Minimization of Drive Tests (MDT) in Mobile Communication Networks

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ABSTRACT
Drive tests are used for collecting data of mobile networks. This data is needed for the configuration and the maintenance of mobile networks. In order to execute drive tests, human effort is required. These measurements cover only a small piece of time and location of the network. The new idea is to use each device which is active in the network; this concept is referred to as Minimization of Drive Test (MDT). This means that standard mobiles should be used for measurements to provide data for the operators. The main difference between these tests is that MDT uses cheap mobiles whereas drive tests make use of high developed measurement equipment. This paper demonstrates that MDT can reduce drive tests, but that there are still use cases where MDT cannot replace drive tests.

Keywords
Minimization of Drive Tests, Cellular Networks, Mobile, LTE, SON

1. INTRODUCTION
Mobile communication networks like GSM, UMTS, LTE and TETRA must be monitored and optimized in order to provide a good network coverage and quality of service. One problem could be that coverage holes exist due to the fact that a new building was constructed which shadows a certain area. To detect and improve such problems, radio measurements are needed. These measurements can be done with highly developed equipment directly at the base station or by Drive Tests (DTs) to cover the whole area. They are carried out by cars with measurement equipment. These collect the data in a cell as a snapshot of the cell coverage at a certain time. Furthermore, DTs are used to assess the mobile network performance [3, 4].

The data which was collected with the test equipment can then be post-processed and evaluated for the configuration and failure handling of the networks. Generating and analyzing this measurement data is a large Operation Expenditure (OPEX) and displays only the network state at a defined time and location [4].

In 2008 "Long Term Evolution" (LTE) as part of 3rd Generation Partnership Project (3GPP) Release 8 was published [3]. Today, there is a collection of different technologies like GSM, UMTS, LTE, WLAN and many more. These heterogeneous networks lead to a new complexity with respect to communication and correct configuration. In order to solve this problem, Self-Organizing Networks (SON) was introduced in Release 8, which targets the problem to configure, optimize and heal cellular networks [3, 14]. SON should now simplify the configuration and management of these networks.

The 3GPP also studied and specified solutions in Release 9 under the name "Minimization of Drive Tests" (MDT) in order to reduce the OPEX for drive tests (DT) [4, 15]. It addresses the automation of the measurements and configurations. The main idea is to use each device which is logged in the network for collecting measurement data.

This paper shows use cases and reasons for drive tests and compares the function of MDT and drive tests.

Note that in the following the Base Transceiver Station in GSM (BTS), Node B at UMTS and Evolved Node B (eNB) at LTE are referred with Radio Access Network (RAN) node. In addition, also the Mobile services Switching Center (MSC), Radio Network Controller (RNC) and Mobility Management Entity (MME) a referred with Core Network (CN) node.

The paper is organized as follows. Section 2 describes reasons for drive tests and shows what kind of data the operator needs. The next Section 3 explains how this data is collected. Thereafter, in the Section 4 the idea and vision how drive tests can be minimized is explained. Section 5 picks up the functionality of each and compares them in terms of the operator tasks. In the last Section 7 the comparison of DT and MDT is summarized.

2. OPERATOR TASKS - REASON FOR DT AND MDT
The main goal of network operators is to provide a network with maximum coverage and minimum usage of hardware.

In [15] the 3GPP Technical Specification Group (TSG) RAN defines the main use cases for the minimization of drive tests - which are coverage optimization, mobility optimization, capacity optimization, parametrization for common channels and Quality of Service (QoS) verification. These use cases are shortly described below [3, 15].

1. Coverage optimization
   Coverage is an aspect a user can easily observe and

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which mainly influences the user-experience. It is a parameter which the user can use to compare different operators.

Sub-use cases:
Coverage mapping: maps based on signal strength.
Coverage hole detection: areas where call drop and radio link failure happen.
Identification of weak coverage: areas where the signal level is below the level needed to maintain a planned performance requirement.
Detection of excessive interference: due to large overlap of cell coverage areas or an unexpected signal propagation between the cells, excessive interferences can occur. These interferences will degrade the network capacity.
Overshoot coverage detection: in a serving cell a strong signal of another cell is detected, which is far away.
Uplink coverage verification: a weak uplink coverage can cause call setup failure, call drop, bad uplink voice quality. Ideally, the uplink and downlink coverage should be equal, but normally the downlink coverage from the BTS is larger than the uplink coverage.

