold was not considered. According to the analysis in [31], cell detection threshold of -6 dB decreases the performance of RF fingerprinting significantly. With ideal performance assumptions, i.e., without Es/IoT threshold, the positioning errors in dense scenario can be 42% to 55% smaller, resulting in too optimistic performance. Moreover, in sparse scenario, the errors were only 28% to 40% smaller.

5.2 Measurement Campaign

A measurement campaign was conducted at Tampere, the third largest city of Finland, during September 2014. Purpose of the measurement campaign was to collect GMDT measurements from a live LTE radio network and validate the algorithms developed in [31], [32] and [43]. The measurements were done separately for three different LTE bands (800 MHz, 1800 MHz and 2600 MHz). In all measurements, the measurement route was repeated at least twice to ensure a sufficient amount of measurement samples to be collected. In the measurements analysis, more than 336,000 LTE RSRP measurements and 264,000 WLAN RSSI measurements were used to create a grid-based fingerprint database. This corresponds approximately to a sample density of 1 million RSRP measurements per square kilometer.

5.2.1 Environment

Measurement environment was a typical Finnish urban city environment consisting of buildings of several floors, open spaces and parks. Measurements were covering approximately an area of 0.33 square kilometres. Measurement route is illustrated in Figure 9. In the figure, blue line is the recorded measurement route based on the location obtained from the GNSS receiver. The numbered circles are markers showing start location, end location and travelled distance in kilometres. Thus, typical measurement was nearly 25 kilometers long. Measurements were repeated at least twice for each measurement band (800 Mhz, 1800 Mhz and 2600 Mhz). This means that more than 150 kilometers of measurements were collected for analysing the GMDT positioning performance by feet, bicycle and car. For each measurement, the route was chosen a bit differently for ensuring some additional randomness in the received signal strength levels e.g., due the body loss. Typically, the measurement device was located either in the left or right front pocket.

Figure 9: Measurement route

5.2.2 Equipment

The measurement was done using a commercial mobile phone (Samsung Galaxy S3 LTE), which was powered with tailored firmware that allows logging 2G, 3G, 4G and WLAN RF measurements together with cell identifiers, location and time stamp (as specified for GMDT/MDT). The device was kept always in RRC connected state and locked on a certain frequency band for avoiding inter-frequency handovers during the measurements. However, for 1800MHz measurements, other frequency bands were reported simultaneously with the 1800 MHz following the RRC inter-frequency measurement configuration provided by the E-UTRAN. This was done for increasing the dimensionality of the LTE-only RF fingerprints.

5.2.3 Performance Results

For understanding the RF fingerprinting performance, measurement statistics were analyzed in more detail. Specifically, the focus was on the amount of detected CID/RSRP and BSSID/RSSI pairs and the dimensionality of the MDT measurements, i.e., how many different CIDs and BSSIDs are detected and measured in a certain location. In Table 7, amount of intra-frequency LTE and WLAN measurements are shown for different cases. It is worth noting that all three LTE bands were measured during the measurements on 1800 MHz since UE was also doing inter-frequency measurement. In this case, 132509 CID/RSRP pairs were measured on 1800 MHz band as shown in Table 7. This is 90.4 % of the total amount of 146546 intra and inter-frequency CID/RSRP measurements recorded during that measurement case. In addition, 13908 measurements on 800 MHz band and 129 measurements on 2600 MHz band were recorded (inter-frequency measurements are not shown in the Table 7).

