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Security, Infrastructure and Trust Working Group

Report on the DFS pilot measurement campaign conducted in Ghana

Report of Quality of Service Workstream

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

A new global program to advance research in digital finance and accelerate digital financial inclusion in developing countries, the Financial Inclusion Global Initiative (FIGI), was launched by the World Bank Group, the International Telecommunication Union (ITU) and the Committee on Payments and Market Infrastructures (CPMI), with support from the Bill & Melinda Gates Foundation.

The Security, Infrastructure and Trust Working Group is one of the three working groups which has been established under FIGI and is led by the ITU. The other two working groups are the Digital Identity and Electronic Payments Acceptance Working Groups and are led by the World Bank Group.

Report on the DFS pilot measurement campaign conducted in Ghana

Quality of Service Workstream

Acknowledgements

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Executive Summary

This report describes the results of the first pilot test campaign of Digital Financial Services conducted in Ghana in June and July 2018; the campaign was based on the methodology described in **Methodology for measurement of QoS KPIs for DFS**. As an overview, the methodology consists of a combination of direct tests for the person-to-person money transfer on both smartphones and feature phone-equivalent devices, and background measurements to obtain information about the quality of basic transport services in the mobile network.

The goal of this test was twofold. The first goal was to perform a proof of concept for the methodology, and to contribute to the evolution of this methodology based on experience gained in the field. The second goal was to create a baseline of measurement data to create insights into the current status of this service, and to provide the basis for evolution of subsequent methods and processes with respect to guidance for regulators.

The tests were deliberately carried out with a high degree of manual execution of testing and data acquisition, thereby providing a high degree of transparency and information useful in future automation of testing and data acquisition as well as for data quality assurance and processing.

Tests were carried out, over a period of four weeks, by two teams working independently in the greater area of Accra, Ghana. A total of 78 locations have been visited with typically 48 DFS transactions carried out per location, totalling almost 4000 data sets. Concurrent background testing produced a total of approximately 45.000 data sets using SMS, USSD, Web Browsing, and http Upload and Download.

Results showed, as expected, a correlation between DFS and carrier service performance, which confirms the assumption (made in the Focus Group Technical Report *QoS and QoE aspects of Digital Financial Services* (05/2016) produced by the ITU-T FG DFS) that basic services provided by mobile networks can be used as proxies which allow for the estimation of expected DFS performance. Furthermore, the results of the pilot campaign report provide a first set of field data which can act as a guideline for required performance levels. In this respect the pilot test already contributes to the goal of providing material for regulatory guidance with respect to required network service quality levels to sustain Digital Financial Services.

It is however important to note that the current pilot test was just a first proof of concept which could only cover a part of the overall parameter space where basic mobile network services were performing well or at least acceptable. Measuring DFS performance under actually poor network conditions, or under dynamic usage conditions (e.g. in motion) was beyond the scope of this pilot test.

In summary, results of this pilot tests confirm the usefulness of the methodology developed for testing DFS QoS, provide a solid initial basis of insight into the relationship between DFS and basic network services QoS, and prepare the way forward to the expansion of the methodology for more DFS related use cases and future tool assisted and automated testing.

1 Acronyms

2G	2nd Generation
3G	3rd Generation
4G	4th Generation
API	Application Programming Interface
DFS	Digital Financial Services
DID	Device Identifier
DL	Download
E2E	End-to-End
EDGE	Enhanced Data rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Plus
HSPAP	HSPA+
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
IMEI	International Mobile Equipment Identity
KPI	Key Performance Indicator
LTE	Long Term Evolution
MDR	Mean Data Rate
MTACT	Money Transfer A-side Completion Time
MTCD	Money Transfer Core Duration
MTCR	Money Transfer completion rate
MTCT	Money Transfer Completion Time
MTFCT	Money Transfer Full Completion Time
MTRCT	Money Transfer Raw Completion Time
NSMS	Notification SMS
OT	Observer Tool
PIN	Personal Identification Number
QoE	Quality of Experience

QoS	Quality of Service
RAT	Radio Access Technology
RSSI	Received Signal Strength Indicator
SMS	Short Message Service (also used for a single text message transmitted by SMS)
SQL	Structured Query Language
SR	Success Rate
ST	Session Time
TA	Transaction
UL	Upload
UMTS	Universal Mobile Telecommunications System
USSD	Unstructured Supplementary Service Data
XML	Extensible Markup Language

2 Introduction

This document describes the DFS pilot measurement campaign conducted in Ghana. The measurement campaign has been based on the QoS measurement and testing methodology for DFS as described in the document **Methodology for measurement of QoS KPIs for DFS**.

The present report elaborates on the following topics:

- Specific methods used
- Procedures for data quality assurance and data consolidation.
- Results from measurements.
- Insights and findings.

The present report describes the results of a feasibility study for the assessment of QoS of DFS by means of a field trial. The efforts of this pilot have been concentrated to hot spots (malls, universities etc.) without taking into account the effects of mobility or the percentage of population covered by the trial.

3 Ghana pilot campaign overview

3.1 General information

The pilot campaign was conducted from June 18, 2018 to (including) July 19, 2018. It took place in the greater area of Accra, Ghana. Two teams visited a total of 78 different locations.

3.2 Campaign key properties

Each team operated four devices for running DFS test cases, and another smartphone device running background measurements (for details of the scenario see Background measurements). DFS test case results were logged to paper forms on location, and transcribed into Excel files later on. For processing, these files were imported into a database along with data from background measurements and from confirmation SMS sent as part of the MoMo service.

4 KPI overview

For convenience of reading, this document replicates some of the content of the Methodology deliverable.

The following indicators were calculated:

Table 4-4-1 Indicators calculated in the Ghana pilot

Indicator	Abbreviation	Computation	Reference to formal KPI
Money Transfer Core Duration	MTCD	T3-T2	
Money Transfer Raw Completion Time	MTRCT	T3-T1	MTCT
Money Transfer completion rate	MTCR	T1 present, T3 present: success Valid Try: T1 present	MTCR
Money Transfer Full Completion Time	MTFCT	T7-T1	
Money Transfer A-side Completion Time	MTACT	T6-T1	

Remark: Consistent with other KPI definitions, elements of type "Time" are understood to represent either time per-transaction, or as arithmetic mean of transaction-wise time data. This depends on the context. Explicit reference is provided where this context is less clear.

5 Data consolidation process

5.1 Data sources

There were three main and two auxiliary data sources, which are described in the following sub clauses.

5.1.1 Main Source A: Testcase logs (data logs)

This is the primary source of data on the performance of the DFS test case. The processing steps are

(Short version; see the full description in the Methodology deliverable:

1. Information is written down to paper log sheets during the testing process.
2. Information is transferred to Excel® files, using a respective template.
3. Files are e-mailed to the processing team and inspected for obvious flaws (such as time/date formatting issues).
4. Files are imported to the main DFS database.

5.1.2 Auxiliary: Source A02: Location logs, source A03: Event logs

These logs contain frame information about device and testing conditions. During the evaluation process, they will be used to further validate data, e.g. by masking out data in case of conditions, which may have affected the validity of measurements.

5.1.3 Main Source B: SMS Backups

For each transaction, confirmation SMS are sent to the originating (A party) and the destination (B party) device. SMS stored on these devices are captured and sent via e-mail to the processing team (both manually and, in addition, periodically automatically. The data is supplemented with information on the respective originating device and then imported into the main DFS database.

5.1.4 Main Source C: Background Measurement Data

For consistent identification of data, devices are assigned to teams, using the last 6 digits of their IMEI. Table 5-1 Assignment of Device IDTable 5-1 shows, exemplarily, the IDs used in the pilot campaign.

Table 5-1 Assignment of Device ID

Device ID (last 6 digits of IMEI)	Team
238089	Team 1
240077	Team 2

Data is uploaded semi-automatically (after the measurement has been stopped by the respective team) to an intermediate data server. From there:

1. Data is downloaded by the processing team at regular (daily) intervals.
2. Initial integrity checks are performed, in order to detect critical operating conditions such as insufficient credit available, indications of measurement system failure, or other unusual behaviour of the devices (typically by value-range and value signature checks).
3. Pre-processing (for all data at once) is done on a file-based level, and output is imported to the main DFS database.
4. In the database, data are further processed to create indicators needed in subsequent stages, and some additional plausibility and integrity tests are performed.

5.2 Time Coverage

The following diagram shows the time coverage for DFS TA and corresponding background measurements (ObserverTool (OT).

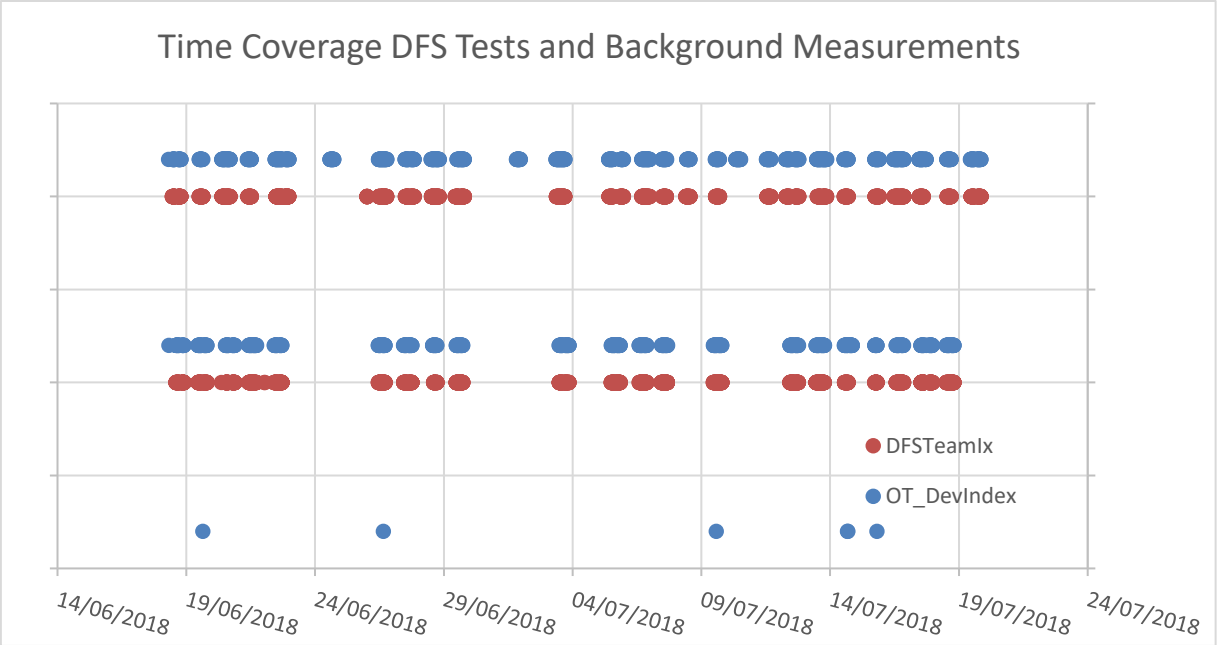

Figure 5-1 Time coverage for DFS and background measurements[1].

This type of visualization is used in measurement data analysis and which provides a quick overview allowing to identify times/places where one type of data is missing. It is effectively a scatter plot, using time stamps and a numerical value for results of transactions for DFS and background measurements. The numerical values are just means to the end of creating a meaningful optical appearance; labelling is therefore omitted for clarity. The values are further chosen to form bands, one for each team. Red data points represent DFS transactions collected by respective teams. Likewise, blue data points represent background measurement transactions.

Data points outside the bands (as those shown close to the bottom in Figure 5-1) indicate unsuccessful transactions. These may have different causes, most likely poor coverage; these are inspected by a different process. Ideally, time ranges where DFS transactions have been recorded have corresponding background measurement coverage.

By closer inspection of Figure 5-1, it can be determined that:

- there are a few points in time where extra background measurements exist (probably due to test runs of the devices); this is considered to be uncritical.
- In some cases background measurements extend further than the time range of DFS tests; this is considered to be uncritical.
- There is one case (date of measurement: 1.7.18) where background measurements for Team 2 are present but no DFS measurement.
- There are some cases where the time range of DFS tests is not fully covered by background measurements (date of measurement: 5.7.18, Team 2). These cases are further investigated also with respect to potential transcription errors from data log to Excel (wrong time, see also 6.1).

[1] See detailed explanation in the text.

Please note that Figure 5-1 deliberately shows an early version of the time-coverage analysis to explain the procedure. The actual checking process is not only done from graphics, but also involves data inspection on a deeper level. The issues described above were subsequently resolved.

5.3 Data integrity tests

5.3.1 Goal and method

A typical error in manual transfer from paper logs to Excel is “eye glitches” which result in entering data from the wrong row. This would manifest itself in duplicate timestamps.

Checking was done in the database using respective SQL scripts for T1 through T7.

5.3.2 Final

There was one remaining duplicate T7 which was deemed to be real (valid result if assumed that B side SMS can be queued).

5.3.3 History

This test was performed last in sequence (after value range checks) so it used an already cleaned database. Testing produced a total of 25 hits.

5.4 Value consistency checks

5.4.1 Goal and method

During data acquisition, there are two main sources of error with respect to recorded time stamps (T1 to T7) of transactions. Times can be read wrongly from clocks or displays, and there can be reading or typing errors when data is transferred from paper logs to Excel® tables.

Timestamps of DFS transactions (T1 to T7) are derived from test case progress and therefore have an inner logic. By checking relations between timestamps, it is possible to detect primary errors. If such inconsistencies are detected, paper logs are checked again for transfer errors. If necessary, further logic inference is applied to resolve remaining inconsistencies.

Tests were made for:

- MTCD: negative values, zero values, and unusually high positive values (>60 s).
- MTRCT: negative values, zero values, and unusually high positive values (>60 s).
- MTFCT: derived, using T7-T3; testing for negative, zero and unusually high values (>120 s).
- MTACT: derived, using T6-T3; testing for negative, zero and unusually high values (>120 s).

For the definitions of the quantities, see section KPI Overview.

5.4.2 Final

After completion of all steps of testing and fixing, there were a total of 53 transactions flagged as “to be ignored”, from a total of 3794 data items, providing a yield of 3741 transactions which passed these tests.

5.4.3 History

5.4.3.1 Time stamp consistency

Tests according to time stamp deltas revealed a total of about 550 transactions with inconsistent timestamps. Almost all of them could be fixed by re-visiting the paper logs.

In most of the cases, transfer errors (reading of handwriting or typing errors in Excel) were found to be the reason.

In about 10% of cases, manual entries were formally correct but comparison to other values in the set, preceding transactions, or subsequent transactions showed primary reading errors (e.g. entering the wrong minute value). Most of these cases were resolved using respective inference. This inference included reasonable relation to other timestamps, and assumptions about typical writing errors.

Remaining cases, where either data was actually missing, or where inference did not provide a reasonable degree of certainty, were flagged as “to be ignored”.

5.4.3.2 Systematic offsets

During initial data analysis, it turned out that core DFS transfer times (T3-T2; MTCD) showed a tendency towards smaller values for Team 2. This was contradictory to the initial assumption that the average CTT should be – within limits of statistical error – equal between teams.

Some results showed otherwise, e.g. a grouping by sender role by team:

Table 5-2 Average of transfer time per sender ID, by team

Average of transfer time	Team	
Sender ID	1	2
FP1	4,8	1,6
FP2	4,6	1,6
SP1	3,7	1,5
SP2	3,9	1,6

Table 5-3 Average of transfer time per receiver ID, by team

Average of transfer time	Team	
Receiver ID	1	2
FP1	3,9	1,6
FP2	4,8	1,5
SP1	4,6	1,6
SP2	3,7	1,5

- Remark: Values shown here are from initial evaluation. Final values are presented in subsequent sections of this report.

Conclusion: There is a significant systematic offset (absolute values) between the results of Team 1 and Team 2, which needs further investigation and explanation.

- Team Assignment: Has team 1 been sent to places that are more problematic?
- Team Instructions: Have the teams been differently instructed?
- Value Distribution: Create value distributions, see if the shape of distribution differs (to be done after completion of data cleaning and re-import into the database).

An initial hypothesis would be a difference in time taking between the teams (i.e. using different devices to read times T1, T2, T3 etc.), combined with a potential time offset between devices in the team.

After consultation with the team supervisor, the effects were attributed to the fact that Team 1 was primarily assigned to suburban and rural locations while Team 2 was mostly testing in city centre locations.

5.5 Location time overlap tests

5.5.1 Goal and method

Locations are subsequently visited by one particular team; each location has been only visited once and within a given time range. These ranges – per team - therefore do not overlap. The overlap test is performed to validate time ranges and to make sure time ranges are consistent. Consistent time ranges are the prerequisite to location-wise consistent assignment of background service KPI to DFS KPI.

The overlap test consists of the following steps, which were performed, in the database by SQL scripts.

1. Group data by location and calculate min T1, max T7 as the overall time span.
2. Create a guard time range around these values using 15-minute slots. Start_Prev15 is the quarter-hour slot that precedes the lowest T1. End_Next15 is the quarter-hour slot after the highest T7.
3. Run a SQL *join* operation location/time range table and a copy of this table to determine if there are MinT1 values of one location which are in the activity interval of another location (for the same team).

5.5.2 Findings

Some overlaps were detected and the raw data were analysed. It turned out that transfer errors (wrong date used in the transcript) were the source. The data were corrected (lossless).

5.5.3 Final

Location time overlap test indicated no inconsistencies anymore.

5.6 Further data consolidation steps

5.6.1 Cross-checking using confirmation SMS

A further step in validating data was to use the timestamps of the confirmation SMS to A and B parties. The method was to search for matching SMS for each DFS TA. The result was that for Team 1, the matching rate was high (almost 98%) while for Team 2 the matching rate was very poor.