2. Mobility optimization
Mobility optimization aims at the minimization of handover failures, which happen when mobiles switch between different cells. It is useful to get measurements at the source and neighbor cells, which are linked to the location.

3. Capacity optimization
The capacity optimization use case aims at the optimization of network capacity planning. The operator, for example, is interested in those parts of the network where the traffic is unevenly distributed. This data helps to determine places for a new base station.

4. Parametrization for common channels
The network performance can also be degraded by configurations of the random access, paging or broadcast channels which are not optimized. An analysis of the connection setup delay, for example, helps to optimize the parameters of a BTS.

5. QoS verification
Aspects like data rate, delay, service response time, packet loss and interrupts are responsible for the QoS. The QoS is not only influenced by the coverage but also by operator specific scheduling of the packet type connections which can lead to bad data rates. The QoS is usually measured with Key Performance Indicators (KPIs), which assess the network. The KPI "Session setup success rate" is, for example, influenced by the performance indicators: RRC establishment success rate, S1 link establishment success rate and ERAB establishment success rate [2].

The drive tests are carried out in the following five scenarios [15]:

1. Deployment of new base stations
Drive tests are needed when new base stations are deployed. The new base station transmits radio waves in a test mode. Then UL/DL coverage measurements of new and neighbor cells are collected with the help of drive tests. Afterwards the results are used to improve the performance of the cell.

2. Construction of new highways/railways/major buildings
In areas where new highways, railways or major buildings are constructed the coverage is probably reduced due to a shadowing of the cell. In addition, the volume of network traffic is increased by new buildings. In order to analyze and reconfigure this new usage profile, drive tests are needed.

3. Customer's complaints
When costumers inform the operator about bad coverage, bad quality of voice or data, the operator also executes drive tests to detect the problem in the relevant area.

4. KPI Alarms at Core Network
The Operators also monitor the network elements. In order to assess these elements, KPIs are used. Most KPIs are composed of several counters, which contain information like dropped calls or handover failures. The operator can execute drive tests for detailed information. If the amount of failures increase in a certain area, the operator in generally carries out drive tests for detailed information [6].

5. Periodic drive tests
Periodic drive tests are additionally used to monitor particular cells. They are needed in order to provide a continuously high level quality and to monitor the coverage and throughput of the network [3].

3. DRIVE TESTS

So far, drive tests are the main source for collecting measurement data from cellular networks. As shown in Figure 1, drive tests are usually carried out with the help of measurement cars, which contain systems of scanners and test mobiles. The scanners can be configured to scan all technologies. This is used for detecting interferences and monitoring all accessible base stations. A scanner operates completely passive and is not recognized by the network. As a result, only data which is not encrypted can be collected, which is mostly the signaling and broadcast messages.

Additionally, test mobiles are needed because they are logged in the network and provide, for example, the details for the handover procedures. Furthermore, they are used for checking the speech quality and transfer (up- and download) rates [13].

In the following the functions of scanners and test mobiles are explained more precisely.

3.1 Scanner

Drive tests are mostly carried out by Scanners like TSMW from Rohde & Schwarz, as illustrated in Figure 2. These scanners support the measurements in different networks and positioning with Global Navigation Satellite Systems (GNSSs). The difference to the test mobile is that the scanner has a broadband RF front-end and a baseband processing system. This is the reason why the scanner can support

Figure 1: A measurement car from Rohde & Schwarz [9]

all types of technologies in the defined frequency range. A test mobile normally supports only a few technologies and cannot detect interferences with other networks like DVB-T [13].

The following list contains the advantages of a scanner from [13]:

1. Significantly higher measurement speed than test mobiles:
   High-speed measurements allow better statistics and lower the possibility of missing important problems, such as interferences.

2. Measurements are independent of the network:
   Mobiles only measure channels which are provided by the BTS neighborhood list. The scanner can measure all available channels and allows the detection of hidden neighborhoods.