Table 7: Amount of recorded measurement samples

Measurement case	**LTE**		**WLAN**	
	CID/RSRP Measurements	**Unique CID**	**BSSID/RSSI Measurements**	**Unique BSSID**
800 MHz	70279	502 cells	60963	2467 IDs
1800 MHz	132509	399 cells	86382	2738 IDs
2600 MHz	133827	373 cells	117373	2547 IDs
Total	350652	1285 cells	264718	3161 IDs

The total number of different cell identifiers detected on different measurement cases is high considering that the size of the measurement area is only 0.33 square kilometers. However, many of the CIDs are measured infrequently and the "reliable" set of CID forms a significantly smaller subset CIDs. This is illustraded in the Figure 10 and Figure 11 by showing cumulative percentage of CID/RSRP observations. For example, 90 % of the all CID/RSRP measurement samples on 800 MHz band are from a subset of 40 LTE cells. This is approximately 8 % of the detected unique cell Identifiers. Similarly on 1800 MHz band, a subset of 16 unique LTE cells from total 399 cells were recorded being only 4% of the detected cells on 1800 MHz band. In the case of WLAN, 1350 different WLAN BSSIDs were detected in the sample set that contains 90% of all measurements. This corresponds to 55 % and 50% of the all detected WLAN BSSIDs in 800 MHz and 1800 MHz measurement cases, respectively. It is worth noting that database pruning, i.e., removing less likely (black listed) cells from the training signatures, can further reduce the dimensionality of the training signatures and size of training database as discussed in Appendix A. However, pruning was not used in this study, and training database and tested RF fingerprints are always consisting of all detected CID/RSRP and BSSID/RSSI measurements.