The teams used a separate device for time-taking in order to achieve the required 1-second resolution. Hypothesis was therefore that there was an offset in time-taking on the device Team 2 was using.

A systematic sweep, varying a time offset, was run. Relevant results are shown in Table 5-1. Please note that matching was checked for all transactions including the unsuccessful ones so the actual degree of matching for successful results is respectively higher.

Nevertheless, there were cases where no match was found. It is assumed that those cases are attributable to transfer or recording errors from logging. It was however decided to ignore them for the time being, as they have no significant effect on the main data output from this pilot.

Table 5-1 Results of offset time variation for Team 2

Time Correction	Window	Match Sender %	Match Receiver %
0	180	**29,2**	**35,2**
110	180	**86,4**	**90,6**
140	180	**91,7**	**92,0**
125	180	92,5	92,3

It is important to understand that an absolute time accuracy was not required in order to achieve the purpose of the test. Therefore, there was no strict requirement with respect to absolute accuracy of this time. However, a 'lesson learned' was that a clear definition and respective checks for setting times and prescribing the method of time-taking should be included in future tests in case manual time-taking is used.

6 Basic DFS KPI

6.1 Overview

The following data has been computed from validated transaction data (Source A) and from background measurement data (Source C).

6.2 Results, data after fixing

6.2.1 Overview

The following diagram shows the core transfer times (T2-T3, MTCD) per location, averaged for all transactions regardless of device roles.

6.2.2 MTCD: Core Duration

Figure 6-1 shows an overview of MTCD values for all locations (not all of them are visible in the label). See subsection 6.2.11 for details.

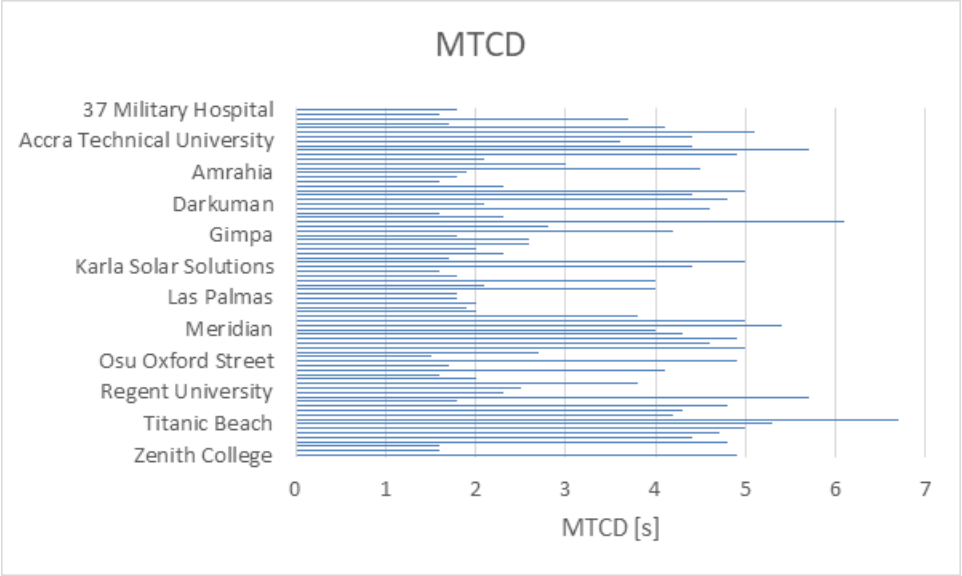

Figure 6-1 MTCD per location (overview)

6.2.3 MTRCT: Raw Completion Time

MTCD only measures the time taken for the last step of a DFS transaction. With the implementation of the MoMo service under test, previous steps (entry of required input data for the transaction) also involve data transfer activity.

In the pilot, time-taking for transactions is made manually which does not allow for sufficiently high resolution. Therefore, MTCT cannot be computed in a meaningful way. This led to the definition of MTRCT as a pragmatic approach to an end-to-end completion time, however involving times taken for manual action. As manual action adds additional variation to data values, it is expected that MTRCT displays a larger variation than MTCD. Nevertheless – as has been discussed in more detail in previous sections, MTRCT is a useful measure to obtain further information on location-dependent QoS.

Figure 6-2 shows the raw completion time (MTRCT) for all locations. To provide an impression on the fluctuation of this value, Figure 6-3 shows MTRCT versus MTCD (core duration from release to completion of the transfer). As can be seen, there are some outliers but the general correlation between values is clearly visible which confirms the usefulness of MTRCT.

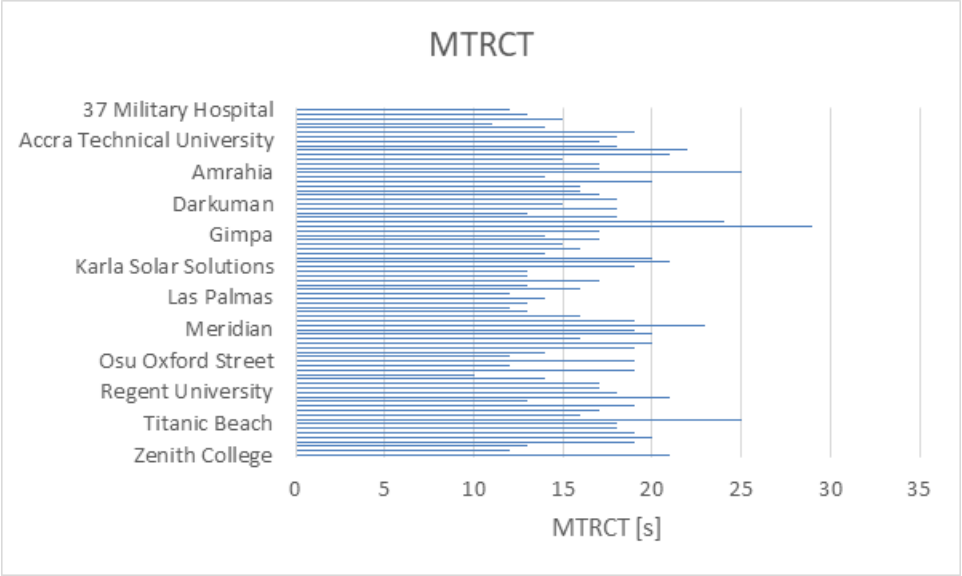

Figure 6-2 MTRCT per location. Not all location data are labelled.

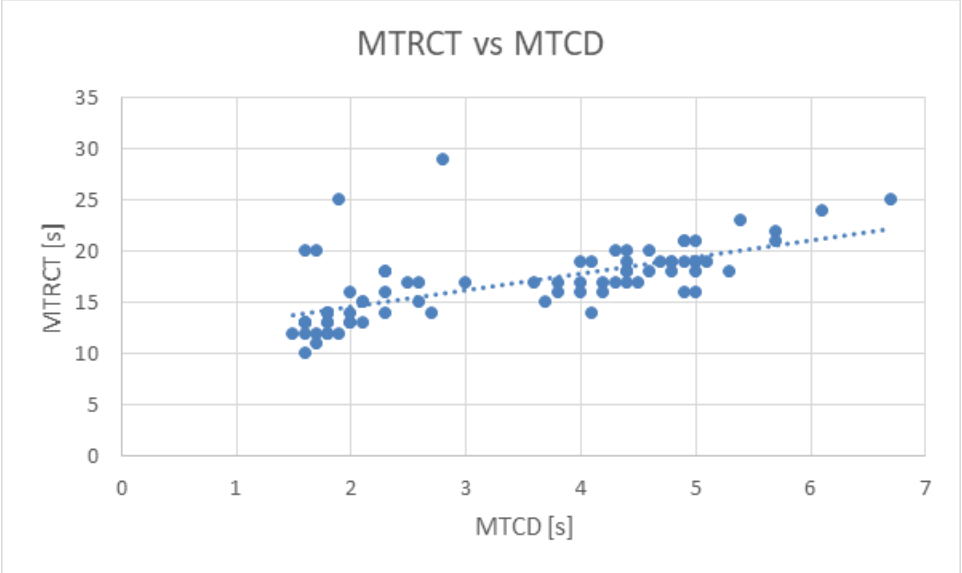

Figure 6-3 MTRCT vs. MTCD[2].

6.2.4 MTCR: Completion Rate

Table 10-1 in Annex A shows that in 52 out of 78 locations, the success rate was 100%. In the other 26 locations, completion rates ranged between 91.5 and 98.9%.

Figure 6-4 shows the per-location averages of MTCR versus MTCD, giving a hint that there may be a correlation between completion rate and core duration. However, it has to be kept in mind, that the transaction count per location was only 48, so the statistical uncertainty is considerable.

[2] Each data point represents the average of values for one location.

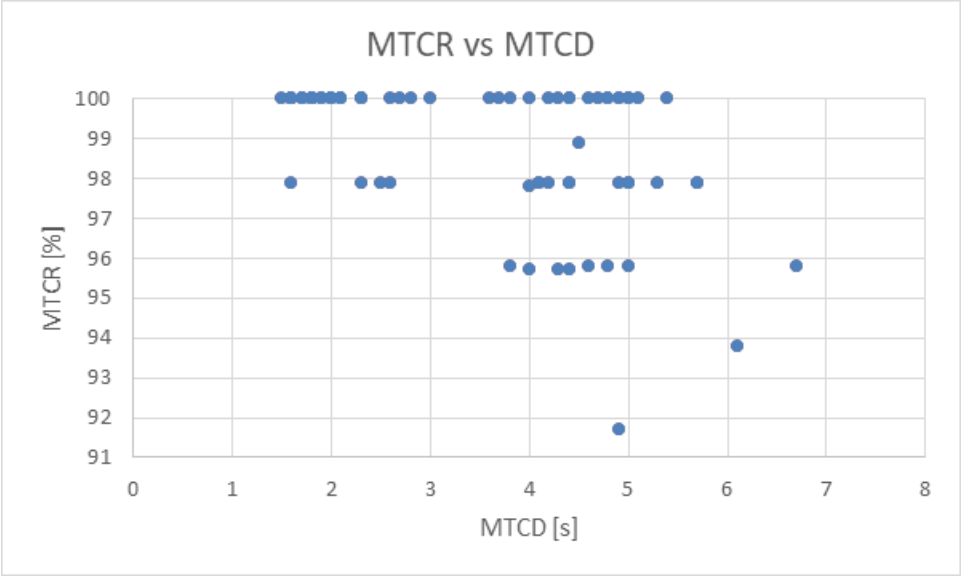

Figure 6-4 Completion rate (MTCR) vs Core Duration (MTCD)

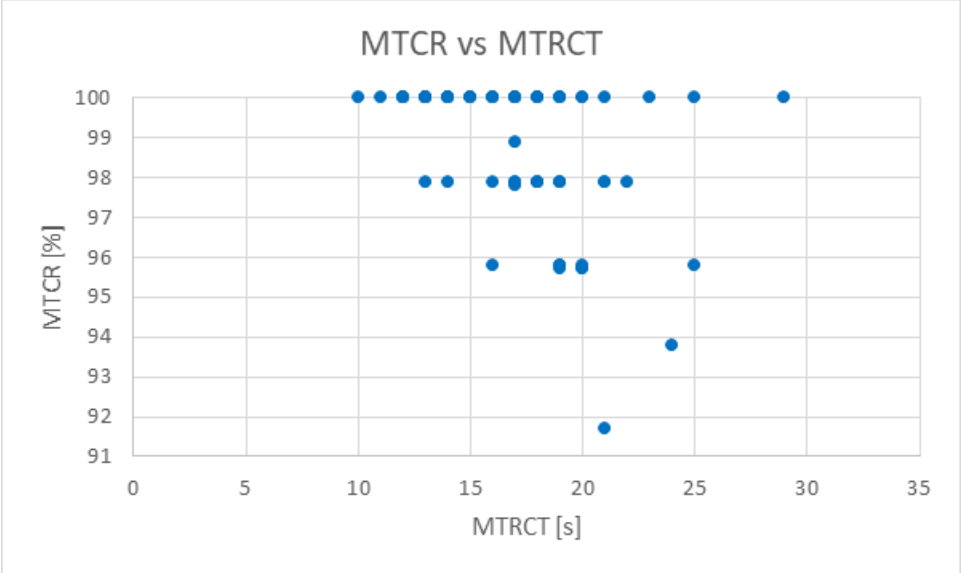

Figure 6-5 Completion rate (MTCR) vs Raw Completion Time (MTRCT)

6.2.5 MTCD: Value Distributions

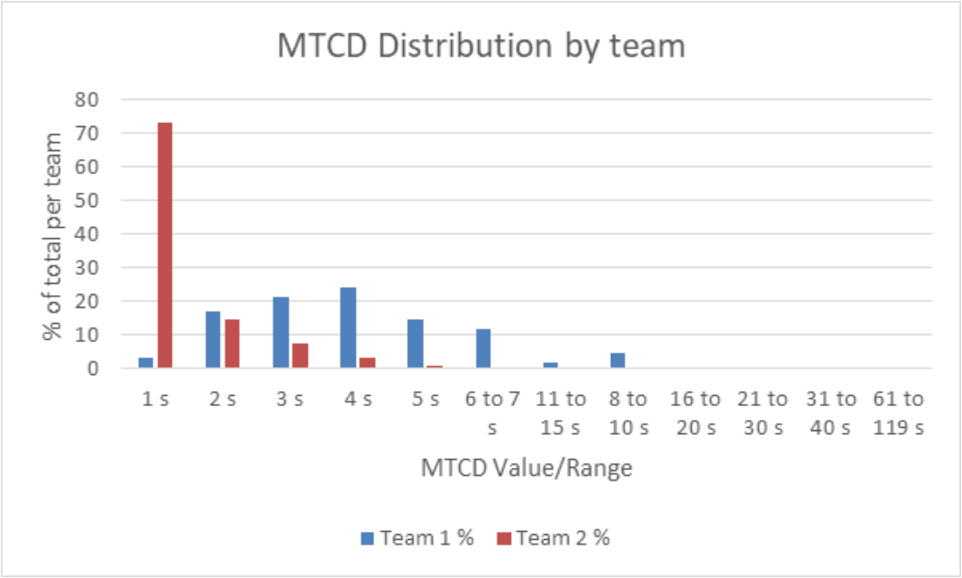

Figure 6-6 Distribution of MTCD values by team

There is a pronounced difference in value distribution between teams. After validation and clarification with the campaign supervisor, it has been determined that the reason is that Team 1 had been primarily assigned to locations where network coverage was expected to be poorer.