3. Use of only one unit for different networks and applications:
   Scanners support a number of different technologies like GSM, UMTS, LTE, TETRA and DVB-T.

4. Spectrum analysis provides additional information:
   Spectrum scans with multiple frequency ranges, for example, between 80 MHz and 6 GHz makes it possible to detect in-band and external interferences.

5. Independent of mobile chipsets:
   Scanners have a broadband RF front-end and baseband processing system which is independent from any mobile phone chipset and supports different technologies. Therefore, it can be used as reference system.

6. Higher level and time accuracy compared to mobile based measurements:
   The scanner uses GNSS signals for synchronizing the local clocks and achieves a more precise timing then normal User Equipments (UEs).

7. Scanners are passive:
   Scanners only listen on the broadcast channels and do not influence the network. This makes it possible, for example, to monitor networks on the borderline without roaming costs.

Figure 2: A scanner from Rohde & Schwarz [10]

3.2 Test Mobile

The main feature of the test mobile is that it works in the network and receives the messages. It therefore reflects the behavior of the user mobiles and is used for the operational tests.

This could be: throughput, connection quality, video quality, voice quality, handover and network quality tests. An identifier for network quality could be the ratio of dropped to successful calls [11].

3.3 Data Aggregation Software

With real-time and post-processing tools like R&S ROMES and Network Problem Analyzer (NPA) the data from the scanners and the test mobiles can be analyzed [11].

The major analysis features are [12]:

1. Coverage Analysis
   Provides information where weak coverage, coverage holes or overshoot coverage exists.

2. Interference Analysis
   Provides information where interference exists and from which technology the interference comes.

3. Call Analysis
   Provides information about the number of successful, dropped or blocked calls.

4. Data Transaction Analysis
   Provides information about the response times.

5. Throughput Analysis
   Provides information about the possible data throughput.

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6. Neighborhood Analysis
   Checks if the provided neighborhood lists of the base stations are equal to the received broadcast information at the scanner.

7. Handover Analysis
   Shows the duration of handovers or details to a handover failure.

8. Spectrum Analysis
   Provides the information which frequency bands are used and how strong the signals are.

4. MINIMIZATION OF DRIVE TESTS

The problem that drive tests need human effort to collect measurement data and that only spot measurements can be performed, has led to automated solutions which include the UEs from the end user. This approach should provide measurement data for fault detection and optimization in all possible locations covered by the network. The feature for this evolution in the 3GPP standard is named MDT. It started in 2008 in the Next Generation Mobile Networks (NGMN) forum, where the automation of drive tests became operators requirement. The 3GPP also realized the need and followed up on the subject. One of the first studies in 3GPP was in 2009 with the 3GPP Technical Report (TR) 36.805 [3]. The 3GPP started two parallel work items, which are the functioning for MDT in the UE and the MDT management. The MDT in the UE is done by the 3GPP TSG RAN and the MDT management by the 3GPP TSG Service and System Aspects (SA) [3].

The MDT should also “reduce the operational efforts, increase network performance, quality and, at the same time, decrease the maintenance costs” [3].

In the 3GPP TR 36.805 the 3GPP TSG RAN group defined the requirements and constraints for MDT solution. The topics are [15]:

1. The operate shall be able to configure the UE measurements independently from the network configuration.
2. The UE reports measurement logs at a particular event (e.g. radio link failure).
3. The operator shall have the possibility to configure the logging in geographical areas.
4. The measurements must be linked with information which makes it possible to derive the location information.
5. The measurement shall be linked to a time stamp.
6. The terminal for measurements shall provide device type information, for selecting the right terminals for specific measurements.
7. The MDT shall be able to work independently from SON.

The solution shall take the following two constraints into account. The UE measurement logging is an optional feature. To limit the impact on the power consumption one should take the positioning components and UE measurements into account. These UE measurements should as much as possible rely on measurements from the radio resource management [15].

4.1 Architecture

In the beginning of MDT in 3GPP TR 32.827 a user plane and control plane solution was discussed [4].