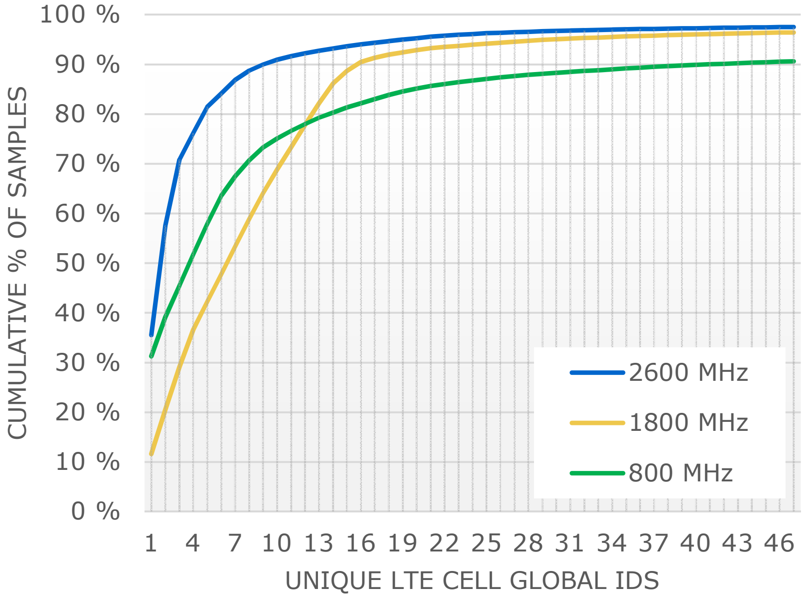

Figure 10: Cumulative distribution of the detected unique LTE cells

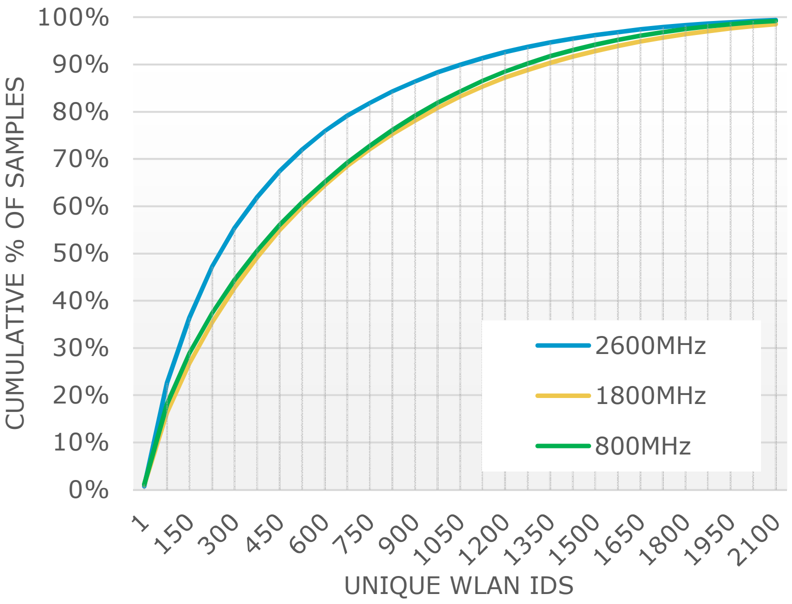

Figure 11: Cumulative distribution of the detected unique LTE cells

Dimensionality of the LTE and WLAN measurements was analyzed for understanding its impact on the RF fingerprinting performance. During the measurement campaign, the LTE cells and RSRP measurements were sampled approximately three times per second, whereas WLAN cells and RSSI measurements were sampled approximately once in five seconds. The dimensionality of the LTE and WLAN measurements corresponds to the number of LTE or WLAN cells detected per one sampling period. The assumption is that high dimensional RF fingerprints are more accurate and can tolerate uncertainties such as missing cells, etc. Cumulative distributions of the LTE and WLAN measurement dimensionalities are illustrated in Figure 12 and Figure 13. In case of 800 MHz and 2600 MHz LTE measurements, 50 % of the measurement samples were reported with two or more detected LTE cells. In case of the 1800 MHz, 50 % of the measurements were reported with more than 4 LTE cells. Higher dimensionality of the 1800 MHz was caused mainly because of the inter-frequency measurements on 800 MHz band as discussed earlier.

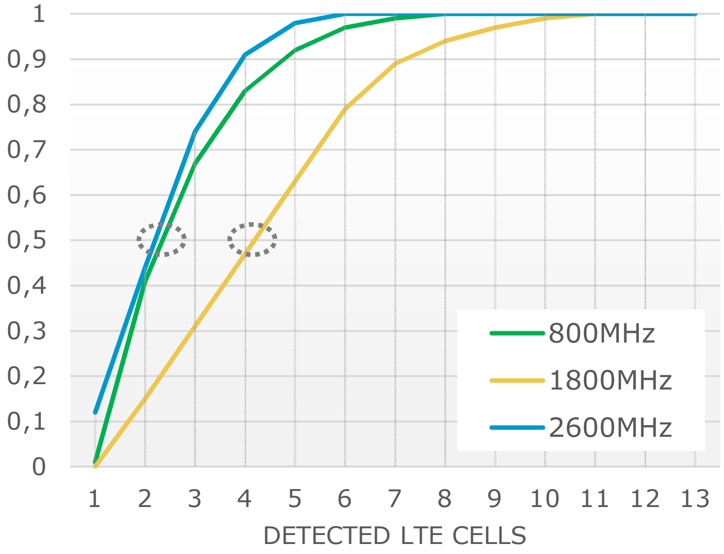

Figure 12: Cumulative distribution of number of LTE cells per measurement

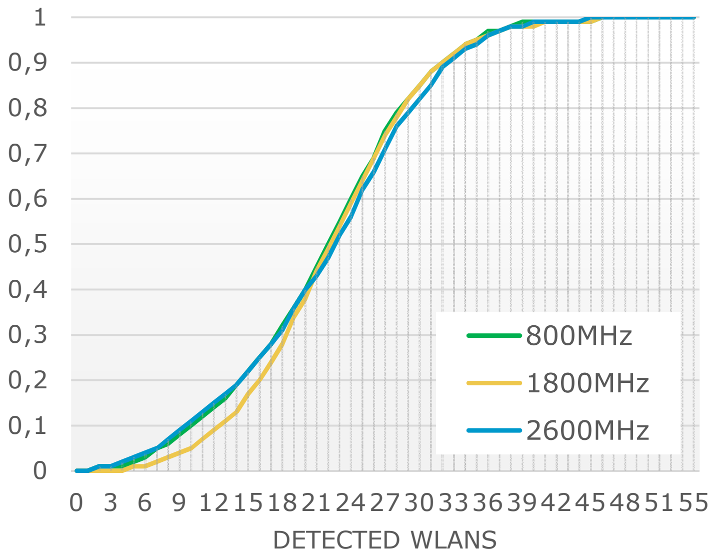

Figure 13: Cumulative distribution of number of WLAN cells per measurement

Dimensionality of the WLAN measurements was not affected by the LTE band selection since in all cases the same WLAN access point should have been measured due to the similar measurement route. 50% of the WLAN measurements contained more than 22 detected WLAN BSSIDs.