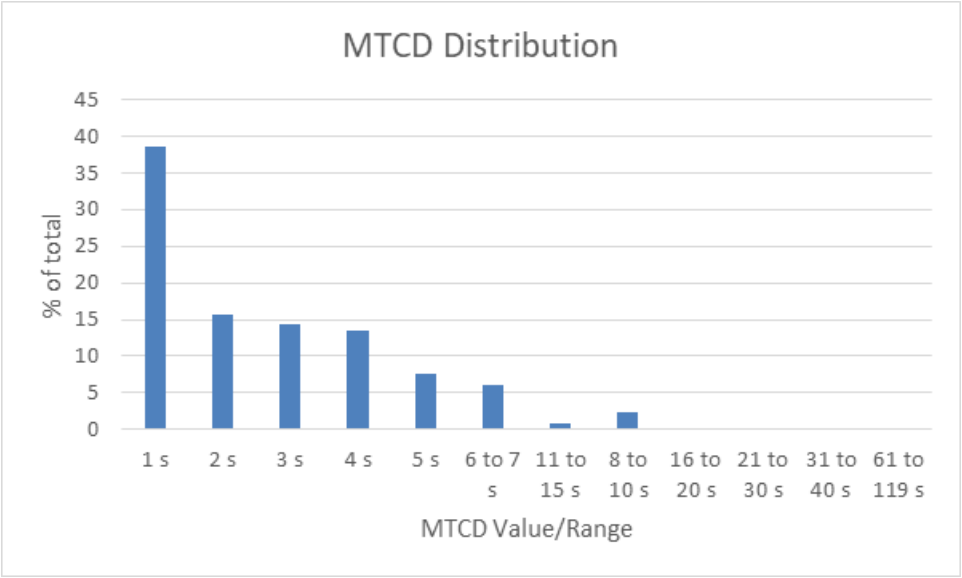

Figure 6-7 Distribution of MTCD values, all teams

6.2.6 MTRCT: Value Distributions

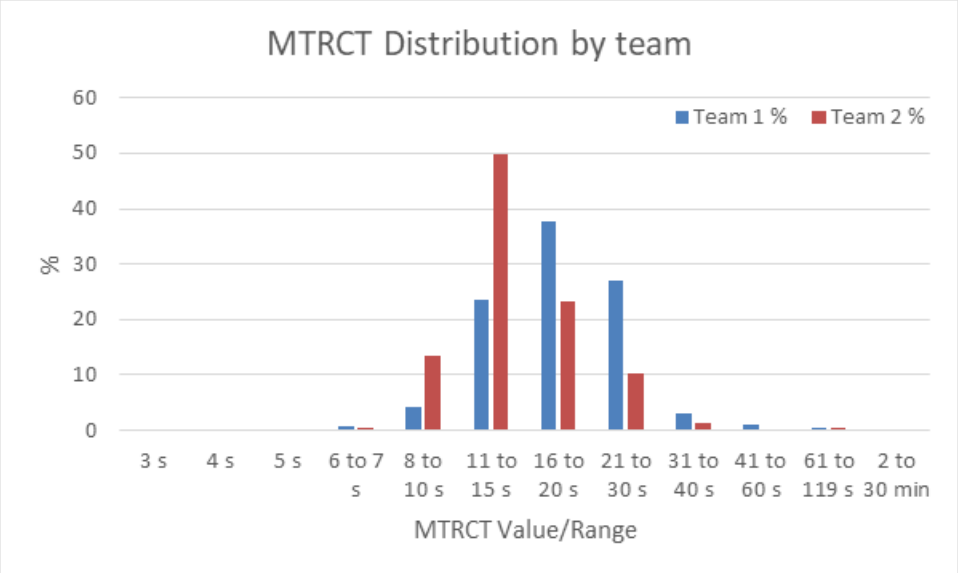

Figure 6-8 Distribution of MTRCT values by team

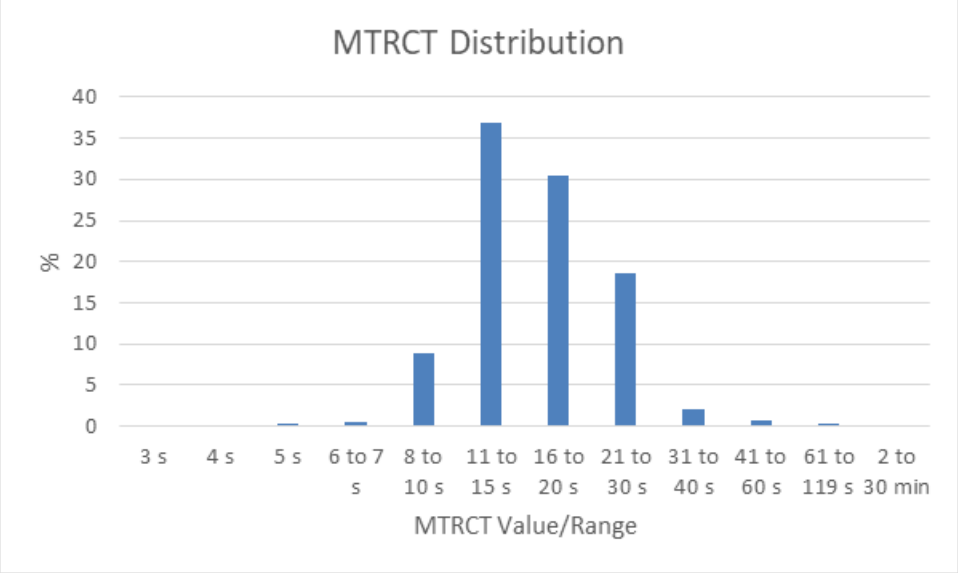

Figure 6-9 MTRCT Distribution, all teams

6.2.7 MTFCT: Value Distributions

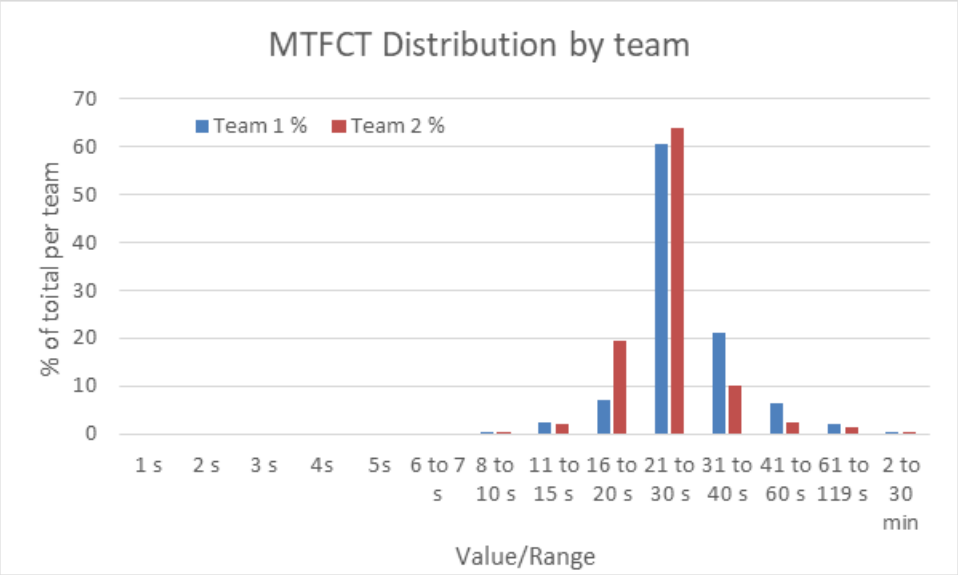

Figure 6-10 Distribution of MTFCT values by team

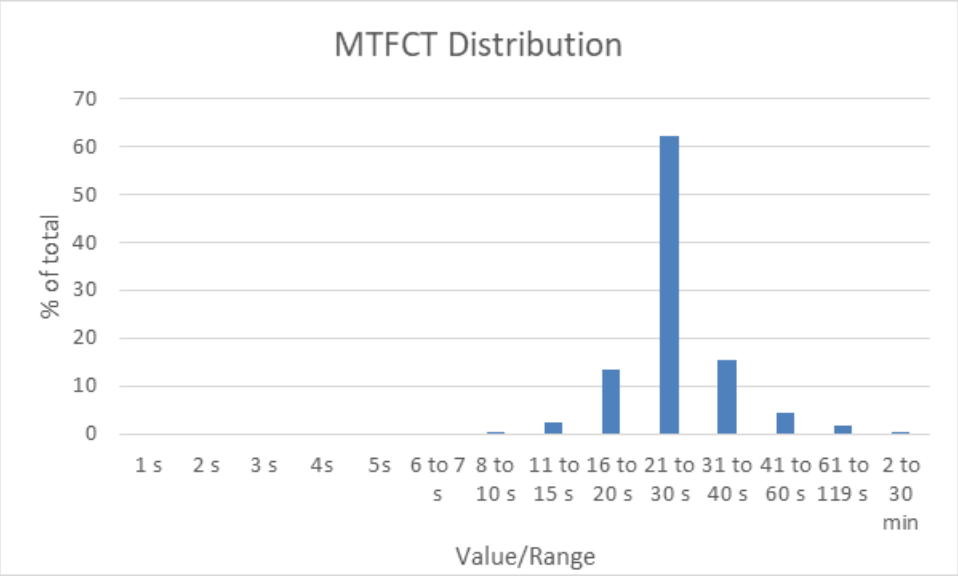

Figure 6-11 MTFCT Distribution, all teams

6.2.8 MTACT: Value Distributions

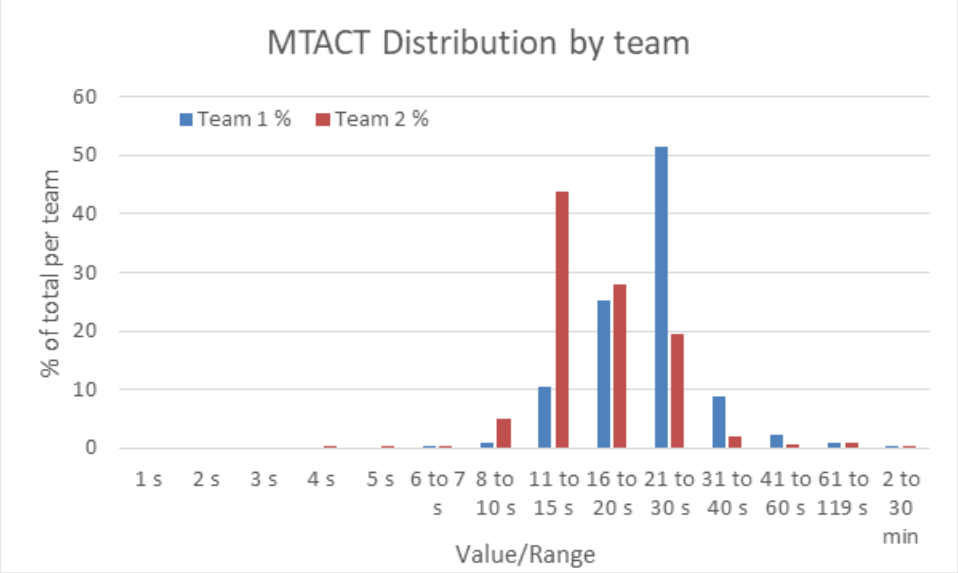

Figure 6-12 Distribution of MTACT values by team

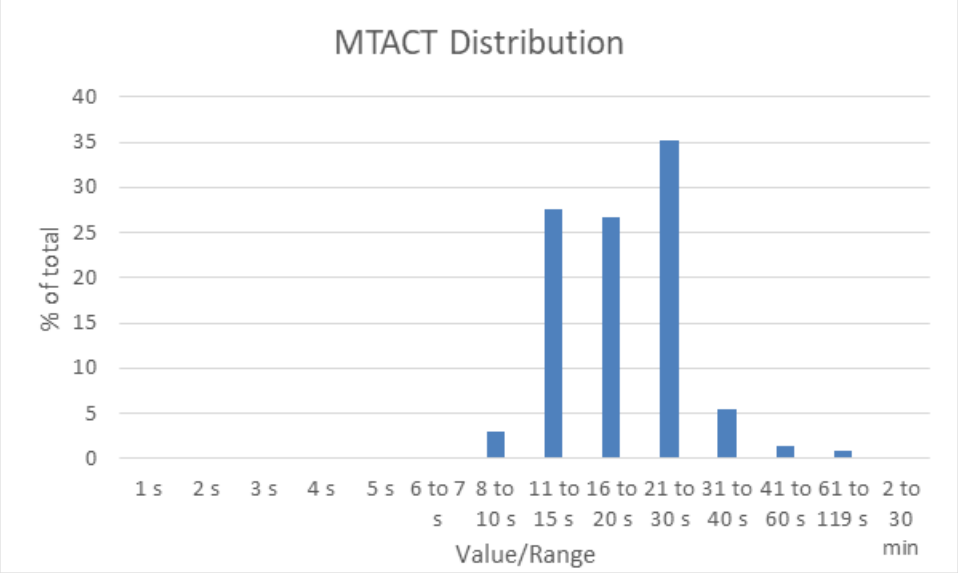

Figure 6-13 MTACT Distribution for all teams

6.2.9 Key Indicators by role

Table 6-1 shows the main KPI, averaged over both teams and all locations, by sender role.

By definition, receiver role does not have an influence on MTCD, MTRCT and MTACT.

As expected, KPI where RAT has an influence are clearly different between the SP and FP type, while the completion rate does not show, within statistical error margins, this dependency.

- Estimation of statistical error for success rate: Each role has ca. 930 valid samples of successful TA. Using the Pearson-Clopper tables (A4.1 and A4.2) in ETSI TS 102 250-6, lower and upper

limits of confidence interval for 1000 samples and 1% rate (1-CR) are 0.48% and 1.8%, respectively.

Table 6-1 KPI by role

Sender ID	AvgMTCD	AvgMTRCT	AvgMTACT	AvgMTCR
FP1	3,1	18,0	21,5	98,9
FP2	3,1	17,8	21,3	99,0
SP1	2,6	16,8	19,9	98,7
SP2	2,7	16,6	19,4	99,1

6.2.10 Average and Median for time values; further considerations

Typically, QoS KPI values of type time are defined as arithmetic average of per-transaction data. Averages react quite strongly to large random variations in the data set, in particular if there are a few outlier values. In contrast, median values are more robust against single extreme values. Therefore, it can be useful to look at both types.

Please note that due to the definition of Median and the fact that time resolution of timestamps (T1 through T7) was 1 s, median values are quantized in 0.5 s intervals.

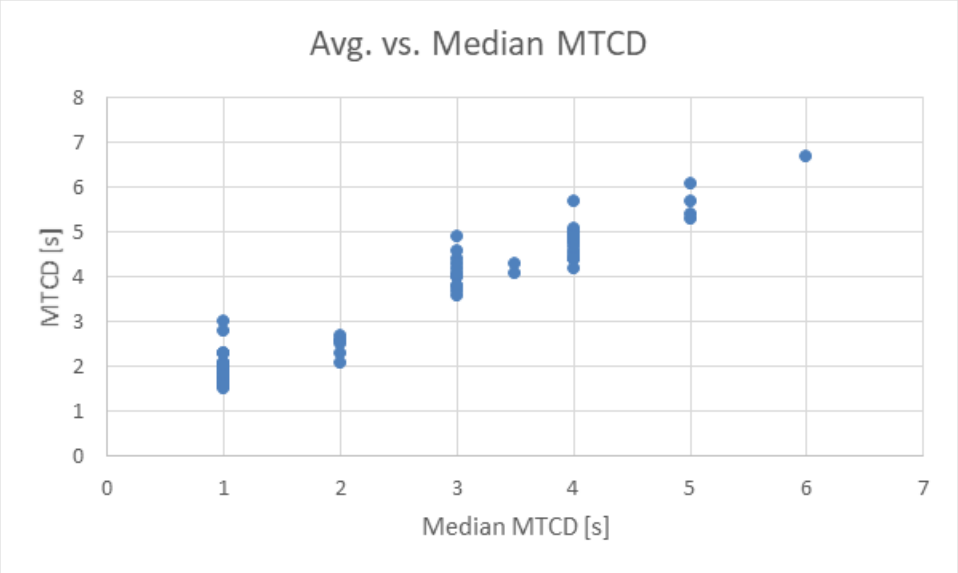

Figure 6-14 Average vs Median MTCD per location

See also **Table 10-2** for the full details of the Median variant of time related KPI.

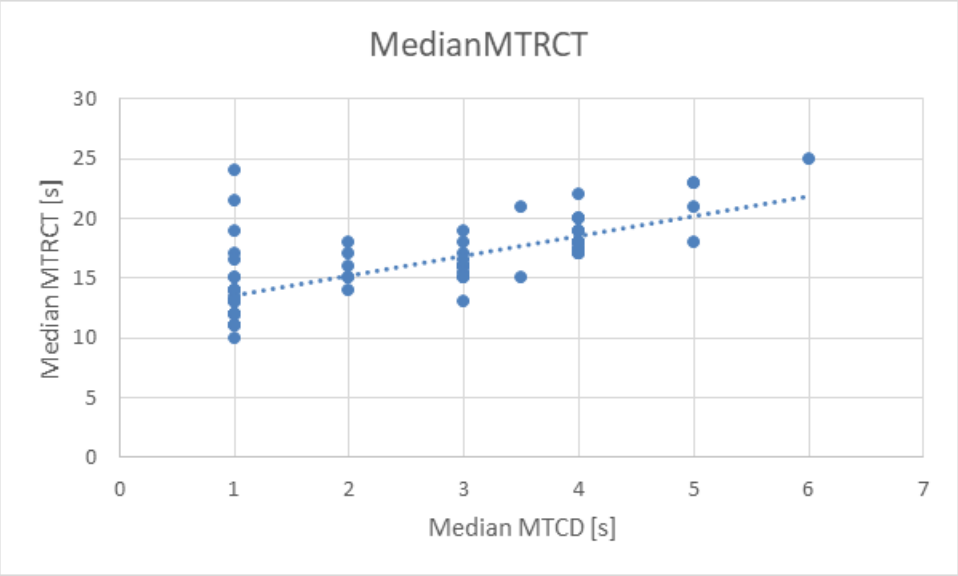

Figure 6-15 Median MTRCT vs Median MTCD

In Figure 6-11, the correlation between the Median versions of MTCD and MTRCT is shown by a scatter plot of respective values. As expected, by comparison to the arithmetic averages (see Figure 6-3 in section 6.2.2), it can be observed that the outlier effects are smaller. The "pile" of values which is prominent in the 1 s category of MTCD is caused by quantization.

By definition of MTRCT, it consists of two components: a part of which depends on the transfer time of data exchanged between the mobile device and the service, and the times taken by manual entry of input data. Using Figure 6-11 and extrapolating to Median MTCD=0, the manual part of MTRCT can be estimated to be approx. 13 s. The same approximation for MTCD in Figure 6-3 yields a manual-entry time portion of 14 s.

6.3 Validation summary

After initial data validation, some transactions (34 out of 3741) where the transfer time had the value of zero, indicating that the transfer time was actually below 1 s. In these cases, the MTCD was set to the value of 1 for location-related averaging.

As can be seen, in some of the cases raw transfer times were zero. This can be understood as an effect of time resolution (for very fast DFS MTCD is can happen within the same 1 second interval). It may also be a result of human reading error. With the given data material, no clear distinction between these cases is possible.

Apart from a few exceptions, the raw number of transactions was 48 (multiples of the full cycle time of 8 transfers). In some cases, transactions were flagged "to be ignored" which reduced the sample count.

The overall success rate of transactions was, in most cases, 100%. There are a few locations with significant failure rates, mostly reported as direct failures, with a few cases of time-out. Such locations will be inspected separately also using respective location and event log sheets.

Additional Info: For this sample size, using [TS 102 250-6 (or ITU-T Rec. E.804[3])], Tables A.4.4 and A.4.5, the 95% confidence interval for a nominal 5% failure rate can be roughly estimated to be ca. 2.5% to ca. 15%.

[3] https://www.itu.int/rec/T-REC-E.804

7 Background measurements

7.1 Overview

As prescribed by the test methodology, background measurements were performed in all locations where DFS tests had been made.

The test scenario covered a spectrum of basic services. Table 7-1 shows the test cases and their parameters.

Table 7-1 Principal test cases and parameters for background test (Carrier services performance tests)

Service Type	Parameter	Purpose
USSD	*156#	Query own number; functional USSD test
USSD	*400#	Deliberately non-functional code; basic USSD probing
SMS	to own device	Basic SMS test (round-trip, sending to self)
HTTP Download	100 kBytes, fixed-time	Basic download performance test (small data volume; not representative for maximum end to end HTTP download data rate)
HTTP Download	100 kBytes, fixed time (different location)	same as above, using a different server
HTTP Upload	100 kBytes, fixed-time	Basic upload performance test (small data volume; not representative for maximum end to end HTTP download data rate)
Web browsing	ETSI Kepler SP ref page	Download test in time-based mode (success rate not relevant), to check the network's transfer performance with complex content
HTTP DL	ETSI Kepler ref page	
Web browsing	Google.de	Basic web browsing test

- Note 1: The session times for USSD include end to end handling. They are not directly comparable to USSD related time components in the DFS service.