In the case of the user plane solution, the measurement data is reported by uploading it to a file server. Therefore, the typical data connection is used and the transport is transparent for the radio access network (RAN) and the core network (CN) [3, 17].

At the control plane solution the reporting is controlled by the Operations, Administration, and Maintenance (OAM) system. It is targeted over the eNB/ RNC to the UE via RRC connections. The measurement should then allow to collect and combine the data at the eNB/RNC and send it back to the OAM system [3, 17]. The result of the study phase was that the control plane architecture is better, because the measurement results can be reused for any automated network parameter optimization. With respect to the SON the redundant data handling is avoided [4].

In 3GPP Technical Specification (TS) 34.422 there are two types of MDT in the network signaling perspective and radio configuration perspective defined [4]. These are described in the following.

4.1.1 Area and subscription based MDT

Out of the network signaling perspective, one type is the area based MDT and the other is the subscription based MDT [4].

At the area based MDT the data is collected in an area, which is defined as a list of cells or as a list of tracking/ routing/ location areas [18]. As shown in Figure 3, the MDT activation from the OAM is directly forwarded to the RAN node, which selects the UE of the defined area.

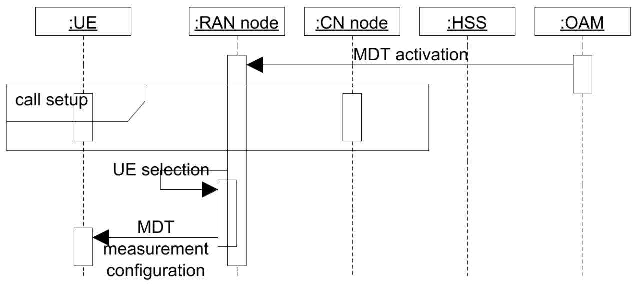

Figure 3: Area based MDT according to [4]

The subscription based MDT addresses the measurement for one specific UE [18, 3]. It is carried out in the OAM by selecting a UE with an unique identifier. As shown in Figure 4, the OAM sends the MDT configuration parameters to the

HSS, which decides if the MDT activation for the selected UE is allowed. The HSS sends the MDT configuration over the CN node and RAN node to the UE [4].

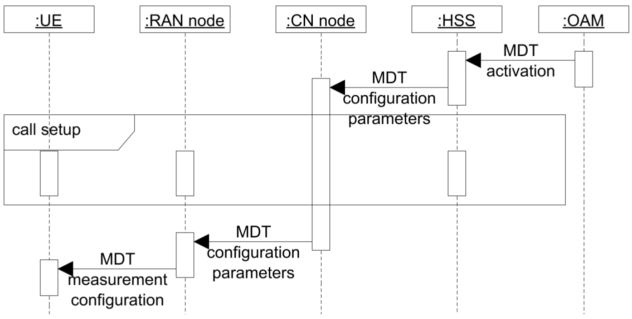

Figure 4: Subscription based MDT according to [4]

4.1.2 Immediate and logged MDT

Out of the radio configuration perspective, one type is the logged MDT and the other the immediate MDT [4].

The immediate MDT allows measurements only in a connected state. It is possible to use several measurement triggers. The UE immediately reports the measurement results, when the configured triggers are met or the reporting configuration matches [16]. These results are collected at the RNC node and as it is shown in Figure 5, this notifies the Trace Collection Entity (TCE), which collects all MDT measurements. After the notification, the TCE uses a file transfer protocol for downloading the MDT log [3].

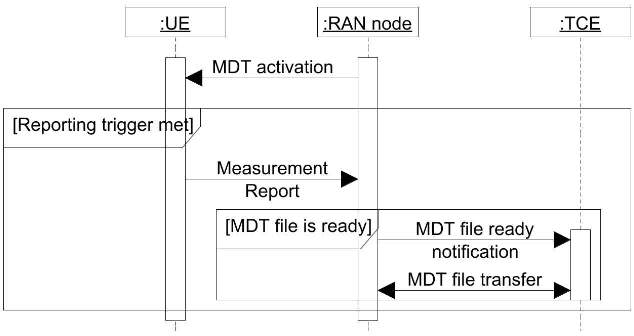

Figure 5: Immediate MDT according to [3]

To support also measurements in the idle state, the logged MDT is used. With the help of logged MDT it is also possible to configure periodical triggers. If this triggers are met, the UE stores the measured information [16]. Additionally, this provides the possibility to store failures if the network is not reachable. The decoupling of measurements and reporting also reduces the battery consumption and the network signaling load. Figure 6 shows that the UE stores the measurements locally and after a defined trigger it is transferred to the RAN node and then to the TCE [3].