Positioning error of the measured RF fingerprints is based on the single grid layer approach consisting of regular 20-by-20 meters or 40-by-40 meters sized grid units. A partial fingerprint matching was used because high dimensional WLAN measurements resulted in a small amount of perfectly matching training signatures. In partial fingerprint matching, testing and training signatures match if more than 90 % of testing signature's cell IDs is matching with the training signature's cell IDs. All such training signatures are considered to be candidates for the nearest neighbours in the Euclidean distance based position estimation. In Euclidean distance based positioning estimation, similarity metric between the training and testing signatures is the Euclidean distance between the RSS measurement vectors. Testing signature location is estimated to be the location of that training signature whose similarity metric is the smallest. Moreover, to avoid too optimistic estimation, 20-fold cross validation with random chunk sampling was used. Random chunk sampling means that all measurement data is divided into chunks consisting of 10 consecutive GMDT measurements. The chunks were ordered in random order to ensure non-biased cross validation. In 20-fold cross validation, training database contains always 95 % of chunks and location estimation is done for the measurements in the remaining 5 % of chunks. This ensures that the tested measurements are not affecting the construction of the training signature database.

Performance of SGL RF fingerprint based location estimation for MDT measurements on LTE 800 MHz and LTE 1800 MHz bands are shown in Table 8. Positioning estimation performance is analyzed using 68 percentile and 95 percentile Positioning Error (PE) points together with the percetange of discarded testing samples. If the percentage of discarded samples is high, it typically means that training signatures fulfilling the partial matching condition were not found. In all cases, 20-by-20 meter grid gave better results than 40-by-40 grid. In contrary, the percentage of discarded samples is higher for denser grid. In the denser grid, the 68%-ile and the 95%-ile positioning errors for MDT measurements on LTE 800 MHz case are 216 meters and 455 meters whereas on LTE 1800 MHz case, they are only 77 meters and 208 meters. If MDT measurements are combined with the WLAN measurements, the 68%-ile and 95%-ile positioning errors are reduced to 16 meters and 39 meters, respectively. This is a significant improvement compared to RF fingerprint positioning using only LTE measurements.

Table 8: RF Fingerprint performance in LTE+WLAN measurements

Measurement band	**Grid Layout**	**68% PE [m]**	**95% PE [m]**	**% of discarded**
LTE 800 MHz	40m-by-40m	295 m	461 m	0%
	20m-by-20m	216 m	455 m	2%
LTE 1800 MHz	40m-by-40m	84 m	224 m	4%
	20m-by-20m	77 m	208 m	6%
LTE + WLAN	40m-by-40m	25 m	48 m	1.8%
	20m-by-20m	16 m	39 m	6%

Figure 14 illustrates the cumulative distribution functions for the positioning error in different measurement cases. In all cases, smaller grid layer resulted in a better positioning accuracy. One reason for such behaviour is that in larger grid units, the horizontal uncertainty increases beacuse the estimated position is mapped to a single point inside the grid unit. However, the benefit of using larger grid cell units is that it allows compressing the size of the the training signature database. This decreases the computational complexity of the signature matching algorithm and reduces the number of discarded testing samples. The major difference between the two LTE cases is the dimensionality of the LTE RF fingerprints as illustraded in Figure 12. Moreover, network deployments e.g., cell densities, are different. In the area of interest, deployment on 800 MHz is 5.34E-07 cells per m^2 whereas on 1800 MHz it is 1.67E-06 cells per m^2. This gives the total cell density of 2.28E-06 cells per m2 by taking into account only the sites that are 5 km away from the geometric center of the measurement area. In such case, the training signatures become less correlated in spatial domain when the measurements from different network layers are combined. This reduces spatial uncertainty and improves the positioning accuracy. Finally, when WLAN measurements are included to the RF fingerprints, the positioning accuracy is improved significantly. This is due to the fact that, the vast amount of small cells that are scattered all around the measurement area allows further improving the positioning accuracies due to the small coverage area of the WLAN cells. More detailed analysis of the network deployments and their impact on the positioning accuracy is left for forthcoming scientific publications.