- Note 2: Data rates for download test cases were end to end, i.e. including set-up and ramp-up times for the transfer. This is due to the relatively small data volumes (refer to Method A in ITU-T Rec. E.804/ETSI TS 102 250-2; first data block on application level may contain the entire data volume). Also, due to this small transfer data volume, throughput values do not represent the maximum data rate the network can deliver for end to end HTTP download.

- Note 3: For download, upload and Kepler SP web site tests, servers in Germany were chosen to also include a view on the international connection of the network under test.

7.2 Geo visualization

In about 50% of the cases, there were valid GPS data for background measurements; in the rest of the cases, there was no GPS information.

GPS information was not requested by the procedure so this data is actually an add-on. For further measurements, is should be considered to request enabling of GPS, resulting then also in extension of the location check list.

Remark: If copyright conditions allow, place marks created from GPS information by e.g. conversion to GPX files, can be used to create map views (e.g. using GIS tools such as Google Earth™ or other products).

Using GIS tools enables additional options for data preparation and consolidation:

- Where GPS data exist, compare location names to actual locations on the map, and validate time ranges
- Otherwise, find geo positions by name, and create a cross reference of date/time of transactions (Source A) and date/time of background measurements.

As an interim measure, a KPI profile for background measurements was created which shows hour-wise aggregated KPI for each test case.

7.3 KPI per time range

The following diagram is shown as a visualization of testing activities over time. Each data point represents averaged values for a one-hour interval. Detailed results per location are shown in subsequent sections of this report.

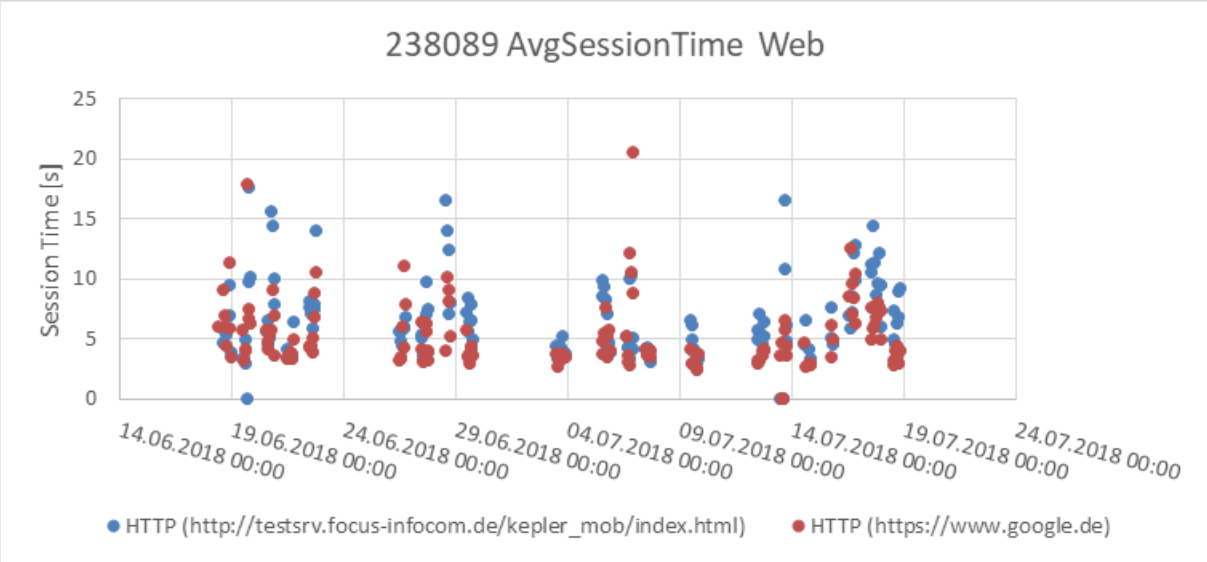

Figure 7-1 Averaged Session Time (Web Browsing, Kepler SP, site 1)[4].

- Assumption is that there are two effects on session time: A) Network performance and page structure; we would expect a systematic difference between URL. B) Changes in latency depending on the route to the server (Kepler page was deliberately hosted in Germany for this purpose with Google as an assumedly locally or regionally hosted page.

[4] Each data point represents the averaged values for a one-hour time slot.

7.4 Network Service KPI by location

7.4.1 Overview

The next step of computation was using time range information to first connect OT measurements to locations, and then compute basic KPI by location for both OT and DFS.

Scenario used:

Table 7-2 Detailed scenario for background measurements

Service Type	B party or destination	Parameters
SMS	to self (roundtrip	Send timeout: 20 s
USSD	code: *156# (query own number)	Timeout: 20 s
Web Browsing	Google	Timeout: 30 s
Web Browsing (http)	ETSI Kepler SP on FI server 1	Timeout: 30 s
HTTP DL	100 kByte on FI server 1	Timebased/Hybrid, time window 10 s
HTTP UL	100 kByte to FI server 1	Timebased/Hybrid, time window 10 s
USSD	code: *400# (presumed non-functional)	Timeout: 20 s
Web Browsing (http)	ETSI Kepler SP on FI server 2	Timeout: 30 s
HTTP DL	100 kByte on FI server 2	Hybrid, time window 10 s

7.4.2 Results

7.4.2.1 Selected results

The following table shows main service KPI per location.

Only locations with at least 20 valid tries per service are shown.

(NULL rows indicate cases where the SMS credit on the observer phone was insufficient)

For some locations, no USSD results are available due local to set-up issues.

Table 7-3 Main service KPI per location

Location	DL SR	DL MDR_E2E	UL SR	UL MDR_E2E	USSD SR	USSD ST	Web SR	Web ST	SMS SR	SMS ST
37 Military Hospital	99	434	100	223			100	3,7	99	2,6
Abokobi	100	468	100	333	94	2,0	100	3,4	100	3,0
Accra Academy	100	0	100	3			0	NULL	100	6,5
Accra Girls	100	416	100	229			96	5,0	100	3,1
Accra Institute of Technology	100	369	100	258	100	1,7	93	5,2	100	2,3
Accra Mall East	100	484	100	312	100	2,0	96	4,0	100	2,9

Table 7-3 Main service KPI per location

Location	DL SR	DL MDR_E2E	UL SR	UL MDR_E2E	USSD SR	USSD ST	Web SR	Web ST	SMS SR	SMS ST
Accra Mall West	100	429	100	313	100	1,9	96	3,7	100	2,8
Accra Technical University	100	38	100	53	100	3,0	15	10,9	0	NULL
Achimota Mall 1	100	272	100	166	100	2,4	90	7,4	100	3,3
Achimota Mall 2	100	405	100	251	100	1,9	91	4,9	100	2,7
Action Chapel	100	432	100	239	100	1,7	100	4,0	100	2,1
Adenta	100	395	100	302	100	2,2	99	3,5	100	2,6
Agbogba	100	464	100	308	100	2,1	94	4,1	100	2,5
Airport	100	292	100	195	100	2,1	84	6,6	100	3,0
Amrahia	100	392	100	300	100	2,7	98	4,4	100	3,3
Awoshie	100	199	100	131	92	6,7	52	13,2	100	7,6
Barn Yard	100	391	100	212			95	4,2	100	2,7
Bubuashie	100	511	100	289	100	2,2	100	4,0	100	2,7
Central University	100	422	100	296	100	1,9	92	4,0	100	2,5
Commercial Area (CU)	100	464	100	331	100	1,6	100	3,5	100	2,2
Community Two	98	123	100	95			44	7,3	100	5,0
Darkuman	100	406	100	208	100	2,9	94	6,0	100	3,5
Data Link Institute	100	355	100	267	100	1,9	92	5,2	100	2,6
Dodowa	100	478	100	308	100	2,2	92	4,0	100	2,7
Forestry commission	98	437	100	315	100	2,0	96	4,4	0	NULL
Fridays	96	89	100	68	100	2,7	38	7,7	100	4,9
Ghana Post	100	460	100	353	100	2,0	100	3,3	100	2,9
GPHA	100	187	100	162	100	3,3	76	8,9	100	3,8
Gimpa	100	408	100	203	100	3,0	93	6,3	100	3,6
GTUC (Tesano)	100	13	100	25	100	2,9	11	11,2	72	5,8
Gulf House	100	507	100	272	100	2,0	92	3,9	100	2,8
Haatso Wisconsin university	100	323	100	208	100	2,4	70	4,8	100	4,4
Homebase TV	100	394	100	300	100	2,1	100	3,6	100	2,6
James Town Tower	100	470	100	312	100	2,2	92	4,3	100	3,2
Jubilee Block	100	0	100	8	100	2,5	0	NULL	100	5,9
Karla Solar Solutions	100	155	100	96			63	9,3	100	2,7
Kasoa	100	548	100	272	100	2,1	86	3,6	100	2,7
Knutsford University	100	370	100	312	100	2,0	93	3,7	100	3,0
Kpone	100	332	100	184			92	8,1	100	3,0
Kwashieman	100	495	100	322	100	2,2	96	3,6	20	2,6
Labone	100	326	100	190	100	1,9	93	5,2	100	2,6
Lancaster University	100	375	100	313	100	2,1	99	3,4	100	2,5

Table 7-3 Main service KPI per location

Location	DL SR	DL MDR_E2E	UL SR	UL MDR_E2E	USSD SR	USSD ST	Web SR	Web ST	SMS SR	SMS ST
Las Palmas(lapaz)	100	486	100	254	100	2,1	96	4,4	100	3,1
Lizzys sports complex	100	407	100	298	100	2,2	97	3,6	100	2,8
Madina	100	317	100	249	100	2,2	80	5,3	100	3,2
Mallam	100	409	100	372	100	2,1	100	5,2	100	2,7
Manet Cottage	100	380	100	345	100	1,6	96	4,3	100	2,4
Manet Ville	98	169	100	93	100	2,3	56	9,2	100	4,4
Marina Mall	100	206	100	116	100	2,0	71	8,1	100	4,4
Mensah Sarbah Hall	100	309	100	195	100	1,6	100	5,3	100	2,6
Meridian	98	71	100	68			59	12,1	100	5,5
Methodist University	100	37	100	54	100	2,8	19	9,9	0	NULL
Michelle Camp	100	555	100	217	100	1,9	81	5,8	100	2,9
Nungua Barrier	100	63	100	42	96	2,4	33	12,3	100	6,1
Nungua Junction Mall	100	267	100	160	100	2,6	70	6,5	100	3,8
Odorkor	100	35	100	52			5	16,2	100	6,0
Orgle Road	100	457	100	263			98	3,4	99	2,4
Osu Oxford Street	100	336	100	215	100	2,4	92	5,3	100	3,0
Oyarifa	100	330	100	333	100	2,2	94	4,7	100	3,1
Palace	100	506	100	324	100	1,7	97	3,6	100	2,4
Pantang	100	42	100	66	100	2,1	15	3,9	100	2,6
Pentecost University	98	439	100	292	100	1,9	95	3,1	100	2,9
Prampram	100	441	100	252			84	5,1	100	2,3
Rawlins park	100	192	100	66	100	2,4	70	12,6	0	NULL
Regent university	100	514	100	298	100	2,3	100	3,4	100	2,4
Regional Maritime University	100	392	100	295	100	1,8	83	3,5	100	2,9
Santa Maria	100	395	100	317	100	2,2	98	3,7	100	2,6
St Thomas Aquinas	100	580	100	325	100	1,7	100	3,3	100	2,3
Tema General Hospital	100	367	100	256	100	1,9	94	5,8	100	2,7
Teshie Nungua	100	246	100	150	100	2,4	71	5,1	100	3,5
Titanic Beach	100	166	100	92			44	12,1	100	4,5
UG Commonwealth Hall	100	403	100	115	100	2,0	79	5,9	100	3,2
UG International Students	100	303	100	248	100	2,8	93	6,6	100	3,6
UG Liman Hall	100	457	100	294	96	2,3	89	4,8	100	3,0
UPSA	100	152	100	137	100	2,8	75	9,6	100	4,3
Valley view university	100	215	100	190	100	3,3	85	8,6	98	4,5
West hills mall	100	477	100	297	100	2,1	94	3,9	100	2,6
Zenith	100	196	100	92	100	2,2	88	7,6	100	2,8

7.4.2.2 Column header abbreviations

Table 7-4 Column header abbreviations

Abbreviation	Internal Name	KPI type	Refers to Test case(s)
DL SR	DL SuccessRatePerc	Success Rate [%]	HTTP DL
DL MDR_E2E	DL AvgMDR_E2E	End to end Mean Data Rate [kbit/s]. E2E means that the time window fully includes the ramp-up time.	HTTP DL
UL SR	UL SuccessRatePerc	Success Rate [%]	HTTP UL
UL MDR_E2E	UL AvgMDR_E2E	End to end Mean Data Rate [kbit/s]	HTTP UL
USSD SR	USSD400 SuccessRatePerc	Success Rate [%]	USSD rate of reception of responses vs. USSD commands sent
USSD ST	USSD400 AvgSessionTime	Session Time [s]	USSD, Time from sending the command to receiving a response
Web SR	Kepler SP SuccessRatePerc	Success Rate [%]	Web Browsing
Web ST	Kepler SP AvgSessionTime	Session Time [s]	Web Browsing
SMS SR	SMS SuccessRatePerc	Success Rate [%]	Rate of SMS received (round-trip) vs. SMS sent.
SMS ST	SMS AvgSessionTime	Session Time [s]	Time between confirmed sending and reception of the return SMS

8 Combined results

8.1 Introduction and overview

For the test cases used, see Table 7-1 and **Table 7-2**.

Final goal of the measurement campaign was to investigate for relationships between network carrier services and DFS performance. From the known way of functioning of DFS, it is assumed that the network performance for USSD may have a primary relation and SMS performance a secondary one, to DFS performance. In the following, respective KPI are compared against each other.

In preparation, it must be kept in mind that background measurements have been done with a smartphone in free-running mode (all available RAT) while DFS measurements have been made with devices in free-running mode (the SP1/SP2 roles) as well as in devices restricted to 2G (the FP1/FP2 roles). Therefore, analysis for correlation is done only for the SP1/SP2 sender roles.

To provide an impression on the relative DFS KPI values for different locations, Figure 8-1 shows MTRCT by role type for a subset of locations (for display reasons). It can be seen that the FP values were somewhat higher in most, but not all cases, which can be attributed to locally different coverage conditions for 2G and 3G/4G.

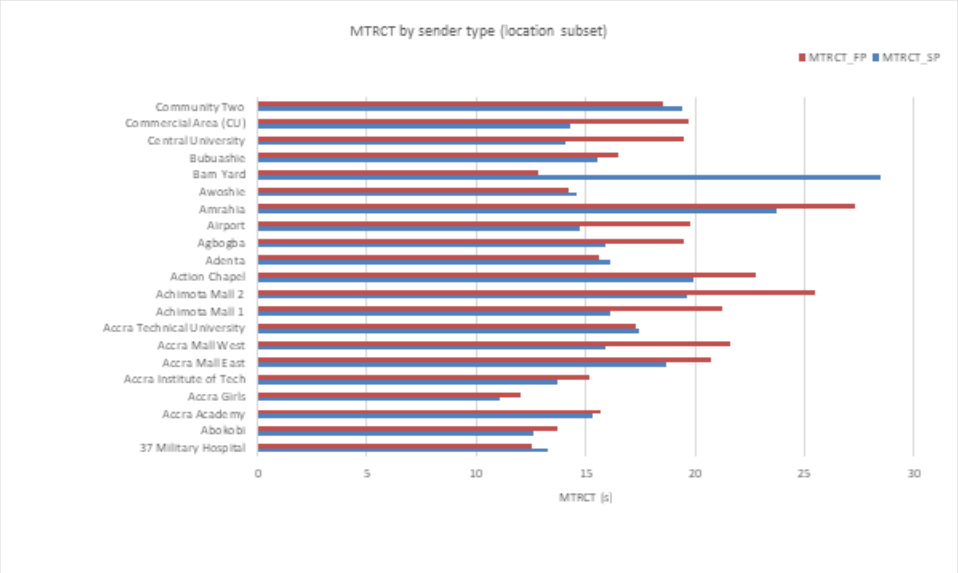

Figure 8-1 DFS KPI MTRCT for selected locations, by sender role

Figure 8-2 and Figure 8-3 display relations between sender role types for MTCD and MTRCT, respectively. These figures shows that while there is a visible correlation. Nevertheless, individual results differ significantly between locations. These figures underline the necessity to restrict comparison between DFS and carrier service KPI to the SP cases.