For the comparison one should consider that coverage holes can only be detected with the logged MDT, because the immediate MDT does not have a connection to the CN node.

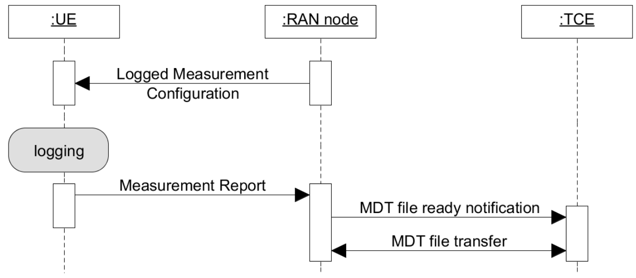

Figure 6: Logged MDT according to [3]

However, the logged MDT is an optional capability and only the immediate MDT is mandatory for the UE [5].

4.1.3 Architecture Elements

The MDT data collection is initiated and controlled by the OAM system. The core network is used for MDT but has no specific MDT logic. The UE and RAN collects the data and sends it to the TCE, which stores the data and can be used for post-processing analysis [5]. This architecture and the usage of the MDT types are shown in Figure 7.

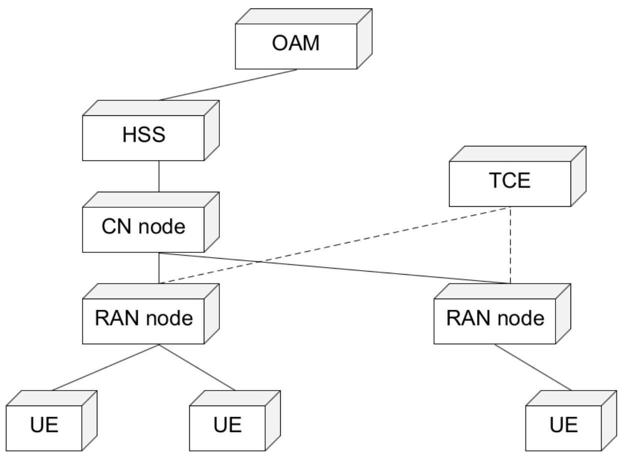

Figure 7: MDT architecture according to [4]

4.2 Managing MDT

The MDT can be configured in the area or subscription based MDT, where the UEs are in the immediate or logged MDT. The configuration of MDT is decided in the OAM which initiates the defined MDT type.

Each constellation between MDT types allows different configurations. In the following is a subset of the MDT configurations parameters from [18] are announced:

1. List of measurements
   It defines the measurements which shall be collected. This could be: data volume, throughput, received signal code power, reference signal received power.

2. Reporting trigger
   It defines if measurement report for UMTS or LTE should be created in a periodical or event based way.

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3. Report interval
   It defines the interval of a periodical reporting from 120ms to 1h.

4. Report amount
   It defines the number of measurement reports that should be created.

5. Event threshold
   It defines the threshold for an event based reporting.

6. Logging interval
   It defines the periodicity for logging in logged MDT.

7. Logging duration
   It defines how long an MDT configuration is valid.

8. Area scope
   It defines in which geographical area MDT should be executed. It could be a number of Cells or Tracking/Routing/Location areas.

9. TCE ID
   It is a identifier which can be resolved to the TCE IP at the RAN node.

10. Anonymization of MDT data
    It defines if the measurement results are saved with an IMEI-TAC[1] or no user information.

11. Positioning Method
    It defines if positioning with GNSS or E-Cell ID should be used.

4.3 Location Information

The location information is as important as the radio measurement itself for drive tests, walk tests and MDT. The analysis of the data is only successful with good location information for each measurement.