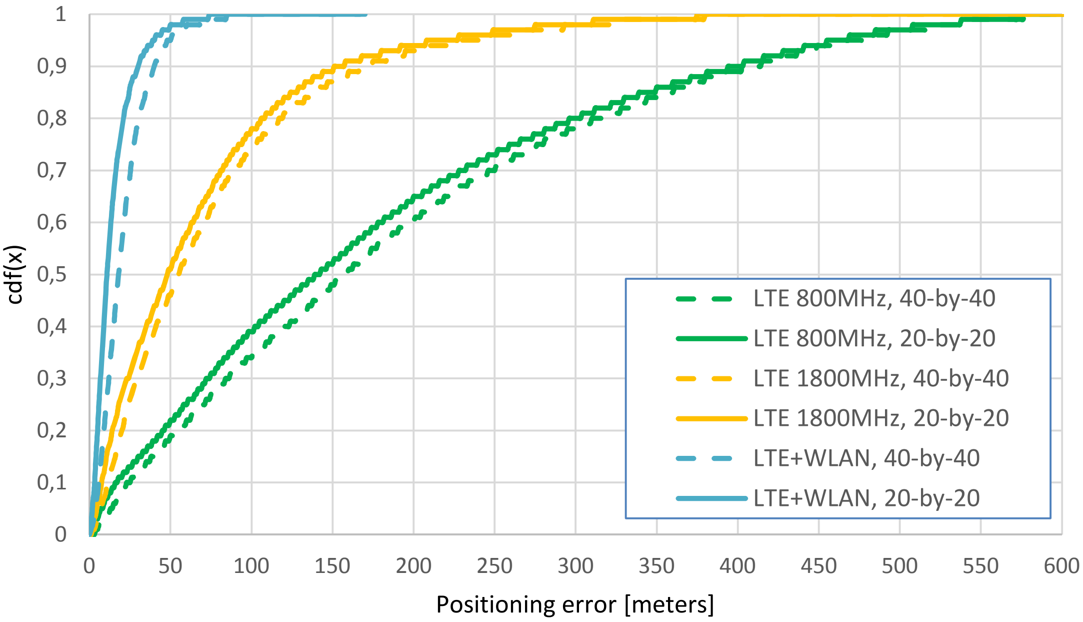

Figure 14: Cumulative distribution of RF fingerprint positioning errors

6 CONCLUSION

This deliverable introduced an enhancement to LTE Release 11 MDT functionality. The enhancement makes it possible to incorporate radio coverage measurements of WLAN access points into MDT measurements. It is evident that network automation is essential in next generation multi-layer, multi-RAT heterogeneous networks in order to optimize network performance and reduce the costs of mobile operators. The proposed GMDT functionality can help to automate the collection of location-aware radio measurements from WLAN access networks and combine these with 3GPP MDT measurements. Both control-plane and user-plane solutions for enabling generalized MDT were outlined. The control-plane solution was aligned as much as possible with 3GPP Study Item on WLAN/3GPP radio interworking with regard to measurements and triggering events. The user-plane solution allows correlating GMDT measurements with MDT measuremenst using user-plane protocols e.g., OMA-DM protocol, for conveying WLAN measurements to O&M with assistance information. However, 3GPP concluded that LTE/WLAN interworking solution does not mandate WLAN measurement reporting from UE to eNB. Thus, the proposed user-plane solution is seen more applicable at the moment for enabling GMDT functionality.