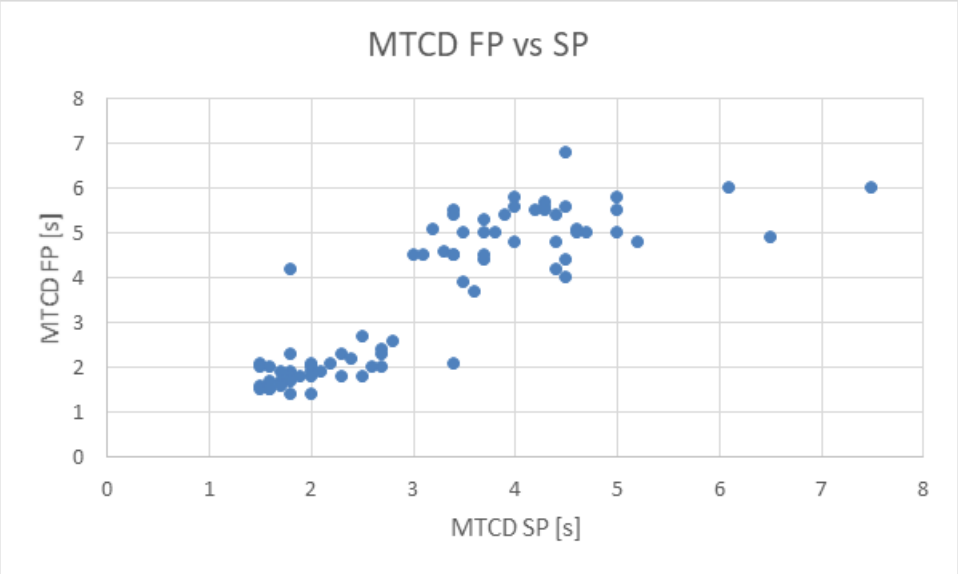

Figure 8-2 MTCD: SP vs FP

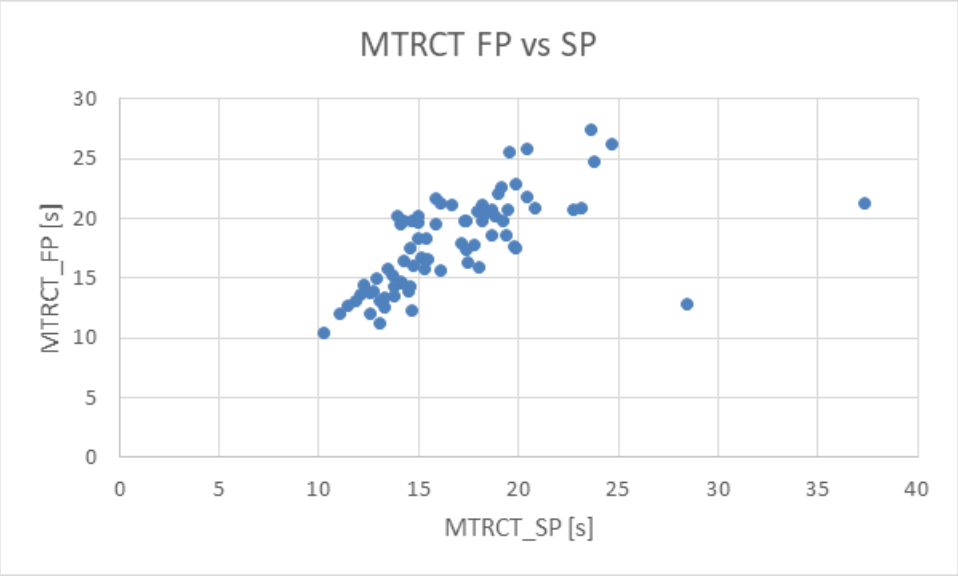

Figure 8-3 MTRCT: SP vs. FP

8.2 Correlation between DFS and OT KPI

8.2.1 General model

The general model of the system under test is shown in Figure 8-4. Please note that this visualization is only provided for explanatory purposes in the present document.

Figure 8-4 General model of the system under test

The essence of this model is that DFS performance and the performance of general network performance, as expressed by QoS KPI, are linked together by the elements they share.

When the DFS service uses basic network services, it is clear that there is a direct causal relationship between respective KPI. A correlation can also exist when service performance can be understood acts as a proxy (which may be easier to measure than the DFS performance itself) for network properties which affect all services, such as radio coverage or network infrastructure performance.

All observable quantities are however subject to fluctuations which are due to the overall dynamics of the system. A correlation between DFS and OT can therefore only be observed if there are enough samples to sufficiently reduce fluctuations by averaging. So sample count is in any case a limiting factor of gaining quantitative insights.

In addition, the observed degree of correlation, both causal and circumstantial, is influenced by the degree of shared resources. For instance, under good radio conditions it can be assumed that the relative influence of fluctuations in radio conditions is small. If also the performance of shared components is good, fluctuations in the non-shared parts of service implementations will have a dominant effect and correlation is expected to be relatively small. If, on the other hand, fluctuations in radio conditions have a dominant effect, correlation between DFS and non-DFS service performance is expected to be strong.

8.2.2 Results

Location KPI as shown here comes from aggregated data for the whole period of time spent at respective locations. The time spent at each location was roughly 3 hours. In case of the DFS data, this means those 24 transactions per location, out of 48 TA, where devices in SP configuration had the sender role. In case of OT measurements, the number of transactions per location and per test case was between 50 and 100.

The following diagrams show scatter plots to visualize the correlation between DFS KPI and selected carrier service KPI.

Assumption was that there should be a correlation for USSD as the DFS uses this function, and, to a certain degree for SMS as SMS is also using L3 signalling.

Figure 8-5 shows a respective scatter diagram for all locations and all device types in the sender role. Visually, it appears there is no correlation; however observe the outlier at ST ca. 7 s. Figure 8-6 shows the set without this outlier and only for smartphones in the sender role. This should provide the highest degree of correlation as the ObserverTool was, as the devices in the SP mode, set to automatic RAT selection.

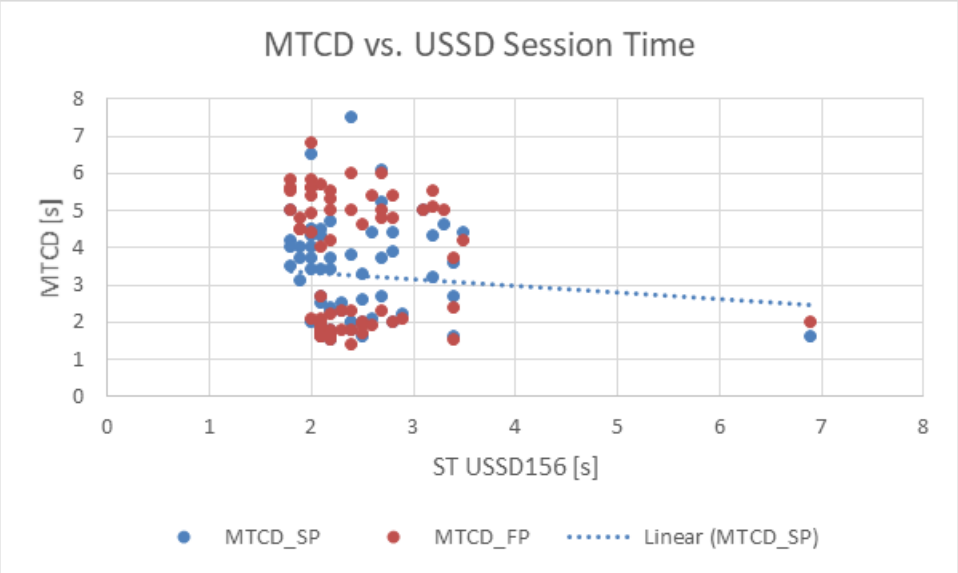

Figure 8-5 MTCD for SP and FP roles vs USSD (*156#) session time

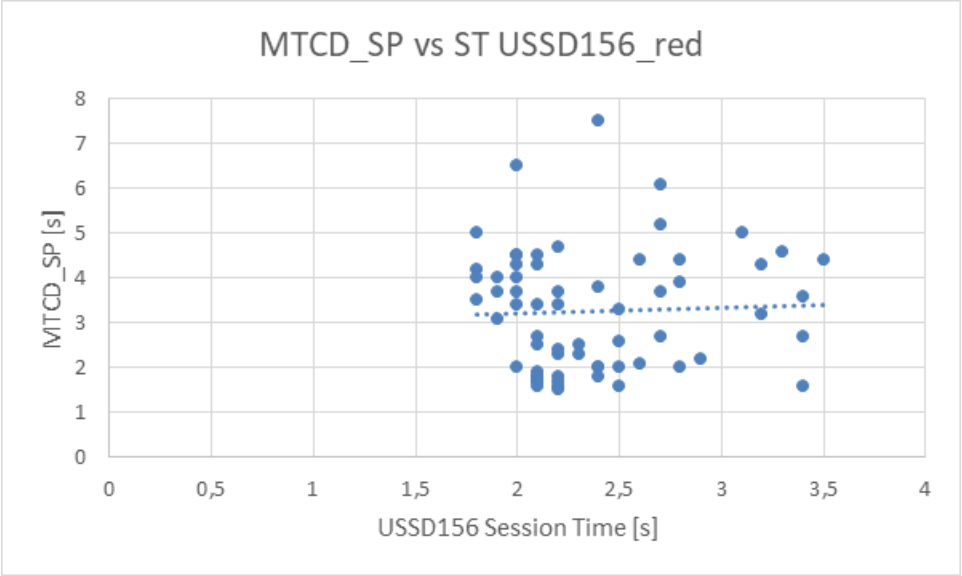

Figure 8-6 MTCD for SP in sender role vs USSD (*156#) Session Time[5].

To check if there are systematic differences between the *156# (functional USSD code) and *400# (non-functional code), Figure 8-7 shows the scatter plot for the session times. It can be concludes that there is, in the limits of variance of values due to the small number of samples, no significant difference across locations.

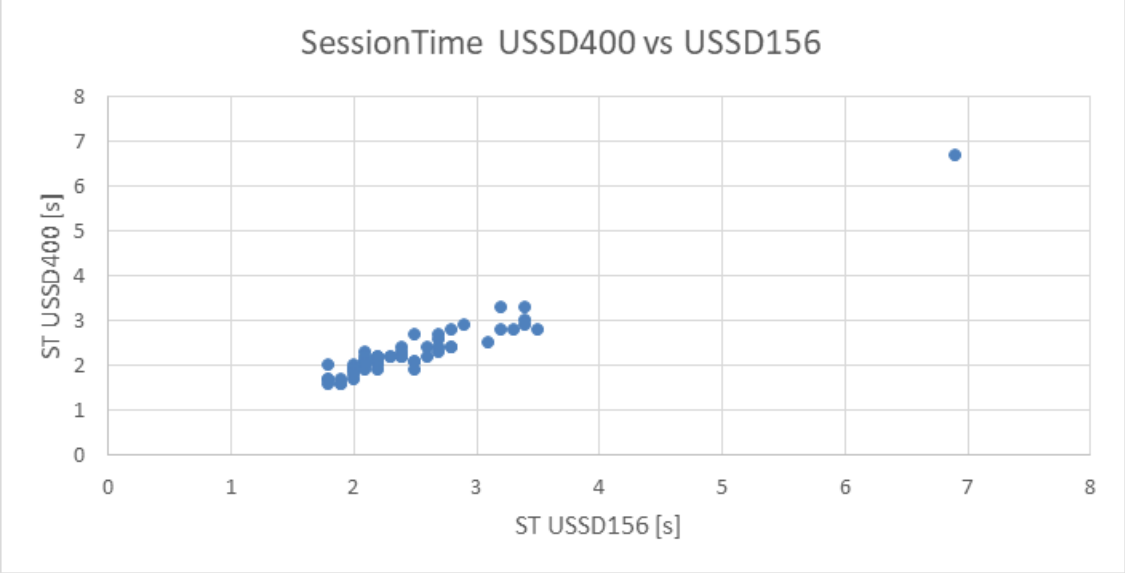

Figure 8-7 Session times for the two USSD test cases. [6]

[5] Each data point represents the average for one location. One outlier at a ST about 7 s was removed here to improve visibility.

[6] Each data point represents the average for one location.

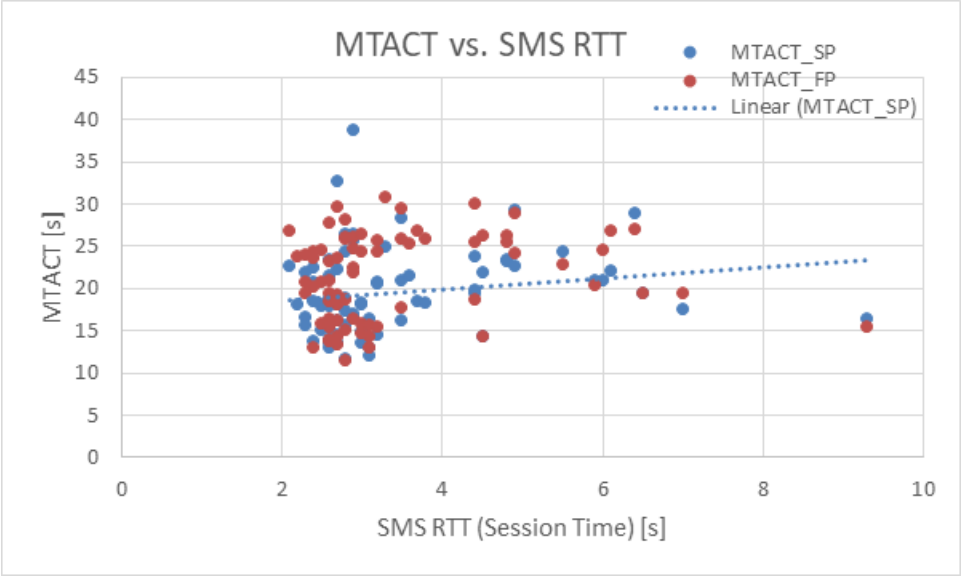

Figure 8-8 Correlation between SMS RTT (Session Time) and MTACT[7]

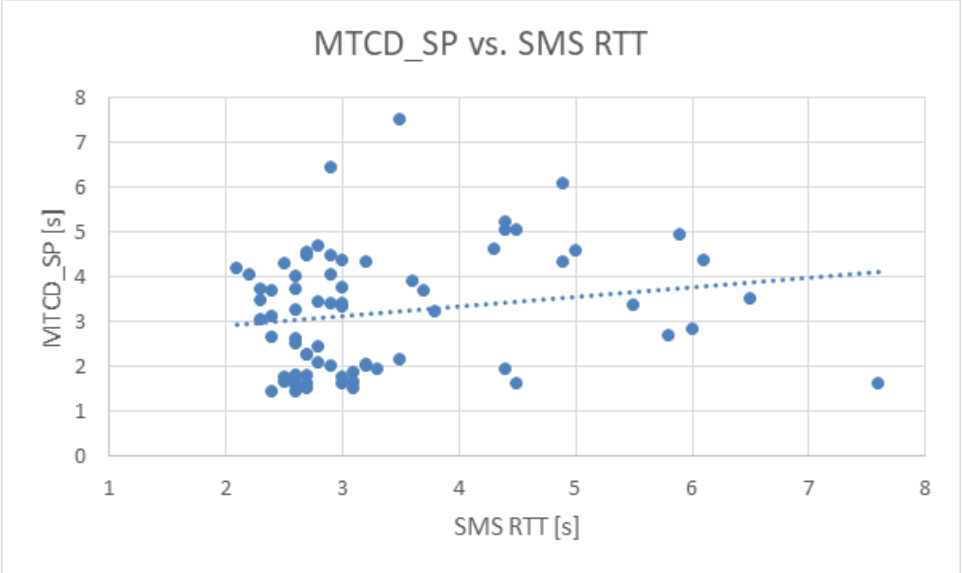

Figure 8-9 MTCD_SP vs SMS RTT.[8]

The correlation between other test case types has also been investigated. Figure 8-10 shows the Mean Data Rate for one of the HTTP Download test cases. Figure 8-11 shows the End-to-End Upload data rate, and Figure 8-12 shows Session Time for the Google web site.

[7] By sender role device type. Each data point represents the average for one location.

[8] Each data point represents the averaged values for one location. In MTCD, only samples for smartphone type devices in the A role were used

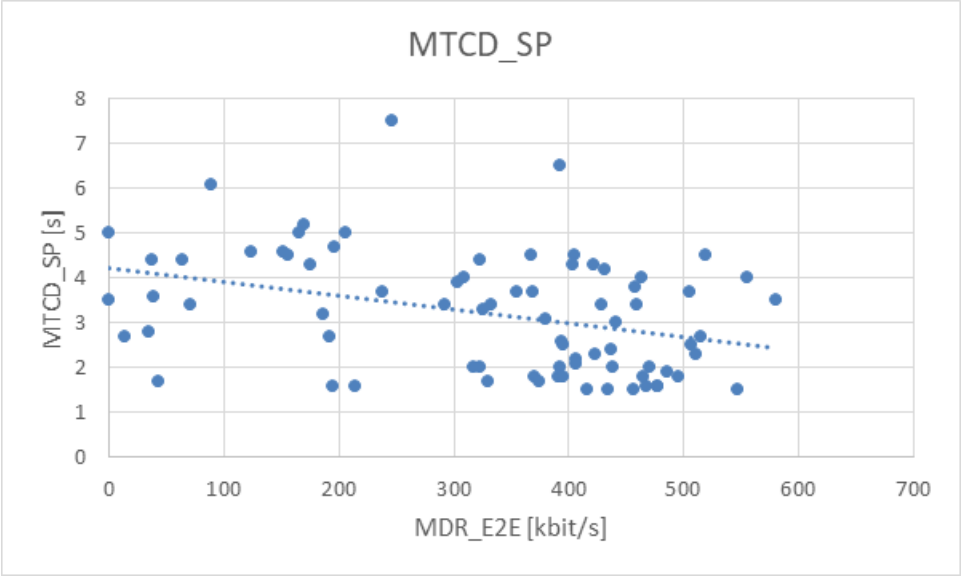

Figure 8-10 Correlation test between MTCD and HTTP DL MDR[9].