In MDT 3GPP Release 10 a best effort location acquisition was defined. This means that the measurement can be tagged with location information if it is available for some other location-enabled application [5]. An location-enabled application could be a map application, which already uses the GNSS chip. In Release 11 it is defined that the network can request the UE to use location information for an MDT session. The problem is that this approach can lead to a higher battery consumption. J. Johansson et. al [5] says that the operator "may choose to handle this by subscription agreements, and only use requested location for subscribers that have consented to this." Additionally, an approximate location can be estimated with RF fingerprint measurements. This can be obtained by signal strength measurements of the neighboring cell [5]. Another point is the tagging of RAN-based measurements. This should be done by post-processing with correlating the timestamps of the UE-based DL measurements, which contains already the location information tag.

[1]The first eight digits of the International Mobile Station Equipment Identity

5. COMPARISON BETWEEN DT AND MDT

After the details concerning drive tests and the minimization of drive tests, the DT and MDT is now compared from the perspective of technologies, operator use case and used hardware.

5.1 Technologies

The MDT in 3GPP is defined for UMTS and LTE. However, there are other technologies like GSM, TETRA, DVB-T for which measurements are needed. For instance, GSM is used as communication and signaling network for the railways as GSM-R. There is also a need for coverage measurements. Furthermore, TETRA is now in Germany used by authorities and organizations with security functions like police, fire brigades and emergency rescue services. This organizations require an very robust and good covered network, which requires measurements. This measurements for the mentioned and other technologies can only be carried out by the classical drive tests.

5.2 Use Cases

Section 2 lists the use cases for the operators from the perspective of MDT. In the next subsections these use cases are used for comparing the DT and MDT.

5.2.1 Coverage optimization

Coverage is one of the most important aspects of the network performance which can be directly recognized by the end-user [3].

With the help of MDT it is possible to detect the signal strength and the location of the mobile, which then could be used as coverage indicator [3]. However, the main problem is, that the signal strength between mobiles at the same location and time can differ much more than +-6dB [13]. Another problem is that it is unknown if the mobile is inside a bag or some car which leads to signal lose. If logged MDT is used it is not possible to know if it was a network failure or the mobile. Possibly, this problem could be solved by collecting many measurement data, which then could be merged and statistically evaluated. Another problem is how to get the location inside a building. In [3] it is also suggested to use a GNSS chip as location provider. However, there is also a need for good coverage inside of big buildings like airports. This requires also indoor measurements, but there a GNSS chip is not usable.

With the help of DT and a scanner as a measurement device it is possible to collect coverage measurements in a high quality. The problem here is that it provides only a snapshot of that area, where the DT was executed.

5.2.2 Mobility optimization

Another use case for optimising the mobile network is the mobility optimisation. The aim is to have handover failure rates which are as small as possible. Handover failure can happen if the mobile and networks do not recognize that the user travels from one cell to another and then as consequence of that the user loses the signal from the old cell. Another problem could be that the load is to high and the handover takes too much time. In most cases the call would be dropped. Operators can optimise their network if

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they have the following information available. They need to know, between which cells the mobile has switched and the handover times.

It is debatable if the MDT can fully lead to mobility optimisation. This should be possible, because the operator gets the information by the cell ids and locations. Then, if a call was dropped and the signal strength was low, the operator can correlate this information to analyze the handovers. The problem is that the UE only uses the neighbor cells which are in the neighborhood list. If the MDT also measures other channels, then hidden neighborhoods can be detected, too.

With a independent measurement equipment like a scanner together with a test mobile, it is possible to check the network state of both cells and provide information if the handover signals from the network were wrong or the mobile received incorrect information. The scanner also provides measurements for all channels and cells. With these measurements the detection of hidden neighborhood cells is possible.

5.2.3 Capacity optimization

For network capacity planning the operator is interested in the downlink and uplink throughput and data volume [5], for instance, in order to deploy an additional picocell.

In 3GPP Release 11 the throughput and volume measurement at MDT was also addressed. MDT allows to measure the throughput at the RAN. A difference to drive tests is also that MDT uses ordinary user traffic and drive tests applications with known traffic characteristics. By measuring at an application level, the results depends on the size of the data which is transmitted. On transmissions with small size, the scheduling delay could have an impact on the measured throughput. Whereas with large data blocks the result is limited by the transmission medium [5].