Several important mobile operator use cases for generalized MDT were presented such as WLAN coverage mapping, ANDSF database update, network based proximity indication and RF fingerprint localization. Performance evaluation of the GMDT based RF fingerprinting was carried out by conducting the system-level simulations and LTE live network measurements. The performance evaluation suggests that by correlating MDT measurements with WLAN measurements, the positioning accuracy of outdoor RF fingerprinting can be significantly improved. In the studied measurements, location estimation error for two-thirds of all MDT measurements is decreased by 79 % to 70 % if WLAN measurements are utilized in addition to LTE measurements. Moreover, since WLAN based positioning is already widely used indoors, the proposed approach is seen as an attractive solution to further enhance the availability of detailed location information of MDT measurements collected from indoor locations. Hence, by linking MDT measurements with WLAN measurements operators can collect low cost extensive and detailed coverage maps autonomously improving significantly positioning performance of MDT measurements.

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APPENDIX A: EFFECT OF TRAINING DATABASE PRUNING

This appendix illustrates the effect of training signature pruning by removing those CID entries from the training signature RF fingerprints that are less likely than the pruning threshold. Hence, the pruning threshold defines how likely a CID/RSRP observation has to be on the area of a certain grid unit that it is included in its training signature. Figure 15 shows cumulative distributions of training signature dimensions i.e., number of cell IDs, in case different amount of database pruning is used for LTE 800 MHz data using 40-by-40 meter grid units. For example, if 10% pruning threshold is used for 40-by-40 meters grid, median value for the training signature length is reduced from 25 to 6 CID/RSRP pairs as illustrated in Figure 15. Moreover, Figure 16 illustrates the effect of the measurement dataset and the grid unit size for LTE 800 and 1800 MHz dataset in case 10% database pruning is used. Clearly, the effect of the grid unit size diminishes and differences in the training signature lengths are mainly caused by the measurement datasets, i.e., denser deployment and inter-frequency measurements. It is worth noting that pruning was not used in this study and RF fingerprints are always consisting of all detected CID/RSRP and BSSID/RSSI measurements.

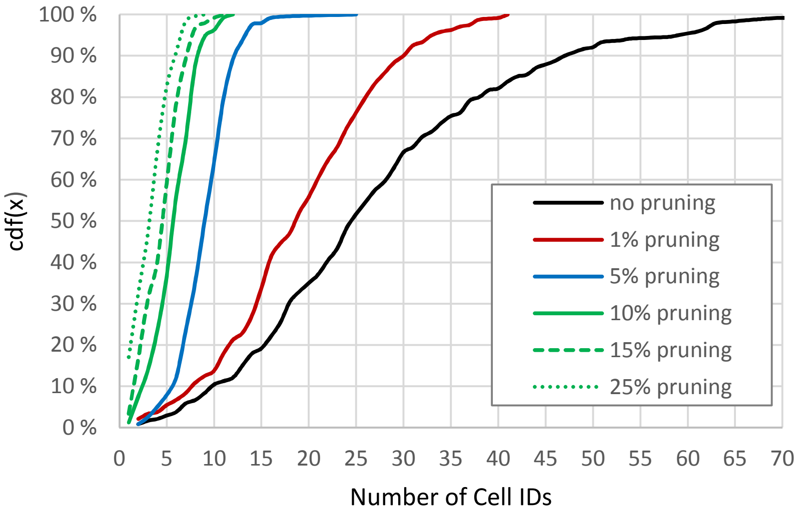

Figure 15: Cumulative distribution of grid unit's training signature lengths for 40-by-40 meters grid utilizing LTE 800 MHz CID/RSRP measurements.