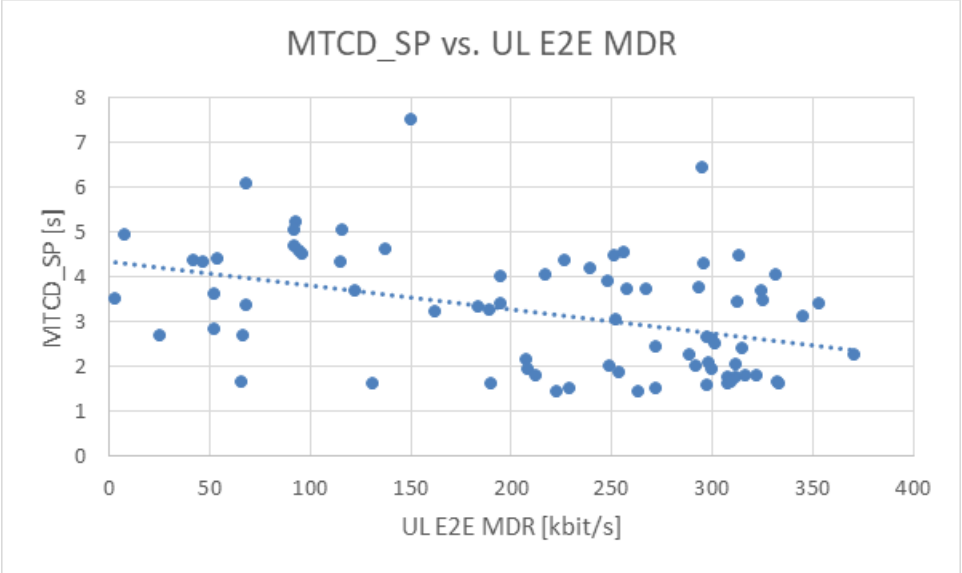

Figure 8-11 Upload MTCD vs. E2EMDR[10].

[9] Each data point represents the average for one location.

[10] Each data point represents the averaged values for one location. In MTCD, only samples for smartphone type devices in the A role were used.

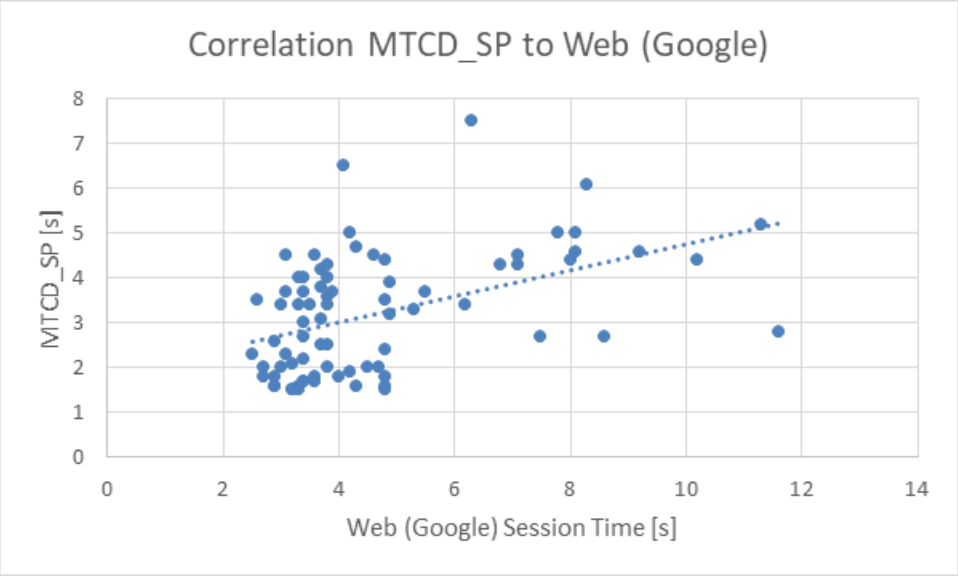

Figure 8-12 Correlation test between MTCD and Session Time for the Google web site[11].

Last but not least, Figure 8-13 shows the correlation between RSSI (taken from the respective Android API on the OT devices) and MTCD. The diagram shows the 3G RSSI values only as there were only a few pure 2G locations and in locations with 2G/3G mixed coverage the device was mostly in 3G. The RSSI value used here was the average per location of values that were in turn averaged during transactions. Data for all service types in the background measurement scenario were used.

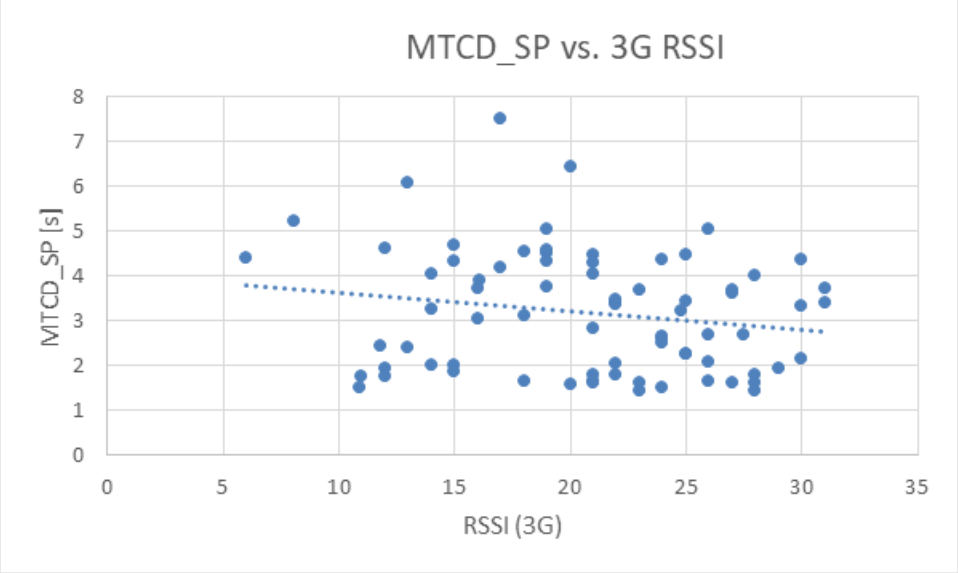

Figure 8-13 MTCD for Smartphone-type devices in the A role vs. averaged RSSI per location.

The graphs for packet data services suggest that there is a correlation between respective KPI and the session time of the MoMo service. As far as known, packet data transfer is not used as transport service for the Ghana implementation of DFS. However, it is reasonable to assume that the performance of these services can be used as a proxy for DFS performance, as the underlying network performance affects all services. From a practical point of view, the Session Time for a small web page such as Google would be a feasible proxy for the general quality of network coverage.

[11] Each data point represents the average for one location.

Even if radio conditions can affect service quality, as long as carrier service quality is above a certain minimum level, the effect on DFS quality is assumed small as compared to other sources of fluctuations, such as load-depended effects in service-specific parts of the transfer chain, and fluctuations in the DFS service quality itself. Measured data suggests that the carrier service quality was, in all or at least most of the locations tested, still in a range where it did not have a dominant negative effect on DFS quality.

To investigate the case further, the next section shows details for selected locations.

8.3 Correlation between DFS and OT KPI, details

From the 78 locations, a set of two were selected for a deeper investigation of measured data. These were Jubilee Block and GPHA, measured by Team 1 on the 13.7.2018.

This day was selected because its KPI values for DFS, USSD and SMS are near the average for all locations. Furthermore, OT data (where the device was always running in automatic network selection mode) indicate that at Jubilee block there was only 2G available while at GPHA 3G was also available.

This predicts that for Jubilee block FP DFS KPI should be close to SP data while for GPHA differences are higher. Table 8-1 confirms this (in the expected limits of statistical accuracy).

Table 8-1 Comparison of DFS KPI between two locations

DFS KPI	GPHA	Jubilee Block
MTCR_SP	100	95,7
MTCR_FP	100	100
MTCD_SP	3,2	5
MTCD_FP	5,1	5
MTRCT_SP	15	23,2
MTRCT_FP	19,6	20,8
MTACT_SP	18,3	28,8
MTACT_FP	25,9	27

There were, however, not many locations with pure 2G coverage (see also section RAT per location for details).

Figure 8-14 shows, for introduction, the time sequence of MTCD for the two locations. The first block exhibits a quite typical property of these data, namely to have a rather small number of values outside an otherwise quite homogenous band of values.

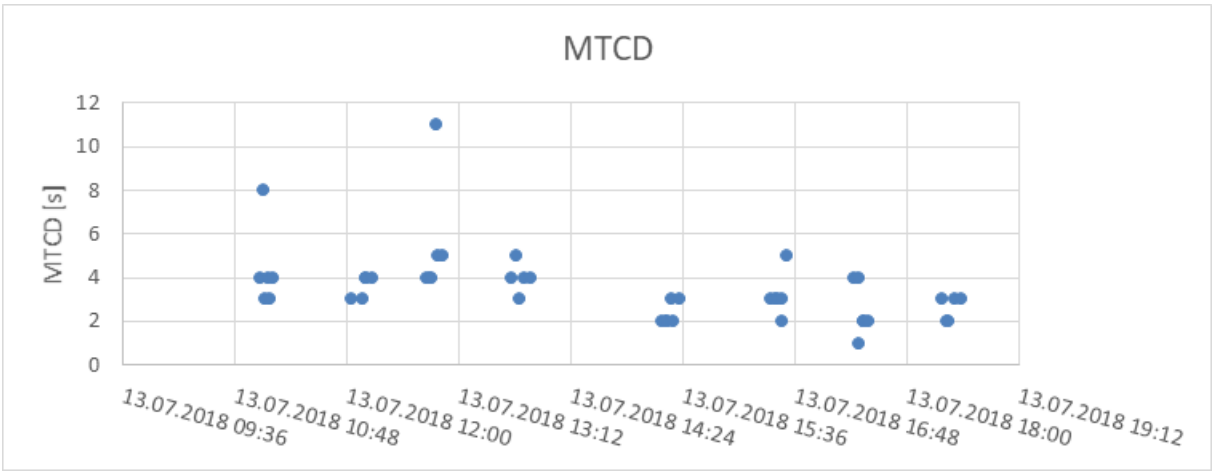

Figure 8-14 MTCD values (SP in sender role only) over time for locations Jubilee Block (first part) and GHAPOA (second part)

Figure 8-15 shows the same data, in addition the Session Time KPI for SMS and USSD are shown.

Remark: There are some cases where apparently the USSD Session Time is below the MTCD value. This is attributed to the one "step-variable" property of time-taking in the DFS with one-second resolution case (whereas timestamps for OT measurements have millisecond resolution).

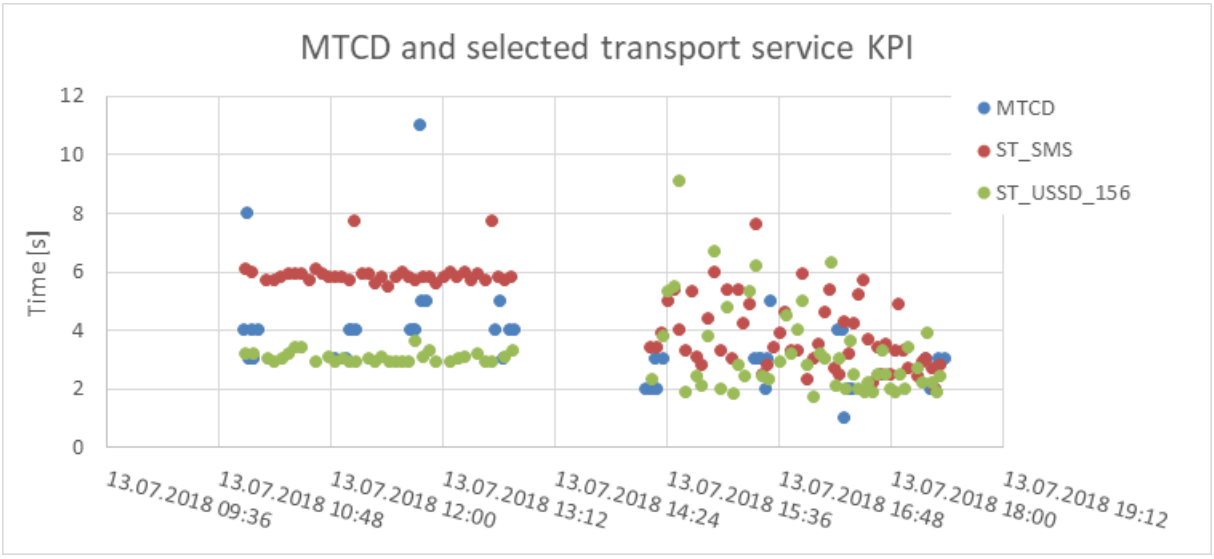

Figure 8-15 MTCD time sequence (SP in sender role only) and selected transport network KPI for Jubilee Block and GHAPOA

Data in Figure 8-15 indicate that the variance of SMS and USSD session time is significantly higher in the GHAPOA location. Comparison with network status shows that in Jubilee Block, the OT device was constantly in 2G (EDGE) while in GHAPOA, network type (as indicated by the respective Android API output function) was rather frequently changing between HSPA and HSPA+, see also Figure 8-16.

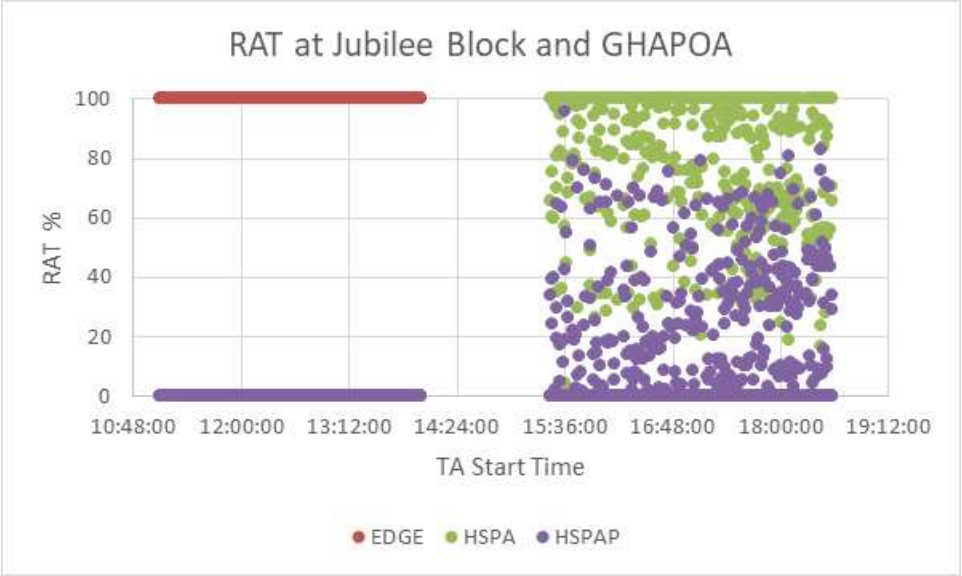

Figure 8-16 RAT at two selected locations

Remark: It may be possible, in addition, that the effect of respective reconfiguration activities in the device is stronger when the device performs constant activity as in the background measurement case at hand.

By visual impression from Figure 8-15, there is actually a tendency for lower USSD and SMS session times for GHAPOA vs. Jubilee block, which shows the expected correlation to DFS KPI. This is however obscured by the large variations in these values.

In investigate the matter of site vs short term correlations between carrier and DFS service KPI, median values of respective OT indicators (session times for selected services) were computed. The following diagrams show exemplary those results. In all cases, each data point represents one location.