With the help of MDT it is possible to measure the amount of traffic within a cell. The location of the sending UE is stored together with the measured data volumes. Per measurement period, the UL and/or DL data volume measurement is carried out by the RAN.

With conventional drive tests it is only possible to measure the available throughput at the UE with a test mobile. It is not possible to measure the data volume of a cell in a selected area or detect areas where users need more data volume.

5.2.4 Parametrization of common channels

The suboptimal configuration of common channel parameters (random access, paging and broadcast channels) can degrade the network performance. For instance, the UE monitors the paging channels, which are needed to react to the incoming calls. If now the information cannot be decoded, the UE is not reachable for other calls [3].

MDT defines in [15] the logging of Paging Control Channel (PCCH) Decoding Error, Broadcast Channel failures. If such a failure happens, the location, time, cell identification and other radio environment measurements are logged. This is also done with DT, but the problem is here that only a short time is measured and maybe time depended failures are not detected. Usually, operators only find out about problems with the common channels, when they receive customers complaints [15].

5.2.5 Quality of Service verification

The verification of the QoS is another important use case. It is not only the coverage which affects the user experienced QoS, but also, for instance, the scheduling principle for packet type connections which is defined by the operator [3]. The high degree of algorithm flexibility leads to different performances. In general, it is difficult to estimate the QoS from radio measurements such as coverage, path loss or average interference [5].

As already mentioned in Section 5.2.3, in 3GPP Release 11 the throughput and data volume measurement introduced, which provides also QoS verifications. An indication for a QoS problem could be, that the throughput observed by MDT is lower than the expected throughput for the number of users in a period of time. A benefit of the MDT throughput measurement is that real user traffic is used and no additional load on the network is produced [5]. The typical KPIs to assess the QoS can be also estimated by MDT.

With the help of DT the KPIs can be estimated, but the problem is here again that only a snapshot of the selected area is available.

5.3 Hardware

Comparing the DT and MDT out of the hardware perspective, it is obvious that the DT equipment can provide higher measurement rates and accuracy.

A problem with MDT is, that the UE must execute a big part of the measurement and additional information e.g. about position, requires a higher power consumption [5]. It is necessary that the additional hardware is cheap enough. The requirements for low power consumption and prices will lead to less powerful MDT devices than DT equipment.

6. PROBLEM INDOOR

Today more and more measurements are needed indoor for mobile communication networks. The reason is that the data and voice traffic from within buildings have increased and now more calls are made from indoor then outdoor [8]. This requires additional indoor measurements for optimizing the networks for indoor usage. With the typical drive test, which makes use of cars, these areas could not be scanned. However, there are several solutions where a scanner in a backpack can be used. The main problem with indoor measurements is the location accuracy. Outdoor, GNSS can be used with an accuracy less than 2.5 meters [19]. However, it is today indoor not usable due to the signal loss. And for example, for bigger buildings like airports a communication access is important. Because of that, higher positioning accuracies are needed then outside.

But the current indoor positioning solutions do not provide this accuracy. Possibly, this target could be reached with higher developed equipment.

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7. CONCLUSION

The MDT features allow new measurements which are user centric and which can help the operators to provide a better communication network.

Parts of the drive test can be carried out with MDT, like coverage, capacity, and QoS. However, for a detailed detection of coverage holes or hidden neighborhoods, a drive test is needed. Furthermore, during the first rollouts of new technologies the MDT cannot be used, because no UEs are in the network. In this case the operator needs the drive test. A drive test is also needed for technologies in which not enough UEs for MDT are used.

It is also a challenge to carry out precise indoor measurements with the mobiles of users, because no GNSS can be used. For the indoor case it is more thinkable to use walk test equipment with special positioning hardware like inertial measurement units (IMUs) [1] or optical devices for visual odometry [7] then MDT.

Overall, one can argue that in the future the MDT will provide great features to solve automatic coverage and QoS measurements in the UMTS and LTE networks.

8. ACKNOWLEDGEMENT

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