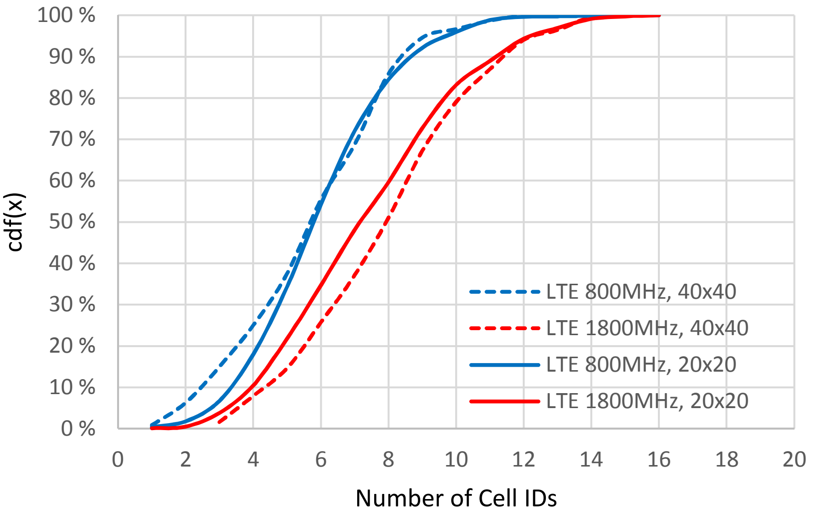

Figure 16: Cumulative distribution of grid unit's training signature lengths for different dataset and grid unit sizes if 10% database pruning is used.

GLOSSARY

3GPP	Third Generation Partnership Project
AAA	Autenthication, Authorization and Accounting
ANDSF	Access Network Discovery and Selection Function
ANDSF-MO	ANDSF Management Object
AP	Access Point
BSS	Basic Service Set
BSSID	Basic Service Set Identification
CGI	Cell Global Identification
CID	Cell Identifier
CN	Core Network
CP	Control Plane
E-CID	Enhanced CID
E-OTD	Enhanced Observed Time Difference
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
E-SMLC	Enhanced Serving Mobile Location Center
eNB	E-UTRAN NodeB
EM	Element Manager
EPC	Evolved Packet Core
ePDG	Evolved Packed Data Gateway
FCC	Federal Communications Commission
GMLC	Gateway Mobile Location Center
GMDT	Generalized MDT
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (GPS)
HESSID	Homogeneous Extended Service Set Identifier
HetNet	Heterogeneous Network
HSPA	High Speed Radio Access
ICT	Information and Communications Technology
IE	Information Element
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IDC	In-device Coexistence
ISM	Industrial, Scientific and Medical
ISMP	Inter-System Mobility Policy

ISRP	Inter-System Routing Policy
I-WLAN	Interworking WLAN
LBS	Location Based Services
LCS	Location Services
LMU	Location Measurement Unit
LPP	LTE Positioning Protocol
LPPa	LPP Annex Protocol
LPPe	LPP Extensions Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MDT	Minimization of Drive Tests
MME	Mobility Management Entity
NGMN	Next Generation Mobile Networks
NMS	Network Management system
O&M	Operation and Maintenance
OMA-DM	Open Mobile Alliance - Device Management
OTDOA	Observed Time Difference of Arrival
PCI	Physical Cell Identifications
PCRF	Policy and Charcing Rules Function
PE	Positioning Error
PI	Proximity Indication
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RCPI	Received Channel Power Indicator
RF	Radio Frequency
RRC	Radio Resource Control
RRLP	Radio Resource Location Services Protocol
RRM	Radio Resource Management
RSCP	Received Signal Code Power
RSNI	Received Signal to Noise Indicator
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SET	SUPL Enabled Terminal

SHARING	Self-organized Heterogeneous Advanced RadIo Networks Generation
SIB	System Information Block
SLC	SUPL Location Center
SLP	SUPL Location Platform
SMLC	Serving Mobile Location Center
SPC	SUPL Positioning Center
SRS	Sounding Reference Symbols
SSID	Service Set Identifier
SON	Self Organizing Network
SUPL	Secure User Plane Location protocol
TCE	Trace Element
TDOA	Time Difference of Arrival
TTI	Transmission Time Interval
UE	User Equipment
UTDOA	Uplink Time Difference of Arrival
UTOA	Uplink Time of Arrival
UP	User Plane
WLAN	Wireless Local Area Network