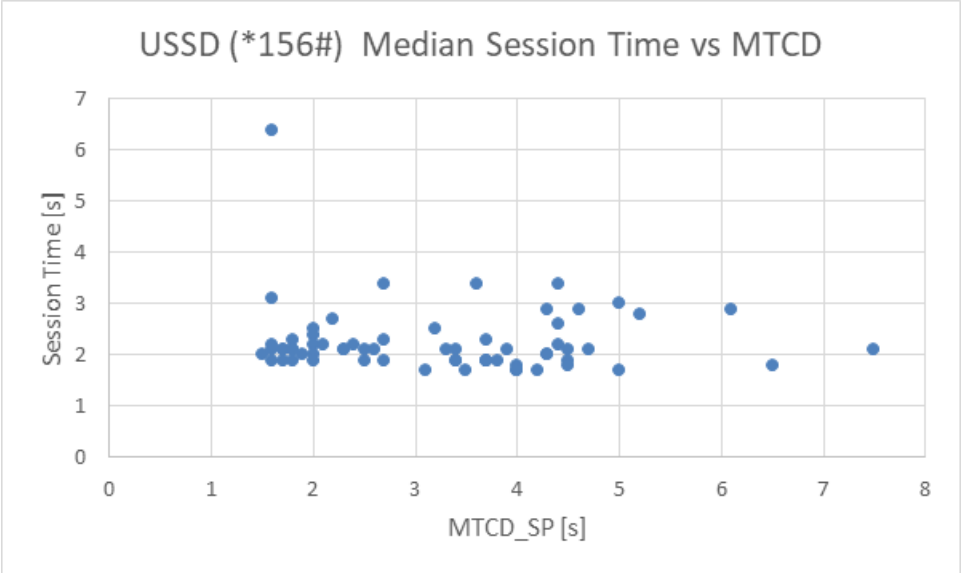

Figure 8-17 USSD Median Session Time vs MTCD

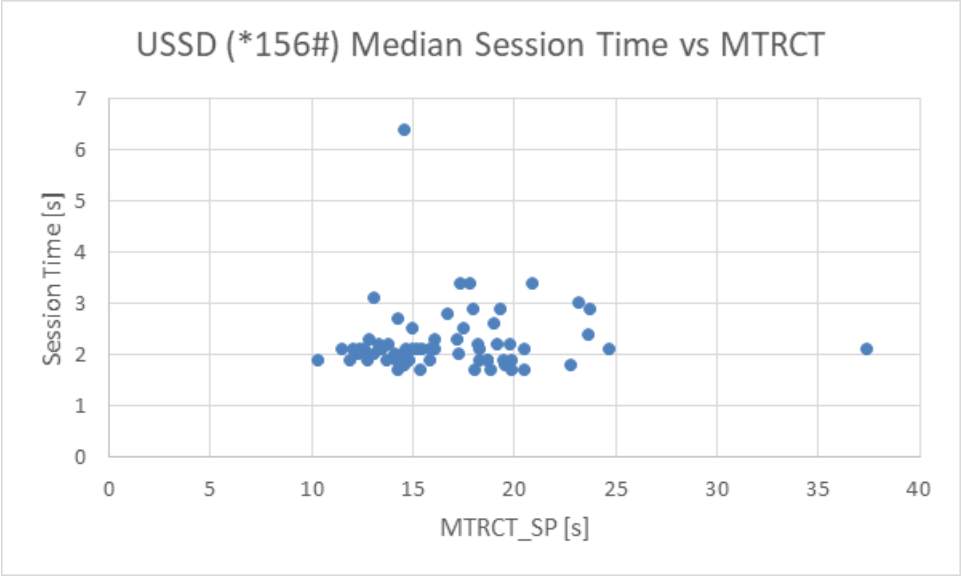

Figure 8-18 USSD Median Session Time vs MTRCT

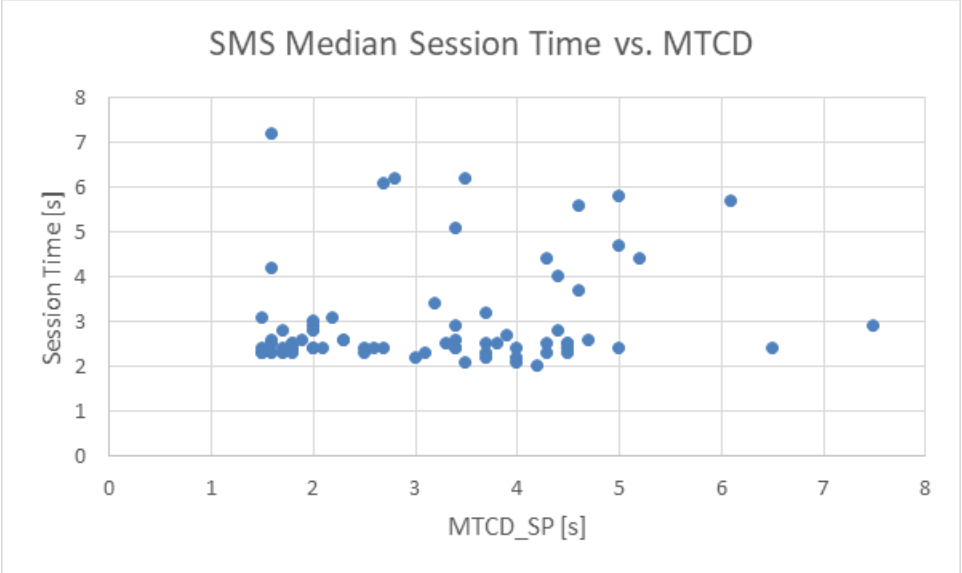

Figure 8-19 SMS Median Session Time vs MTCD

Apparently the visible correlation between DFS KPI and median values of SMS and USSD session times per location is even weaker than for average values.

The following diagrams show, for completion of the topic, scatter plots for the correlation between Median and Average versions of selected DFS service KPI.

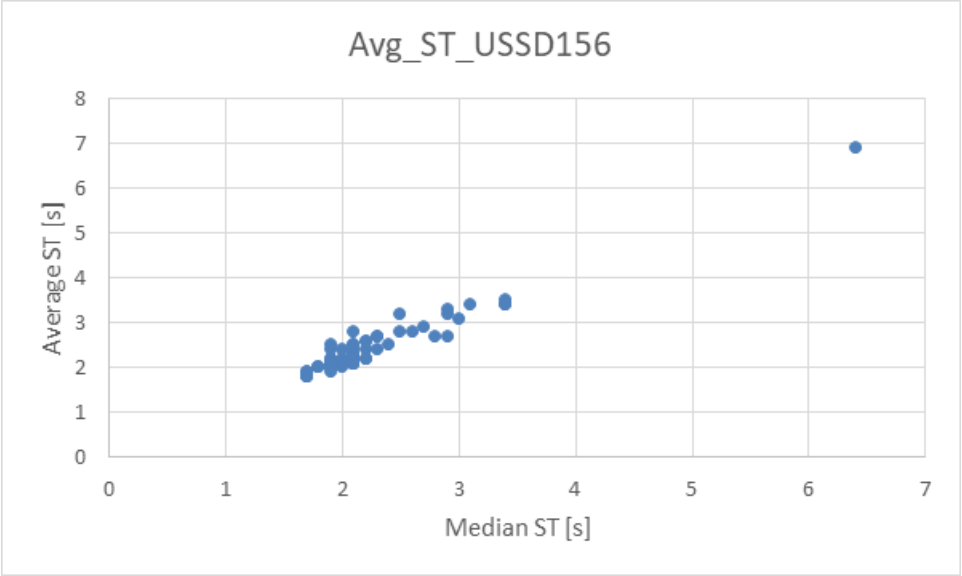

Figure 8-20 USSD156 Average Session Time vs Median Session Time

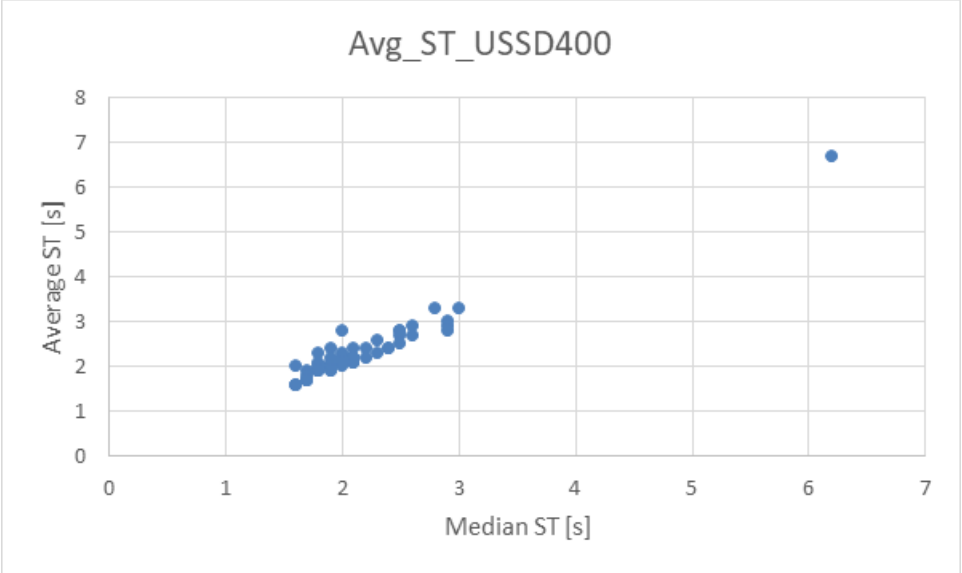

Figure 8-21 USSD400 Average Session Time vs Median Session Time

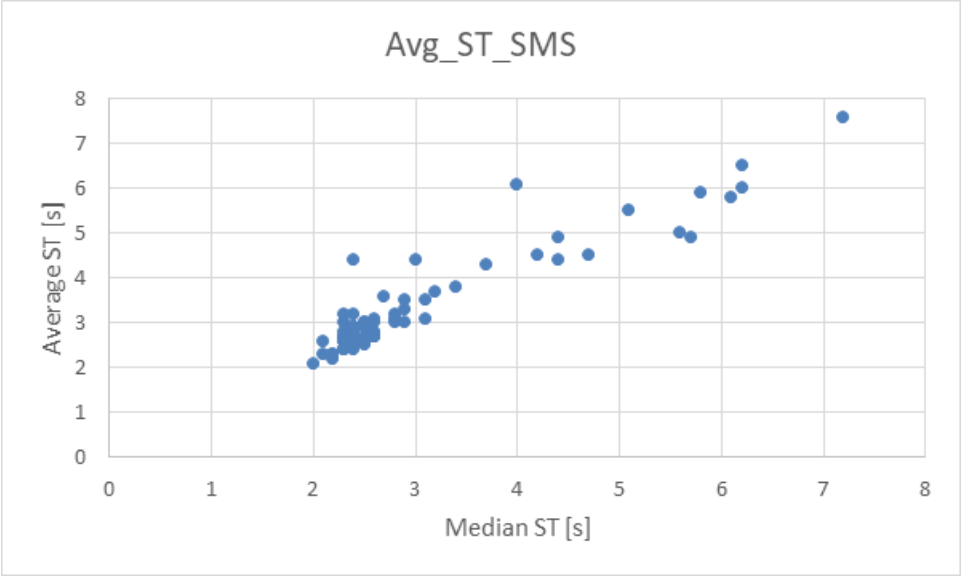

Figure 8-21 SMS Average Session Time vs Median Session Time

The conclusion, which can be drawn from these results, is that for the range of carrier services KPI at the locations visited in the pilot campaign, fluctuations of DFS service, or shorter-term fluctuations of carrier services were playing the dominant role. Therefore, correlation, while weak in general, is more pronounced in the Average versions of respective KPI than in the Median versions.

Therefore it can be assumed that in the locations tested in the pilot, average carrier service quality was in a region of the value space which is sufficient for good or at least decent sufficient DFS session times. Figure 8-15 hints, however, that there may have been periods of time where DFS session times were affected by poorer transport service quality.

Remark: SMS can be seen as a proxy for the performance of DFS data transfer quality as it uses L3 signalling.

To further investigate this topic, a shorter-term time correlation analysis was attempted by< dividing the measurement time into 10-minute slices (shorter slices were deemed to not make sense as the number of coinciding transactions per slice would be too small). Again, only the DFS transactions where the devices were in “Smartphone” configuration were taken into account. Each data point represents the average (arithmetic mean) of the respective KPI over a time period of 10 minutes. A few outliers (4 values per graph) are, in the diagrams below, excluded by scaling to improve overall readability of the diagrams.

The following scatter plots show, however that there was also no visible correlation between OT and DFS KPI. This underlines the fact that in the pilot, transport service performance in the locations visited was in a range where it had no significant negative impact on DFS performance.

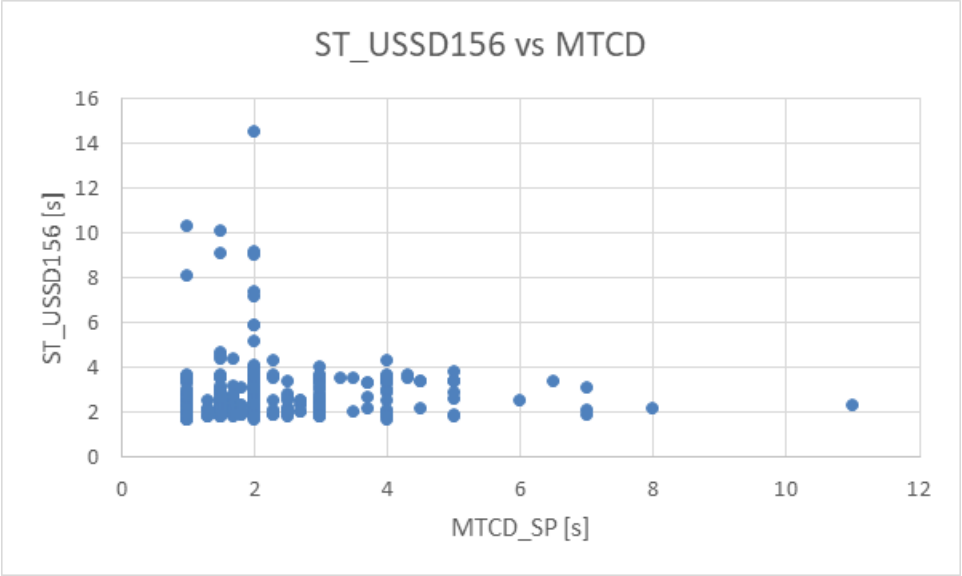

Figure 8-22 Session time USSD (code *156) vs MTCD (SP role only)

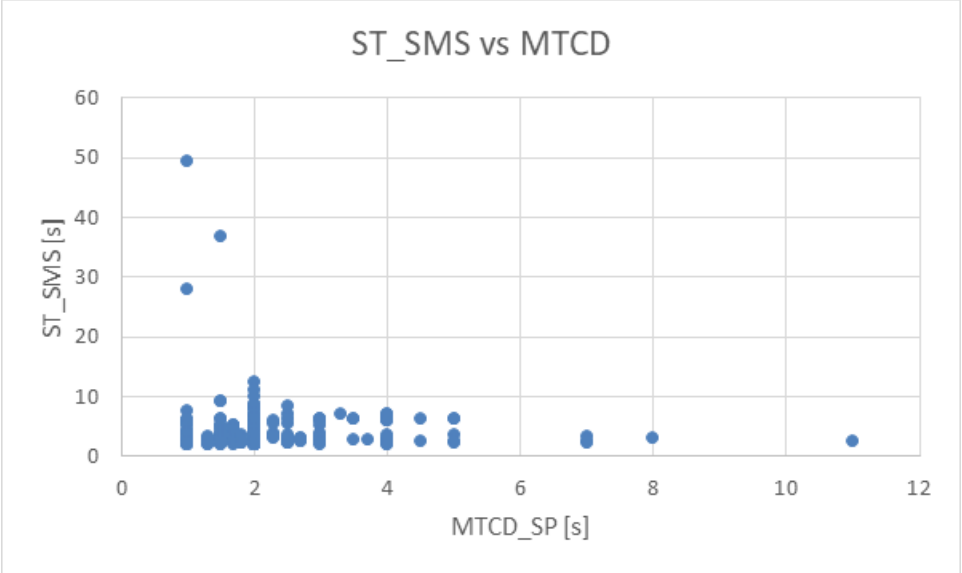

Figure 8-13 Session time SMS vs MTCD (SP role only)

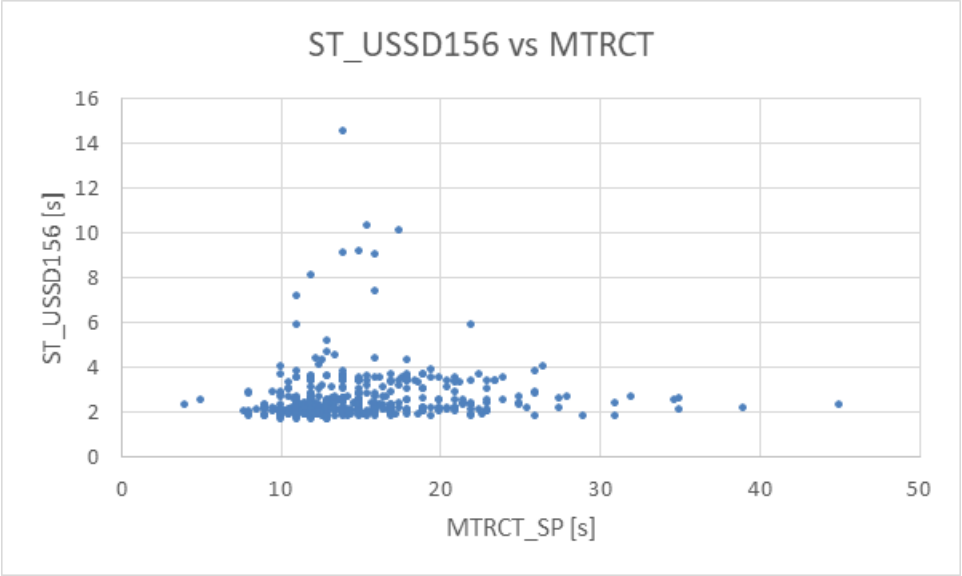

Figure 8-24 Session time USSD (code *156) vs MTRCT (SP role only)

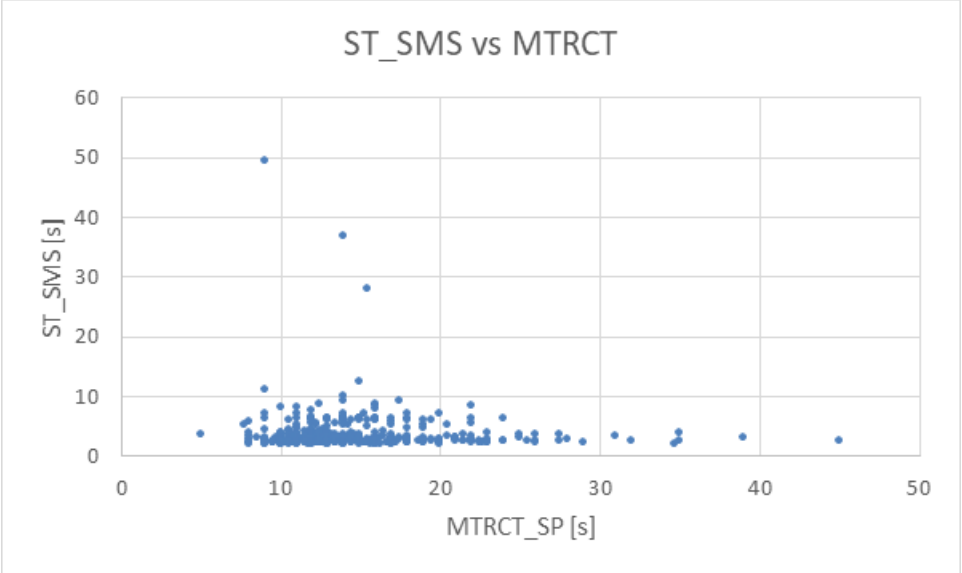

Figure 8-25 Session time SMS vs MTCD (SP role only)

9 Conclusions and way forward

The results shown in the present report indicate that there is a correlation between the performance of most service types used in the background measurement scenario, and the main DFS KPI.

Such a correlation can be caused by two mechanisms (see details on the assumed model in section General model). Firstly, the respective carrier service can be used directly in the DFS implementation. It can also be an indirect effect; after all, the performance of all services depend, to different degrees, on the performance or functional quality of all elements in the chain, such as radio conditions, RAN performance, core network performance, and connecting elements to external components of service provision.

It is of course desirable to use a test case for measurements which directly involves the carrier service used by the MoMo service under test. From a pragmatic point of view, using another service, as long as there is a sufficiently clear relationship, may also be a feasible solution if this offers advantages in terms of simplicity or testing efforts. It is of course mandatory that this proxy relationship is properly validated, which also involves a long-term monitoring aspect; after all, MoMo service implementations can change and therefore the 'proxy' property may also change.

As the actual network performance may vary on rather short time scales, using averaged values of MoMo and carrier service (or radio related) will always limit the degree to which correlations or causal relations can be observed. This degree also depends on the size of fluctuations in the actual service implementation relative to the fluctuations in network-related functional quality. If, for instance, the transfer time of relevant data between the network and end mobile device varies by 2-3 seconds due to carrier service quality, this will only be visible in DFS KPI of type session time if the response time of the DFS implementation itself is relatively constant. If this response time shows large fluctuations, transfer time fluctuations in the carrier service are much less visible.

In any case, given the limited nature of this pilot in terms of both sample count and accuracy of measurements, it may be necessary to increase the confidence level of results. The following aspects should be investigated further:

- The current test was dealing with a range of network quality – and DFS quality - which was, obviously, in the 'good to fair' range. None of the locations where tests have been conducted had a really poor network coverage. It may be desired to also collect further information on the region where MoMo quality is becoming poor to unacceptable, and to observe related transport service quality and radio coverage indicators.
- Due to the testing method used, there is a quite high 'statistical noise' in DFS data. On the time scale of typical DFS session times, the limited time resolution of 1 s causes a significant level quantization noise, but as long as times are taken manually, even a higher time resolution, as provided by tailored multi-state stopwatches, would give only limited improvements.
- The scale for tool related improvements covers a wide range of technically feasible solutions on different levels of automation and depth of data access. The highest level of automation would be provided by 'electronic remote control' of the MoMo application on Android smartphones, i.e. by full automation of the use case. Extended monitoring is available on modified devices (requiring root access to the device's operating system). With such access, monitoring on chipset data level would provide Layer 1 data as well as L2 and especially L3 signalling.

10 Annex A: Details

10.1 Time ranges and KPI per location

Table 10-1 DFS TA overview per location

Location	MTCR	MTCD	MTRCT	MTFCT	MTACT	StartPrev15	EndNext15
37 Military Hospital	100	1,8	12	22	14	19.07.2018 11:15	19.07.2018 14:45
Abokobi	97,9	1,6	13	22	14	03.07.2018 13:15	03.07.2018 16:45
Accra Academy	100	3,7	15	23	19	16.07.2018 17:15	16.07.2018 21:00
Accra Girls	100	1,7	11	19	12	17.07.2018 11:00	17.07.2018 15:00
Accra Institute of Technology	97,9	4,1	14	23	18	09.07.2018 11:15	09.07.2018 15:00
Accra Mall East	100	5,1	19	31	25	03.07.2018 16:45	03.07.2018 21:00
Accra Mall West	100	4,4	18	27	22	03.07.2018 11:45	03.07.2018 15:15
Accra Technical University	100	3,6	17	29	23	20.06.2018 13:45	20.06.2018 17:00
Achimota Mall 1	97,9	4,4	18	28	22	05.07.2018 12:00	05.07.2018 16:00
Achimota Mall 2	97,9	5,7	22	33	26	05.07.2018 17:00	05.07.2018 20:30
Action Chapel	91,7	4,9	21	30	24	21.06.2018 14:00	21.06.2018 17:45
Adenta	100	2,1	15	27	19	07.07.2018 12:00	07.07.2018 15:45
Agbogba	100	3	17	27	19	06.07.2018 16:30	06.07.2018 20:00
Airport	98,9	4,5	17	27	22	29.06.2018 11:30	29.06.2018 17:45
Amrahia	100	1,9	25	38	27	08.07.2018 09:30	08.07.2018 13:30
Awoshie	100	1,8	14	27	15	13.07.2018 17:15	13.07.2018 21:00
Barn Yard	100	1,6	20	34	25	19.07.2018 17:00	19.07.2018 20:45
Bubuashie	100	2,3	16	24	18	18.06.2018 11:00	18.06.2018 13:45
Central University	100	5	16	28	21	07.07.2018 10:30	07.07.2018 13:30
Commercial Area (CU)	100	4,4	17	26	20	07.07.2018 14:00	07.07.2018 16:45
Community Two	100	4,8	18	28	23	16.07.2018 13:30	16.07.2018 16:30
Darkuman	100	2,1	15	23	16	22.06.2018 20:30	22.06.2018 23:45
Data Link Institute	100	4,6	18	28	23	12.07.2018 15:15	12.07.2018 18:30
Dodowa	100	1,6	13	22	14	05.07.2018 10:00	05.07.2018 14:00
Forestry Commission	97,9	2,3	18	31	22	19.06.2018 12:00	19.06.2018 15:45
Fridays	93,8	6,1	24	34	29	18.06.2018 20:00	18.06.2018 22:15
Ghana Post	100	2,8	29	38	30	29.06.2018 10:45	29.06.2018 14:00
GPHA	100	4,2	17	28	22	13.07.2018 15:15	13.07.2018 18:45
Gimpa	100	1,8	14	24	15	26.06.2018 20:00	26.06.2018 23:30
GTUC(Tesano)	97,9	2,6	17	35	20	18.06.2018 16:30	18.06.2018 19:15
Gulf House	100	2,6	15	25	17	27.06.2018 17:15	27.06.2018 20:30
Haatso Wisconsin University	100	2	16	30	19	06.07.2018 20:15	07.07.2018 00:00

Table 10-1 DFS TA overview per location

Location	MTCR	MTCD	MTRCT	MTFCT	MTACT	StartPrev15	EndNext15
Homebase TV	100	2,3	14	25	17	22.06.2018 14:45	22.06.2018 17:45
James Town Tower	100	1,7	20	31	22	29.06.2018 15:30	29.06.2018 19:15
Jubilee Block	97,9	5	21	33	27	13.07.2018 11:00	13.07.2018 14:00
Karla Solar Solutions	97,9	4,4	19	32	26	17.07.2018 20:15	17.07.2018 23:30
Kasoa	100	1,6	13	21	14	12.07.2018 15:15	12.07.2018 19:00
Knutsford University	100	1,8	13	22	15	27.06.2018 12:15	27.06.2018 15:45
Kpone	97,8	4	17	27	21	18.07.2018 16:45	18.07.2018 19:30
Kwashieman	100	2,1	13	24	15	09.07.2018 13:15	09.07.2018 17:00
Labone	100	4	16	24	19	15.07.2018 17:45	15.07.2018 20:00
Lancaster University	100	1,8	12	23	15	26.06.2018 11:30	26.06.2018 14:45
Las Palmas	100	1,8	14	24	16	28.06.2018 16:15	28.06.2018 19:45
Lizzys Sports Complex	100	2	13	24	15	26.06.2018 15:15	26.06.2018 19:00
Madina	100	1,9	12	22	14	14.07.2018 13:15	14.07.2018 17:00
Mallam	100	2	13	23	14	13.07.2018 12:00	13.07.2018 16:00
Manet Cottage	95,8	3,8	16	27	21	06.07.2018 14:00	06.07.2018 17:30
Manet Ville	100	5	19	28	22	06.07.2018 18:15	06.07.2018 21:15
Marina Mall	100	5,4	23	33	27	22.06.2018 14:45	22.06.2018 17:30
Meridian	95,7	4	19	29	22	17.07.2018 12:45	17.07.2018 15:45
Methodist University	95,7	4,3	20	31	27	21.06.2018 09:30	21.06.2018 12:45
Michel Camp	100	4,9	16	25	19	14.07.2018 13:30	14.07.2018 17:00
Nungua Barrier	95,8	4,6	20	32	24	19.06.2018 16:15	19.06.2018 19:30
Nungua Junction Mall	95,8	5	19	28	23	20.06.2018 18:45	20.06.2018 21:30
Odorkor	100	2,7	14	29	18	16.07.2018 11:45	16.07.2018 16:00
Orgle Road	100	1,5	12	20	13	18.07.2018 13:00	18.07.2018 17:00
Osu Oxford Street	97,9	4,9	19	28	23	20.06.2018 12:45	20.06.2018 16:15
Oyarifa	100	1,7	12	23	13	03.07.2018 09:00	03.07.2018 13:00
Palace	97,9	4,1	19	27	22	21.06.2018 10:15	21.06.2018 13:30
Pantang	100	1,6	10	19	11	15.07.2018 18:00	15.07.2018 22:00
Pentecost University	100	2	14	24	16	28.06.2018 12:30	28.06.2018 15:30
Prampram	100	3,8	17	27	20	18.07.2018 12:15	18.07.2018 15:45
Rawlings Park	97,9	2,5	17	27	20	20.06.2018 09:15	20.06.2018 12:45
Regent University	100	2,3	18	28	21	22.06.2018 11:30	22.06.2018 14:30
Regional Maritime University	97,9	5,7	21	32	25	19.06.2018 11:00	19.06.2018 14:45
Santa Maria	100	1,8	13	24	14	11.07.2018 13:00	11.07.2018 17:00
UG Sarbah Hall	95,8	4,8	19	29	24	26.06.2018 11:00	26.06.2018 13:30
St Thomas Aquinas	100	4,3	17	25	21	09.07.2018 15:45	09.07.2018 19:15

Table 10-1 DFS TA overview per location

Location	MTCR	MTCD	MTRCT	MTFCT	MTACT	StartPrev15	EndNext15
Tema General Hospital	97,9	4,2	16	26	21	12.07.2018 10:30	12.07.2018 14:00
Teshie Nungua	95,8	6,7	25	35	28	18.06.2018 14:15	18.06.2018 17:45
Titanic Beach	97,9	5,3	18	29	24	16.07.2018 17:45	16.07.2018 20:30
UG Commonwealth Hall	97,9	5	18	34	23	26.06.2018 14:15	26.06.2018 17:30
UG International Students	100	4,7	19	30	23	27.06.2018 15:00	27.06.2018 18:30
UG Limann Hall	95,7	4,4	20	30	24	27.06.2018 10:45	27.06.2018 13:45
UPSA	100	4,8	19	29	24	28.06.2018 14:30	28.06.2018 17:45
Valley view university	100	1,6	13	22	14	05.07.2018 19:45	05.07.2018 23:30
West Hills Mall	100	1,6	12	22	13	12.07.2018 07:00	12.07.2018 10:45
Zenith College	100	4,9	21	35	26	22.06.2018 10:00	22.06.2018 13:15

10.2 Time related KPI (Median variant) per location

Table 10-2 Median variant of time related KPI per location

Location	MedianMTCD	MedianMTRCT	MedianMTACT	MedianMTFCT
37 Military Hospital	1	13	14	21
Abokobi	1	12	13	22
Accra Academy	3	15	19	23
Accra Girls	1	11	12	19,5
Accra Institute of Technology	3,5	15	18	23
Accra Mall East	4	18	23	28
Accra Mall West	4	18	22	27
Accra Technical University	3	17	22	28
Achimota Mall 1	3	16	21	26
Achimota Mall 2	5	21	24	32
Action Chapel	4	22	25	29
Adenta	1	14	15,5	24
Agbogba	1	17	18	26
Airport	4	17	21	26
Amrahia	1	24	25	33
Awoshie	1	13	14	26
Barn Yard	1	12	15	22

Table 10-2 Median variant of time related KPI per location

Location	MedianMTCD	MedianMTRCT	MedianMTACT	MedianMTFCT
Bubuashie	1	15	18	24
Central University	4	17	21	26
Commercial Area (CU)	4	17,5	20	26
Community Two	4	18	22,5	27
Darkuman	2	15	16	23,5
Data Link Institute	3	16	21	26
Dodowa	1	12	13	21
Forestry Commission	2	16	18	27
Fridays	5	23	27	31
Ghana Post	1	19	20	29
GPHA	3	16	21	26
Gimpa	1	14	15	24
GTUC (Tesano)	2	18	20	28
Gulf House	2	15	17	25
Haatso Wisconsin University	1	15	16	25
Homebase TV	1	13	16	23
James Town Tower	1	21,5	23	30,5
Jubilee Block	4	18	24	29
Karla Solar Solutions	4	18	25	30
Kasoa	1	13	14	21
Knutsford University	1	13	15	23
Kpone	3	16	20	25
Kwashieman	1	13,5	15	24
Labone	3	16	20	24
Lancaster University	1	12	14,5	22
Las Palmas	1	14	15,5	23
Lizzys Sports Complex	1	12	14	22
Madina	1	11	12	20,5
Mallam	1	11	12,5	21
Manet Cottage	3	16,5	21	25
Manet Ville	4	18	22	25,5
Marina Mall	5	23	26,5	34,5
Meridian	3	18	22	26

Table 10-2 Median variant of time related KPI per location

Location	MedianMTCD	MedianMTRCT	MedianMTACT	MedianMTFCT
Methodist University	3,5	21	25	29,5
Michel Camp	3	15,5	19	24
Nungua Barrier	4	20	24	29,5
Nungua Junction Mall	4	19	23	28
Odorkor	2	14	19	23
Orgle Road	1	12	13	20
Osu Oxford Street	4	19	23	26
Oyarifa	1	12	13	22
Palace	3	19	22	26
Pantang	1	10	11	19
Pentecost University	1	14	15,5	24
Prampram	3	15	19	23,5
Rawlings Park	2	17	20	27
Regent University	1	16,5	18,5	26
Regional Maritime University	4	20	24,5	28,5
Santa Maria	1	13	14	23
UG Sarbah Hall	4	17,5	22	27
St Thomas Aquinas	3	13	17	22,5
Tema General Hospital	4	17	21	27
Teshie Nungua	6	25	29	33
Titanic Beach	5	18	23	28
UG Commonwealth Hall	4	17	22	28
UG International Students	4	18	22	28,5
UG Limann Hall	4	19	24	28
UPSA	4	18	23	27
Valley view university	1	13	14	22
West Hills Mall	1	11	12	21
Zenith College	4	20	24	28

10.3 RAT per location

In order get a fast impression on the radio access technology per location, an indicator named RATNum, provided by the background measurement (OT data) was used. RATNum is generated per transaction from any RAT status information. The component values are numerical indices to the RAT name as provided by the Android API times 100. For instance, a value of 300 indicates pure EDGE while a value of e.g. 840 indicates that RAT was changing between HSPA (700) and HSPA+

(900). Of course, it is not easy to estimate the exact RAT composition from aggregated values; non-multiples of 100 indicate in any case that the RAT is varying within the respective data set.

RATNum primary values are:

Table 10-3 Numerical RAT indicator (RATNum) value assignment

RAT Name	RATUnk	NNA	GSM	GPRS	EDGE	UMTS
RATNum	-100	0	100	200	300	400

RAT Name	HSDPA	HSUPA	HSPA	Rsvd	HSPAP	LTE
RATNum	500	600	700	800	900	1000

The following table shows the averaged RATNum per location, with locations where there was pure 2G (EDGE) highlighted.

Table 10-4 Numerical RAT indicator (RATNum) per location

Location Name	AvgRATNum
37 Military Hospital	799
Abokobi	778
Accra Academy	300
Accra Girls	786
Accra Institute of Technology	775
Accra Mall East	775
Accra Mall West	778
Accra Technical University	395
Achimota Mall 1	765
Achimota Mall 2	754
Action Chapel	778
Adenta	774
Agbogba	774
Airport	770
Amrahia	769
Awoshie	742
Barn Yard	786
Bubuashie	773
Central University	780
Commercial Area (CU)	780

Table 10-4 Numerical RAT indicator (RATNum) per location

Location Name	AvgRATNum
Community Two	511
Darkuman	771
Data Link Institute	774
Dodowa	776
Forestry Commission	771
Fridays	454
Ghana Post	775
GPHA	753
GTUC (Tesano)	326
Gulf House	771
Haatso Wisconsin University	598
Homebase TV	774
James Town Tower	773
Jubilee Block	300
Karla Solar Solutions	774
Kasoa	710
Knutsford University	745
Kpone	786
Kwashieman	775
Labone	791
Lancaster University	777
Las Palmas	776
Lizzys Sports Complex	774
Madina	689
Mallam	768
Manet Cottage	772
Manet Ville	602
Marina Mall	787
Meridian	711
Methodist University	359
Michel Camp	827
Nungua Barrier	646

Table 10-4 Numerical RAT indicator (RATNum) per location

Location Name	AvgRATNum
Nungua Junction Mall	680
Odorkor	380
Orgle Road	804
Osu Oxford Street	775
Oyarifa	770
Palace	775
Pantang	708
Pentecost University	765
Prampram	807
Rawlings Park	761
Regent University	774
Regional Maritime University	715
Santa Maria	774
UG Sarbah Hall	777
St Thomas Aquinas	777
Tema General Hospital	772
Teshie Nungua	680
Titanic Beach	576
UG Commonwealth Hall	742
UG International Students	786
UG Limann Hall	778
UPSA	717
Valley view university	765
West Hills Mall	766
Zenith College	769